Application Note

Using the Z8 Encore! XP® as a Low-Cost Speed Controller for Single-Phase, Permanent Split Capacitor Motors

AN025802-0810

Z8 Encore! XP® Flash Microcontrollers

Abstract

This application note describes a low-cost speed controller for a single phase, permanent split capacitor AC motor (a convection fan motor). The design is based on the Zilog Z8 Encore! XP® 8-pin microcontroller. Motor speed is controlled using AC phase control.

> **Note:** The source code (AN0258-SC01) associated with this reference design has been tested with ZDS II version 4.11.0. The code is available on www.zilog.com.

Features

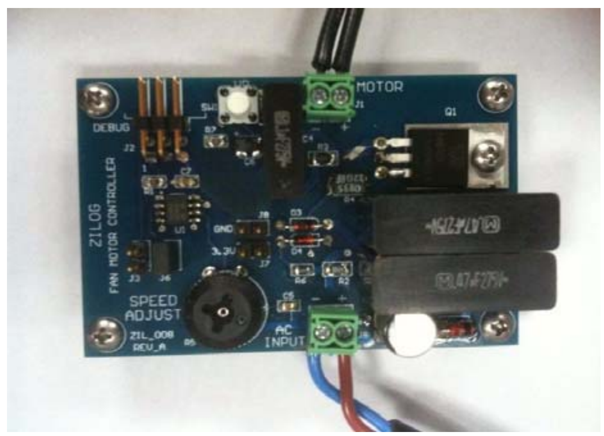
Features of the low-cost speed controller include:

- Simple AC/DC converter reduces overall circuit cost.
- Adjust motor speed using either a potentiometer or two momentary-action pushbutton switches.
- Simple design yields fewer components and lower device cost (see Figure 1).

Z8 Encore! XP® Overview

The Z8 Encore! XP products are based on the eZ8 CPU and introduce Flash memory to Zilog's extensive line of 8-bit microcontrollers. Flash memory in-circuit programming capability allows for faster development time and program changes in the field. The high-performance register-to-register based architecture of the eZ8 core maintains backward compatibility with Zilog's popular Z8 MCU. Z8 Encore! XP MCUs combine a 20 MHz core with Flash memory, linear-register SRAM, and an extensive array of on-chip peripherals. These peripherals make the Z8 Encore! XP MCU suitable for a variety of applications including motor control, security systems, home appliances, personal electronic devices, and sensors.

Figure 1. Low-Cost Speed Controller for a



Single-Phase, Permanent Split Capacitor AC Motor

Discussion

The Z8 Encore! XP Flash MCU is based on Zilog's advanced eZ8 8-bit CPU core and is ideally suited for implementation in Universal Motor control systems. Target applications include home appliances, power tools, and industrial automation.

A block diagram of the Z8 Encore! XP Flash MCU is provided in Figure 2.

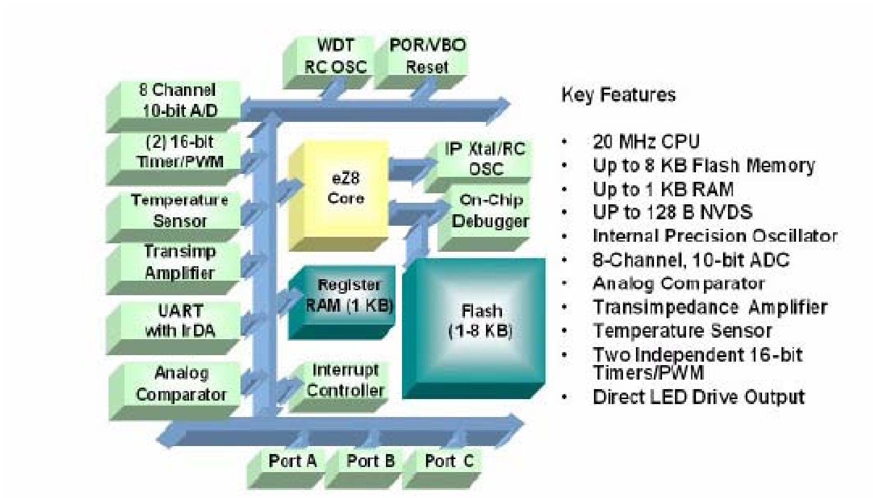


Figure 2. Block Diagram of the Z8 Encore! XP® Flash MCU

Here, the rich set of on-chip integrated analog peripherals allows for realization of a number of control features, and also provides for low overall system cost.

The 10-bit analog-to-digital converter (ADC) provides for data conversion of up to eight single-ended/differential channels with 1X differential input gain. Furthermore, for high precision current measurements, an integrated on-chip transimpedance amplifier is integrated in the ADC module, eliminating the need for an additional external component.

Along with the multi-channel ADC, the device's two enhanced 16-bit timer blocks featuring PWM as well as Capture and Compare capability can be used to operate two loads (motors) simultaneously. The direct LED drive output can be used to trigger LEDs at the onset of a pre-defined event, without the need for additional hardware. Other features include the integrated analog comparator, the Fail-Safe oscillator mechanism providing for reliable operation, an on-chip integrated temperature sensor, and up to 128 B of NVDS.

Theory of Operation

The principle used to set the motor speed in our application is AC phase control. See Figure 3.

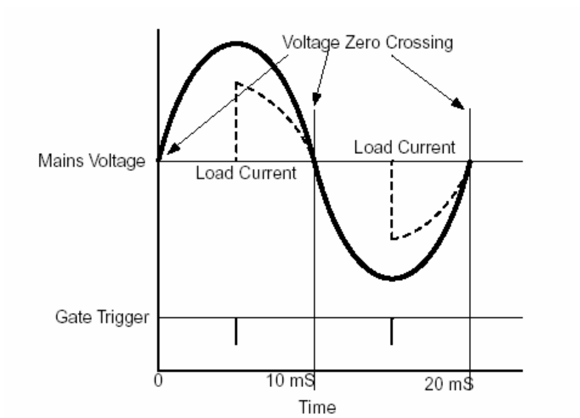


Figure 3. AC Phase Control

Our application uses a TRIAC to control motor speed. We use the Z8 Encore! XP Flash MCU on-chip integrated analog comparator to determine the zero crossing and synchronize the TRIAC firing angle.

When the AC line voltage crosses zero, the application starts a timer. The timer reload value is set from the position of the potentiometer. The timer provides a delay after which the TRIAC is fired to start conduction. Increasing or decreasing the phase angle by varying the time delay during each cycle controls the motor speed. See Appendix C — Calculation of Firing Angle for 60Hz.

The time delay must be synchronized with the AC supply. The chip turns the TRIAC ON by supplying a gate pulse, and turns the TRIAC off when the load current reaches zero.

Motor Description

We used an Electric Motors & Specialties motor designed for convection applications to test this application note. The motor rating is provided below:

- Type of Motor: PSC
- Power rating: 1/375 HP
- Speed: 1350 RPM
- Number of Poles: 4
- Voltage: 115 V
- Frequency: 60 Hz
- Rated current: 0.05 A

Hardware Architecture

This design involves the load control circuit illustrated in the schematic. This circuit is comprised of a low cost AC/DC converter, AC zero crossing detection, speed control through a potentiometer and a load-switching TRIAC.

The microcontroller senses AC zero crossing on PA5 (pin-7). Pin PA5 is initialized as positive input for the comparator. The comparator itself is referenced to 1.4 V. An interrupt is generated when the AC crosses 1.4 V.

The interrupt service routine reloads the timer with a value determined by the setting of the potentiometer. The longer the hold-off time, the less power is delivered to the load. The shorter the hold-off time, more of the AC waveform is realized at the load (motor), increasing the power delivered.

Our design is based on the fact that a TRIAC conducts until the next zero crossing, when it receives a pulse on its input. The Z8 Encore! XP microcontroller controls the firing angle in the AC source waveform in a pulse to the TRIAC. The user modifies the firing angle (desired power angle) by adjusting the Pot to increase or decrease power to the load. The design includes a low-cost AC/DC voltage regulator, and a simple AC source voltage zero crossing circuit. The zero crossing circuit functions independent of source voltage.

When the timer overflows, another interrupt is generated. The timer interrupt service routine triggers the TRIAC gate pulse through PA0 (pin 2). The TRIAC conducts until the next zero crossing of the source waveform. In a 60-Hz system, a zero crossing occurs every 8.33 ms (10 ms in a 50-Hz system). After 8.33 ms, the timer is re-loaded with a value corresponding to the firing angle. This cycle repeats on each waveform.

AC/DC Converter

The AC/DC converter design provides voltage current reduction through capacitors C1 and C2, and resistor R2. The Zener Diode D2 holds the voltage to 4.7 Volts. The reduced AC voltage is then rectified onto capacitor C3 through Diode D1. We selected values of components C1, C2, and R2 to provide a low-cost voltage dividing and current reduction circuit.

Caution: The AC current reduction capacitors C1 and C2 must be rated for working line voltage.

Resistor R2 provides further current protection in the circuit and acts as a fuse if capacitor C1 or C2 fails.

Diode D1 (1N4148) provides half-wave rectification into 470 µF capacitor C3. The voltage on C3 is the Zener voltage of 4.7 V, minus the voltage drop across D1 of approximately 0.7 V. The resulting DC supply for the application is approximately 4 V. A lower voltage is produced when the Z8 Encore! XP controller is connected and the voltage drops and remains within the range, as specified in the product specification for the microcontroller.

Calculations:

C1 + C2= 0.47 + 0.47 = 0.94 µF

R2 = 470 Ω

D2 = 4.7 V Zener diode

D1 = 1N4148

C3 = 470 µF

Input AC = 110 V, 60 Hz

Capacitive reactance, $X_{C12} = 1/(2 * \pi * f * (C1 + C2)) = 1/(2 * \pi * 60 * 0.94\ \mu F) = 2822.42\ \Omega$

Total Impedance, $Z_T = ((X_{C12})2 + (R2)^2)^{1/2} = ((2822.42)^2 + (470)^2)^{1/2} = 2861.28\ \Omega$

Diode D1 rectifies only half of the sine wave. So RMS voltage of half-wave of AC = $V_{HALF} = (V_{Peak} - V_Z)/ 2 = (1.4142 * 110 - 4.7)/ 2 = 75.43$ V

$I_{IN} = V_{HALF}/Z_T = 75.43/2861.28 = 0.026A = 26$ mA

V_{OUT} = Volt across zener - voltage across rectifier diode = 4.7 V - 0.7 V= 4.0 V

Rating for R2 = $I^2R = (22mA)^2 * 470 = 0.22$ W = 1/4 Watts

It is recommended to use 1/2 Watt for the increased safety margin.

Rating for C1 and C2= 2 * Line voltage = 2 * 110 V = 220 V

Rating for D2 = V * I = 4.7 * 22mA = 0.103 W = 1/4 Watts

Rating for D1 = V * I = 0.7 * 22mA = 0.015 W = 1/4 Watts

Rating for C3 = 16 V Electrolytic

AC Synchronization

The AC synchronization circuit consists of a resistor R6 of 3.3 MΩ to limit the current to the Z8 Encore! XP port pin. Diodes D3 and D4 (both 1N4148) clamp the voltage to the port pin from 0.7 V to Vcc. The AC input is sensed by controller through port PA5 (pin 7). Since our design is supporting an inductive load, the current and voltage waveforms do not coincide. We therefore synchronized the AC voltage waveform only.

Potentiometer

A 10 KΩ linear potentiometer for smooth speed control is included in our design. Its use is software-selectable during controller programming. The pot is supplied with V_{REF} through port PA1 (pin 3). Analog voltage is sensed by port PA4 (pin 6).

Oscillator Circuit

The internal Z8 Encore! XP microcontroller 5.53 MHz IPO is fast enough to ensure degradation-free microcontroller operation. This configuration provides the extra pins required to interface other peripherals to the controller.

TRIAC

TRIACs vary greatly in gate current requirements and load carrying capability. We selected a logic-level TRIAC (BT136 - 600D) for our design. Logic-level TRIACs typically require lower gate current and can be triggered directly from the microcontroller. Since a non-logic-level TRIAC might require an optocoupler, use of a logic-level device lowers overall circuit cost. Port PA0 (pin 2) is used to supply the gate drive signal to the TRIAC gate.

Snubber

Since the motor is inductive, the current across the TRIAC continues even after AC voltage has crosses the zero point. The current flowing against the voltage polarity of AC (which has already crossed zero) reduces at a faster rate and leads to high value of dI/dt. A higher value of dI/dt can overstress the TRIAC and potentially cause it to misfire (even when the gate is not triggered). To solve this issue, a series RC combination (called a snubber) is connected across the two TRIAC terminals. For this application, standard values of R and C were selected as 0.1 µF and 1 KΩ.

Caution: The capacitor for snubber must be rated for working line voltage.

For more details on hardware connections, see Appendix A—Schematics on page 15.

Software Implementation

Refer to Appendix B—Flowcharts for details on the software functions described below.

The software is comprised of three major functions:

- **Initialization.** Hardware modules such as GPIO, comparator, timer, and ACD are initialized.
- **Interrupt.** The timer and comparator generate periodic interrupts, depending upon the frequency of the AC supply. These interrupts control the TRIAC firing angle and therefore the voltage applied to the motor.
- **Background loop.** An infinite loop in the main routine that manages functions such as polling ADC to read the value of the set-speed command through the potentiometer. The loop also updates the value for timer reload from the lookup table.

Auto Frequency Detection

The software code contains a section that detects the frequency of AC supply, while start-up. When the controller starts from main(), it initializes the GPIO, comparator and timer module. Then the control goes to a function that starts and stops the timer during each subsequent comparator-interrupt. Thus the value of timer count is proportional to the frequency of AC supply. By comparing with a fixed value, the frequency is determined to be 50 Hz or 60 Hz.

To eliminate any spike/ disturbance in the AC supply, the comparison is made for 5 consecutive cycles. If a successful value of frequency is not determined, the control goes to an infinite loop. This feature also makes sure that unless a valid frequency (50 Hz or 60 Hz) is determined, the speed control for motor is not possible.

Mechanism for Speed Control

Our design covers one way to control the speed of the motor.

- **Using the Potentiometer.** Turning the potentiometer from the MIN to the MAX position increases the speed from 0RPM to maximum RPM.

Testing Setup

The test setup to demonstrate the application design is shown in Figure 4.

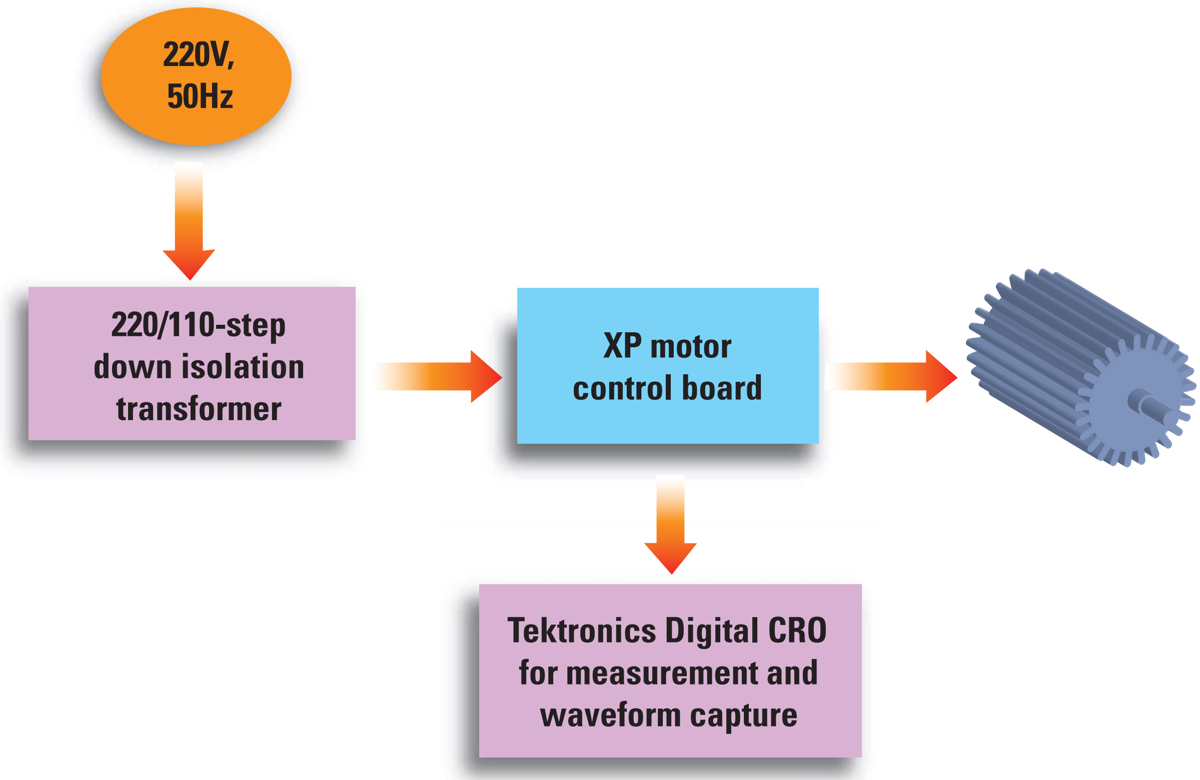


Figure 4. Testing Setup for Speed Control of an AC Motor

Equipment Used

- Optical tachometer as speed sensor
- Tektronics Digital Phosphor Oscilloscope.
- 220/110 V step down isolation transformer
- Fluke Multimeter
- PSC Motor with Convection Fan mounted on shaft

System Configurations

- System running Windows XP (SP2).
- ZDS II version 4.11.0 installed in the system.
- Optically isolated USB smart cable for program download and debugging.

Procedure

1. Build the code on ZDS II v4.11.0 and download the code through the USB smart cable.
2. Connect the CRO across the TRIAC terminals.

3. Connect the Z8 Encore! XP motor control board to the power supply (through isolation transformer).
4. Power ON the supply and observe the waveform on CRO.
5. Rotate the Potentiometer counter-clock-wise until the voltage across the motor is highest and it runs at highest speed.
6. Record the readings (Table 1) and carry out the process for each step of speed reduction.

Table 1. Motor Performance Test Results

Test Seq#	Motor Speed (RPM)	Voltage Across TRIAC (V)	Voltage Across Motor (V)	Voltage at Vcc of 8-pin Z8 Encore! XP (V)	Delay (msec)
1	1237	2.2	105.6	2.9	1.52
2	1220	2.9	100.7	2.9	2.24
3	1192	3.7	95.4	2.9	2.88
4	1130	26.5	87.4	3.1	3.52
5	994	34.	78.8	3.2	4.08
6	728	44.7	70.2	3.3	4.56
7	500	54.5	60.8	3.3	5.04
8	0	66.3	50.3	3.4	5.6

Results

Figure 5 shows the relationship of voltage (VAC) versus speed from Table 1. All of the test sequence measurements captured on the CRO from Table 1 are taken from data shown in Figures 6 through 13.

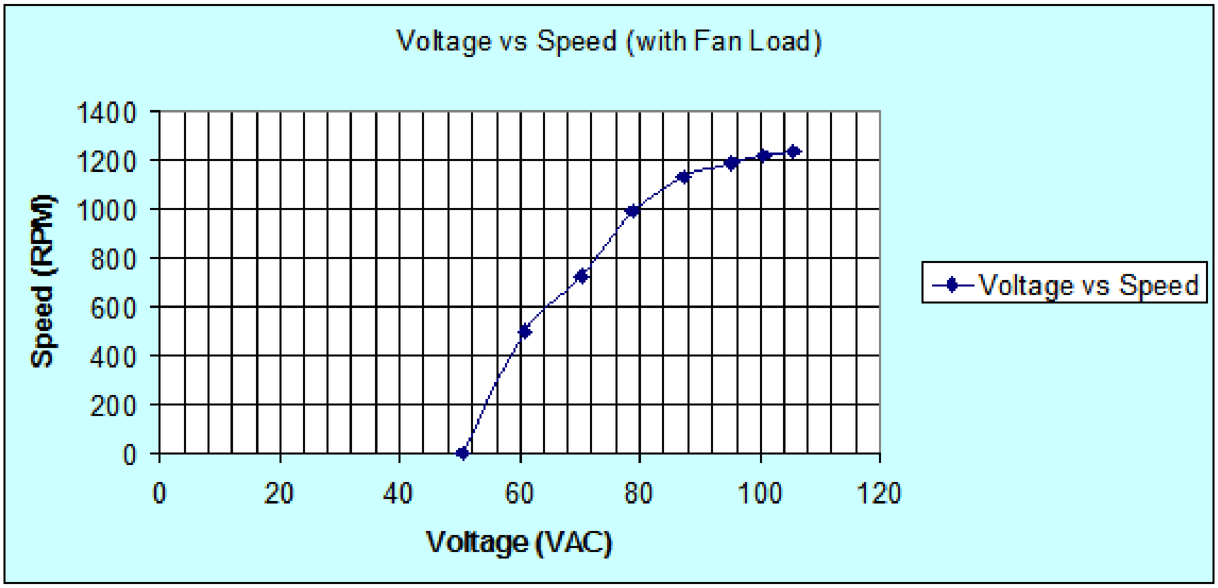


Figure 5. Voltage Vs. Speed (with Fan Load)

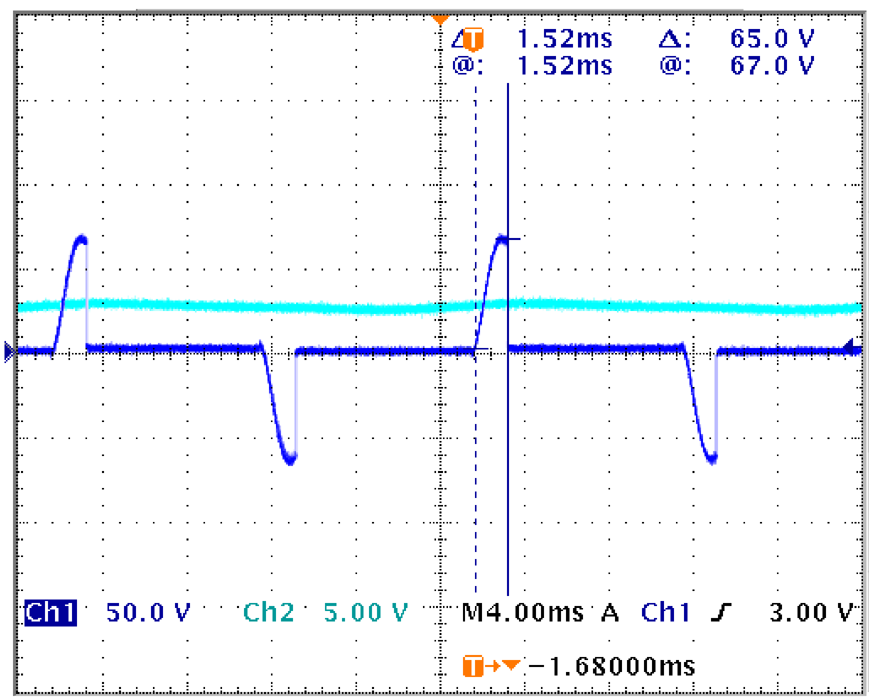


Figure 6. Test Sequence 1 Measurements

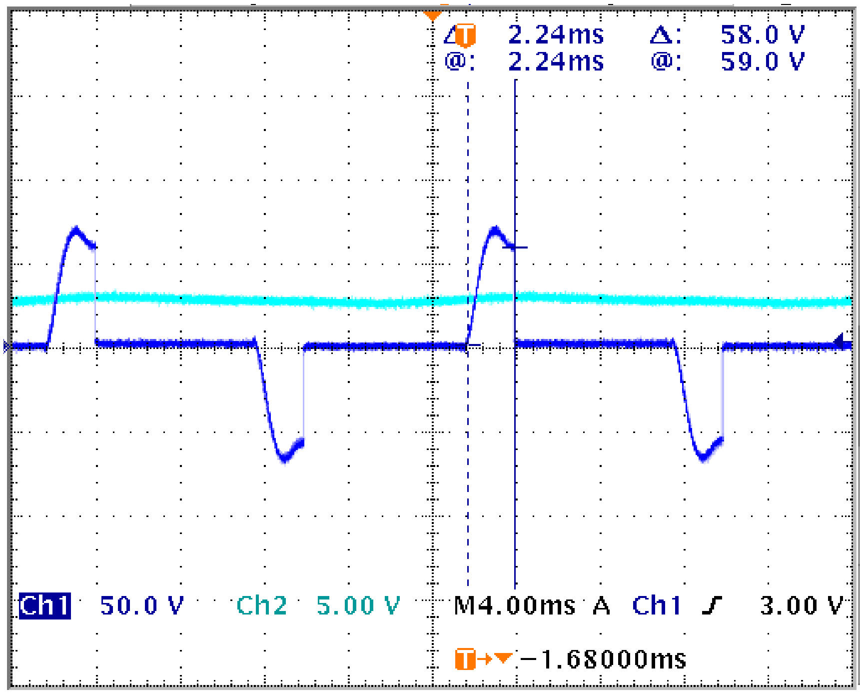


Figure 7. Test Sequence 2 Measurements

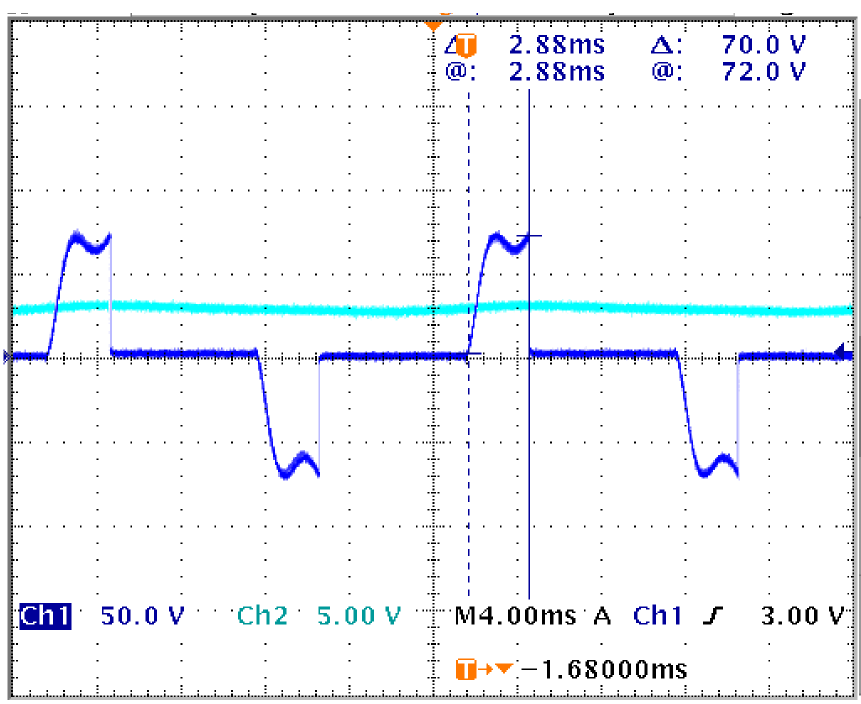


Figure 8. Test Sequence 3 Measurements

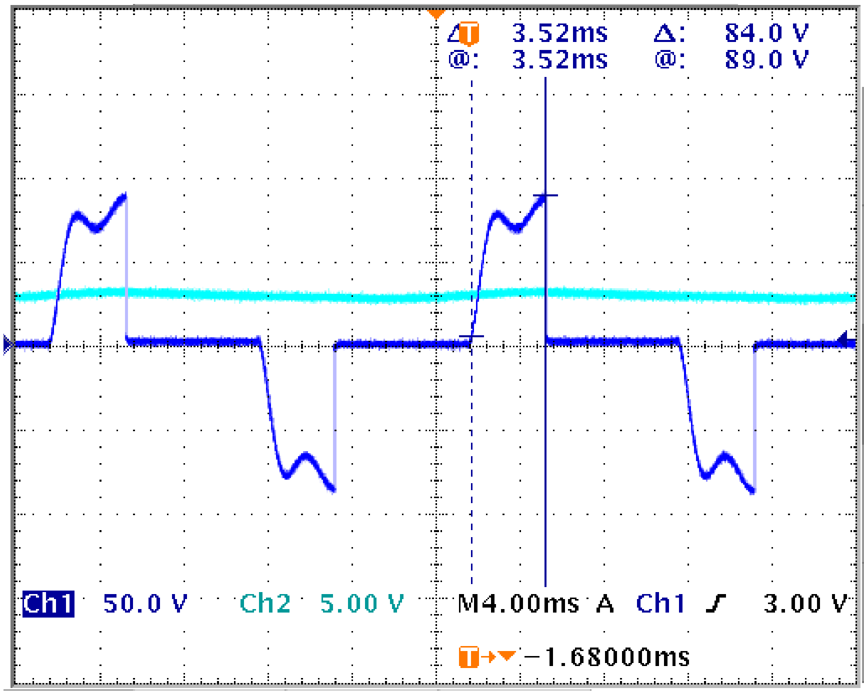


Figure 9. Test Sequence 4 Measurements

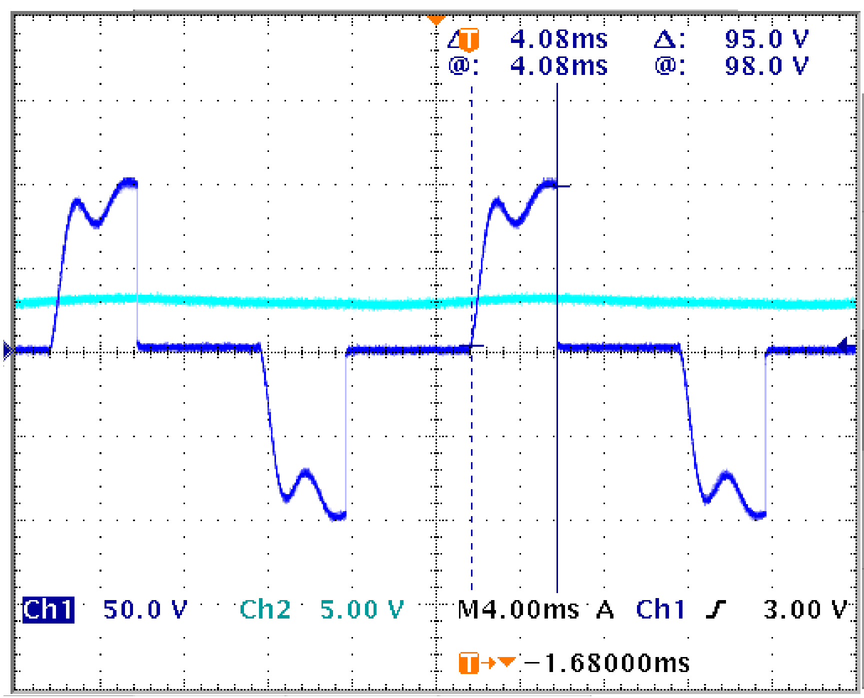


Figure 10. Test Sequence 5 Measurements

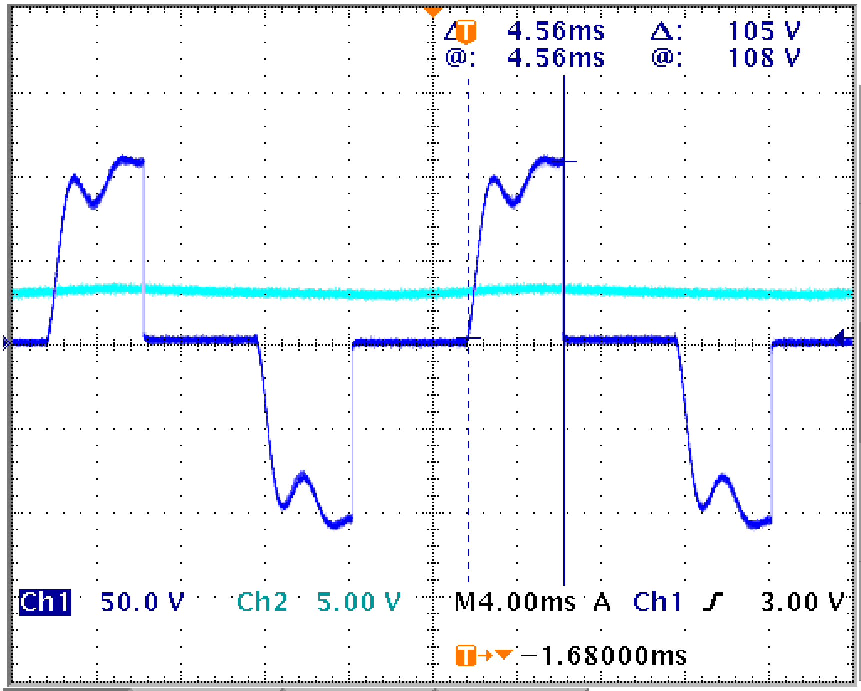


Figure 11. Test Sequence 6 Measurements

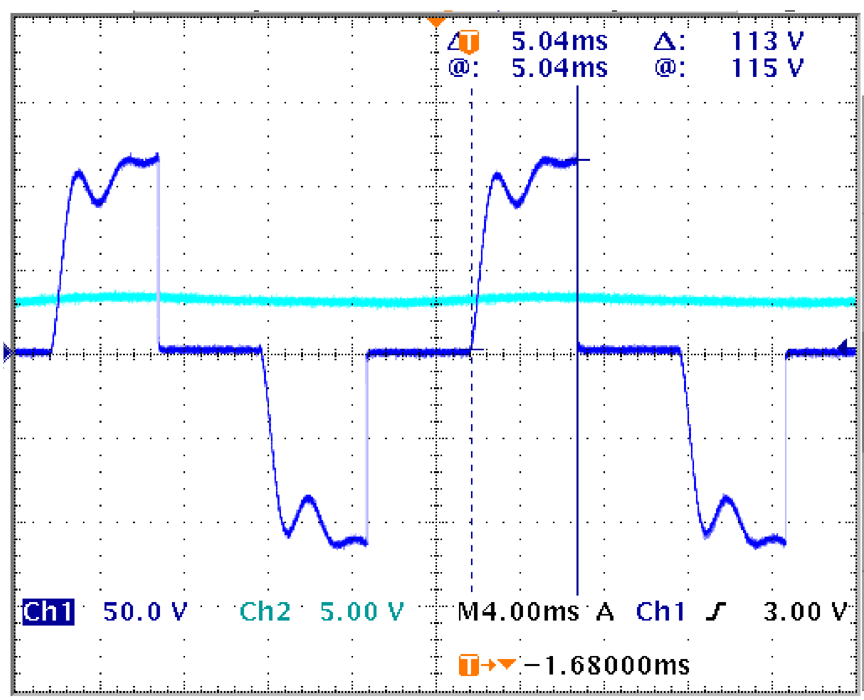


Figure 12. Test Sequence 7 Measurements

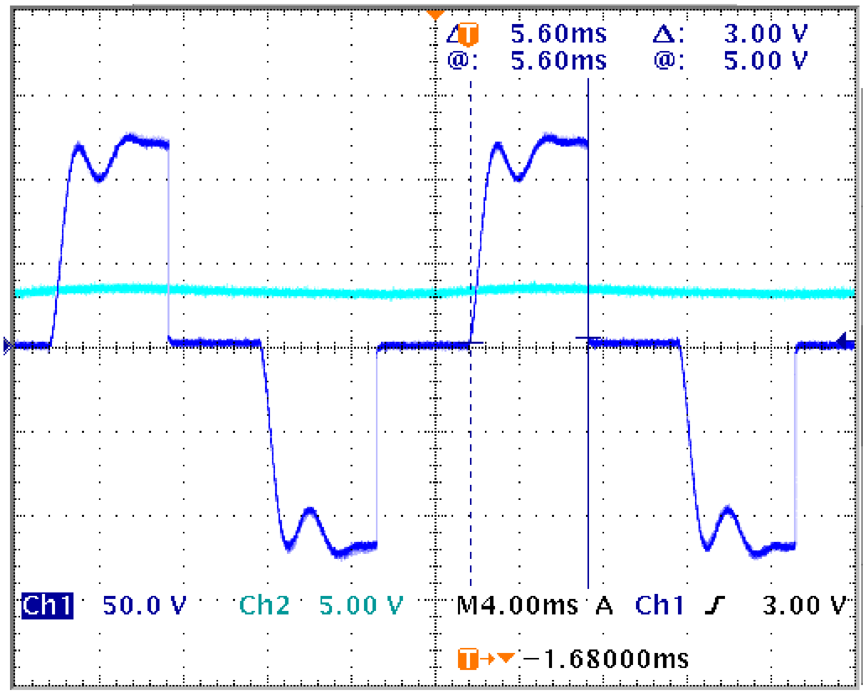


Figure 13. Test Sequence 8 Measurements

Parts List

The low-cost speed controller design uses the parts listed in Table 2.

Table 2. Parts List

Component	Value	Quantity	Manufacturer
R2	470 Ω, 1/2 W	1	Precision Electronics
C1	0.47 µF, 220 V	1	Precision Electronics
C2	0.47 µF, 220 V	1	Precision Electronics
D1	1N4148, 1/4 W	1	Fairchild
D2	5.1 V, 1/4 W	1	Fairchild
C3	470 mF, 16 V	1	Precision Electronics
R4	220 Ω, 1/4 W	1	Precision Electronics
C4	0.1 µF, 220 V	1	Precision Electronics
R3	1 KΩ, 1/4 W	1	Precision Electronics
D3	1N4148, 1/4 W	1	Fairchild

Table 2. Parts List

Component	Value	Quantity	Manufacturer
D4	1N4148, 1/4 W	1	Fairchild
R6	3.3 MΩ, 1/4 W	1	Precision Electronics
C6	10 µF, 16 V	1	Precision Electronics
Potentiometer	100 KΩ, Linear[1]	1	Precision Electronics
C5	0.1 nF, 16 V	1	Precision Electronics
C7	0.1 µF	1	Precision Electronics
C8	10 µF	1	Precision Electronics
R7	10 KΩ, 1/4 W	1	Precision Electronics
R8	10 KΩ, 1/4 W	1	Precision Electronics
SW1	Push (NO)	1	Precision Electronics
SW2	Push (NO)[3]	1	Precision Electronics
Q1	BT136, 600D	1	Philips
U1	Z8 Encore! XP	1	Zilog
J5	Connector for Power[2]	1	Precision Electronics
J1	Connector for Motor	1	Precision Electronics
J4	Connector for Motor	1	Precision Electronics
J7	Access point for Vcc	1	Precision Electronics
J8	Access point for GND	1	Precision Electronics
J3	Jumper for debug port[2]	1	Precision Electronics
J6	Jumper for TRIAC gate	1	Precision Electronics
R1	10 KΩ, 1/4 W	1	Precision Electronics
J2	Debug Port	1	Precision Electronics

Note: 1. Potentiometer will be used as a mechanism for speed adjustment.
Note: 2. These jumpers and points are accessible only during development. Omit them after design is complete.
Note: 3. SW1 and SW2 are left optional for user.

Summary

This Application Note demonstrates a low-cost solution for controller fan motor speed using the Z8 Encore! XP MCU. The MCU's wide array of innovative, integrated digital and analog modules result in optimized control of the motor speed. In addition, on-chip integration of these features provides for reduced system cost and faster development cycle timer.

References

The documents associated with Z8 Encore! XP MCU available on www.zilog.com are provided below:

- *Power Phase Control Using the Z8 Microcontroller*, AN0045
- *Dimmer Using Z8 Microcontroller*, AN0017
- *Universal Motor Control Using the Z8 Encore! XP Microcontroller*, AN0235
- *Z8 Encore! XP Microcontroller Product Specification*, PS0228
- eZ8 CPU User Manual, UM0128

Appendix A—Schematics

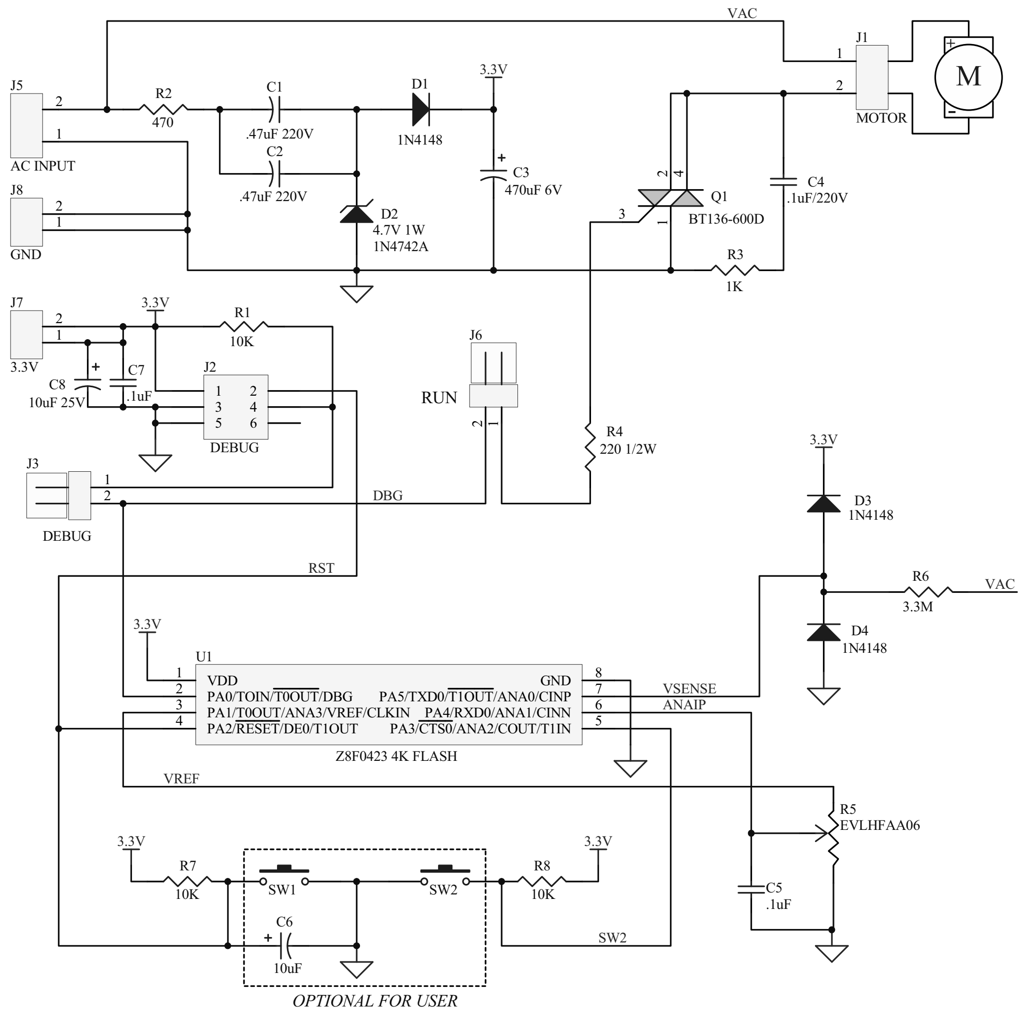


Figure 14. Schematic, Low-Cost Speed Controller for Single-Phase Permanent Split Capacitor Motor

Appendix B—Flowcharts

Flowcharts for the software portion of the low-cost speed controller are provided in Figures 15 through 18.

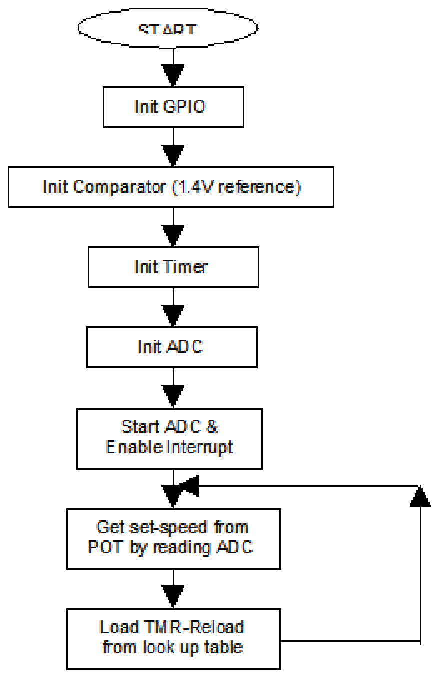


Figure 15. Main Function

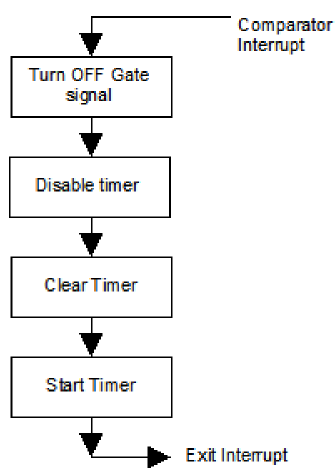


Figure 16. Flowchart for Comparator ISR

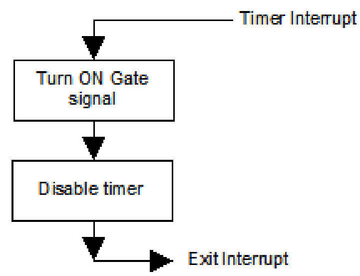


Figure 17. Flowchart for Timer ISR

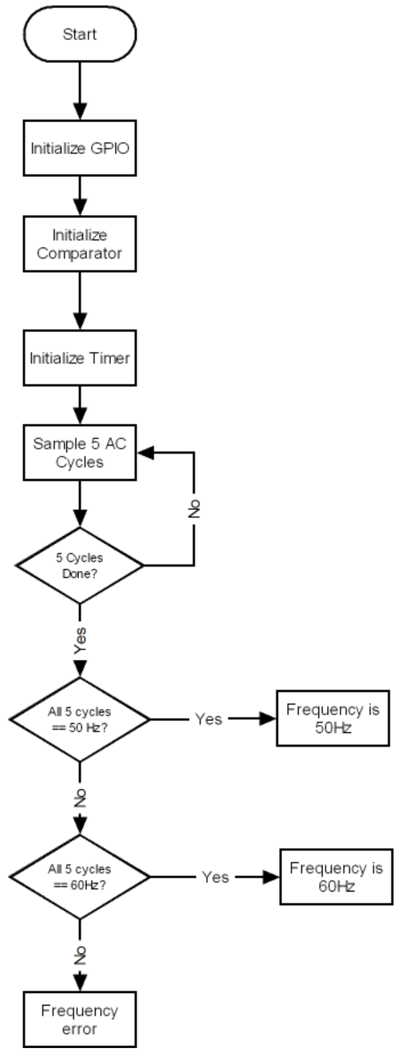


Figure 18. Flowchart for AC Frequency Test

Appendix C — Calculation of Firing Angle for 60Hz

Frequency = 60Hz
IPO Frequency = 5.53MHz
Timer-0 Prescalar = 8
Time for 1 full cycle of AC Mains = 1/60 = 0.016666667Sec
Time for 1 half cycle of AC Mains = 1/(60 * 2) = 0.008333333Sec
Clock input to TMR-0 = (5.53 * 1000000)/8 = 691250Hz
Time for 1 pulse = 1/691250 = 1.44665E-06Sec
Number of pulse for one half cycle = 0.008333333/ 1.44665E-06 = 5760

Table 3. Calculation of Firing Angle for 60Hz

Firing Angle (%)	Decrement	T0RH - T0RL (decimal)	T0RH - T0RL (hex)	Index (hex)
0	1	5760	1680	0
5	0.95	5472	1560	1
10	0.9	5184	1440	2
15	0.85	4896	1320	3
20	0.8	4608	1200	4
25	0.75	4320	10E0	5
30	0.7	4032	0FC0	6
35	0.65	3744	0EA0	7
40	0.6	3456	0D80	8
45	0.55	3168	0C60	9
50	0.5	2880	0B40	10
55	0.45	2592	0A20	11
60	0.4	2304	0900	12
65	0.35	2016	07E0	13
70	0.3	1728	06C0	14
75	0.25	1440	05A0	15
80	0.2	1152	0480	16
85	0.15	864	0360	17
90	0.1	576	0240	18
95	0.05	288	0120	19

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