



# Lab 2 / HW 2 Arduino Interfacing and Motor Control using FPGA

Spring 2020

College of Engineering and Computing

Department of Electrical and Computer Engineering

ECE 387: Embedded Systems

March 13<sup>th</sup>, 2020

Tyler McGrew

## **Description**

The aim of this project is to build a system that can read in high frequency analog signals and store samples of data for later retrieval. This is to be accomplished using a 10-bit analog-digital converter IC (MCP3002), an EEPROM IC (24LC256), an FPGA development board (DE2-115), and an MCU (Arduino Uno). The analog signal is fed into the ADC, which is sampled through the FPGA via Serial Peripheral Interface (SPI), buffered, and written to the EEPROM via Inter-Integrated Circuit (I<sup>2</sup>C). Then, the data is to be read and displayed at a later point via the MCU without using any existing I<sup>2</sup>C libraries. The data resolution is permitted to be only 8 bits/sample; however, the sampling/writing rate is to be maximized.

## Results

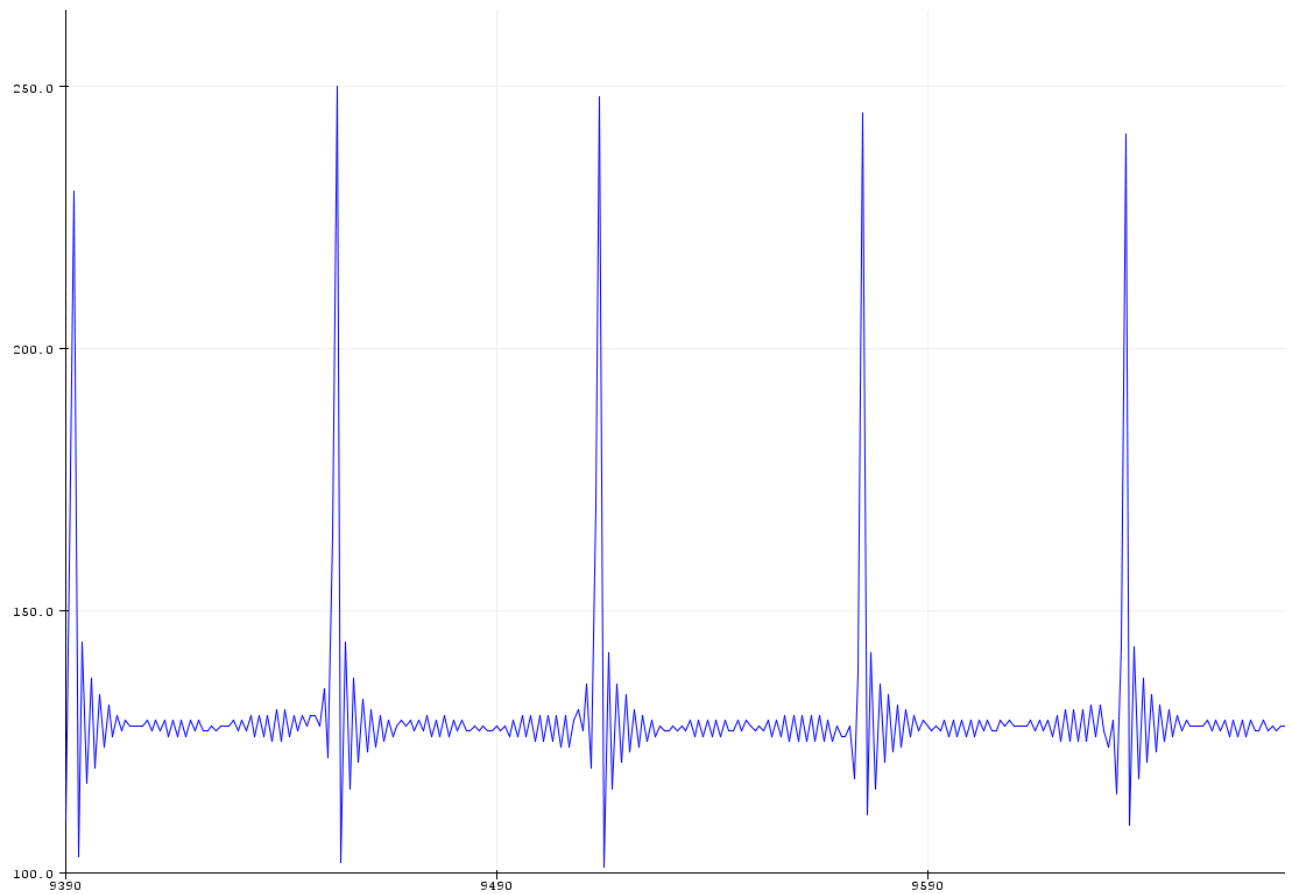


Figure 1. Arduino IDE plot of data from EEPROM (Original signal @ 100Hz)

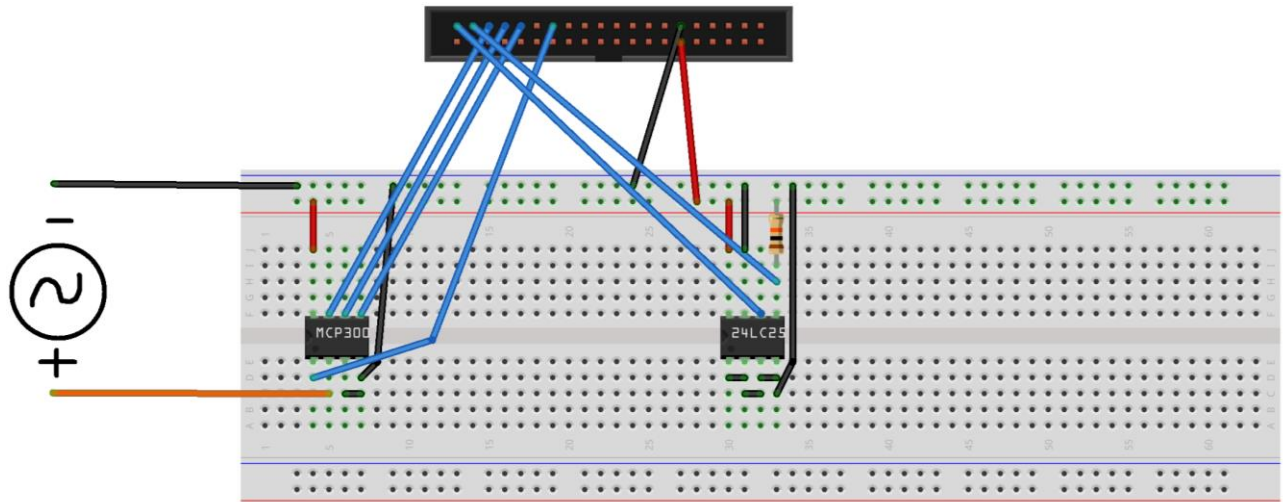


Figure 2. Circuit layout for sampling and writing data to the EEPROM using ADC and FPGA

GPIO pins

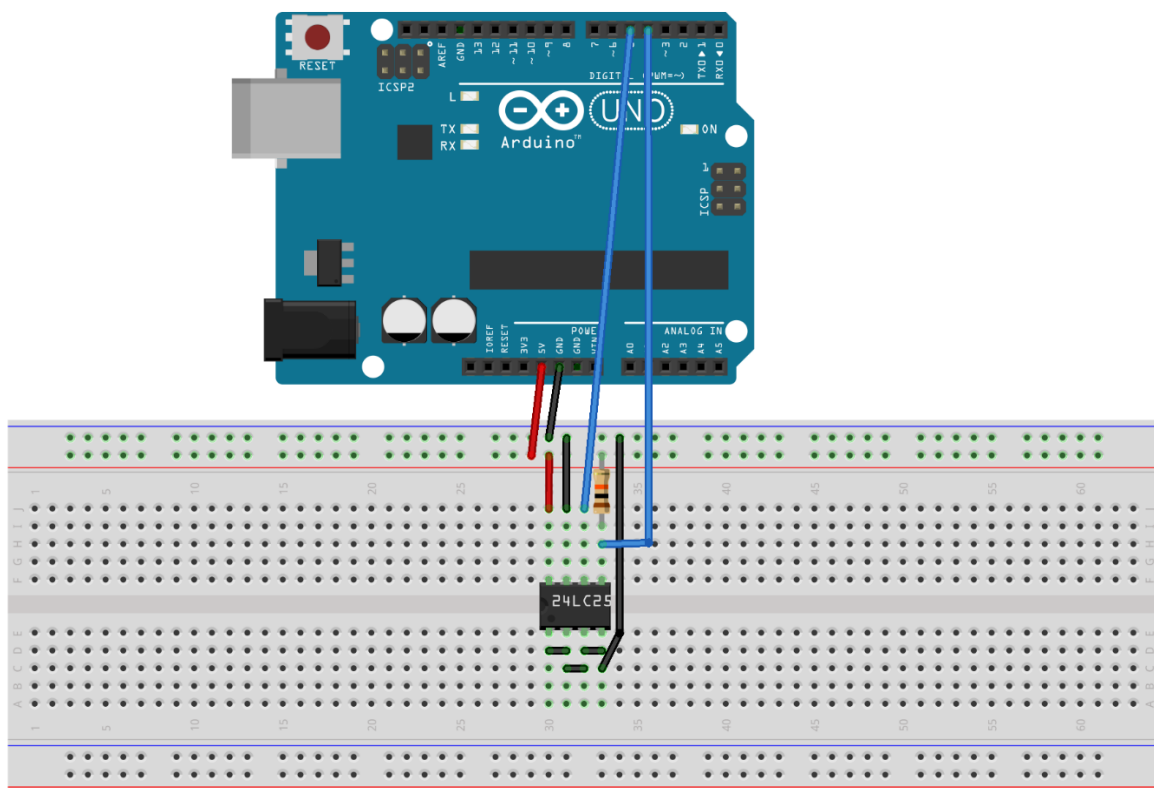


Figure 3. Circuit layout for reading and writing data to/from EEPROM with Arduino

Our completed system samples data from the ADC at 6.1ks/sec, buffers 64 eight-bit values, and writes a page (64 bytes) to the EEPROM while already buffering the next page from the ADC. The FPGA sends a “page-write” command to the EEPROM every 10.5ms using a 390kHz clock. The max clock frequency for the EEPROM is 400kHz and there is a minimum of 5ms between write operations permitted by the EEPROM. Additionally, our FPGA takes 1.6ms to send the control and data information for a page write operation. So, this system is near optimal and works without any noticeable issues for its purpose.

Similarly, the ADC allows for 75,000 samples/sec and a serial clock speed of 1.2MHz at 2.7V  $V_{DD}$ . Our system uses a 390kHz clock to sample at 6.1kHz because of the EEPROM bottleneck. Since each sample transfer takes only 14 clock cycles, this enables a sampling rate of 27ks/sec from the ADC- of which the FPGA uses only about one in four.

The FPGA layout is described in Verilog HDL within nine modules. There are two timer modules (“samplecountertimer.v”, “downclock.v”), four waveform generating modules (“startcon.v”, “stopcon.v”, “writehigh.v”, “writelow.v”), a module for obtaining samples from the ADC (“adcreader.v”), a module for writing a page of data to the EEPROM (“pagewriter.v”) and a high level control module to combine the other modules into a functional system (“eeprom.v”). Of these, only “adcreader.v”, “pagewriter.v”, “eeprom.v” can be considered state machines and “adcreader.v” is minimal in complexity. Most of the challenge and complexity comes in correctly implementing the I<sup>2</sup>C page-write operation (“pagewriter.v”) and in determining proper timing, control, and data flow between ADC and EEPROM (“eeprom.v”).

The page-writer module is implemented using six high level states: CONTROL, ADDRESS\_HIGH, ADDRESS\_LOW, DATA, STOP, and WAIT. To conduct a write operation

to the EEPROM the master must send a start condition, a control byte, two address bytes, 64 data bytes, and a stop condition. These states correspond to these bytes with the start condition being conducted by the data byte and the wait state looping in between write operations. Each state has up to 11 sub-states corresponding to bits and changing/resetting of signals between bytes. This module was very difficult to create without a digital logic analyzer to debug. Fortunately, we were able to use the waveform simulation feature of Quartus to get this module working properly.

The high-level control module “eeprom.v” was similarly difficult to implement. The module is a state machine that cycles through 64 states corresponding to the 64 bytes in a page. The states are cycled through in a rate which was calculated to allow the page to be filled with 64 evenly spaced samples in time for another page-write operation to be executed in order to have no discontinuities in the sampled data. On the rising edge of each state, the next byte of the page buffer is updated from the ADC. Every 64 bytes, the page buffer is copied into another buffer, the writing address is increased by one page, and the page writer’s enable signal is pulsed high. This is what allows the page writer to take multiple samples worth of time to write the page while the buffer is already being updated with new samples.

We wrote our own code for the Arduino which is able to read and write pages worth of information to/from the EEPROM over I<sup>2</sup>C. This was the first thing we worked on because it was quicker and easier than doing it on the FPGA and allowed us to reliably evaluate the performance of the FPGA system as we developed it. The program uses straight-forward “bit-banging” to turn on and off the two I<sup>2</sup>C lines in correct sequence using delay statements and reusable functions such as start() (start condition), write\_high (writes one bit high), and read\_bit().

## Appendix 1 – Arduino Code

Can also be found here:

[https://github.com/tymcgreww/EEPROM\\_Data\\_Logger/blob/master/Arduino/eprom/eprom.ino](https://github.com/tymcgreww/EEPROM_Data_Logger/blob/master/Arduino/eprom/eprom.ino)

```
const int s_data = 4;
const int s_clk = 5;
const int delay_time = 1;

void setup() {
    pinMode(s_clk, OUTPUT);
    pinMode(s_data, INPUT);
    Serial.begin(9600);
}

void loop() {
    for (int i = 2048; i < (2048)+(3*64); i += 64)
    {
        //page_write(i,0);
        page_read(i);
    }
    while(true);
}

void page_read(int start_address) {
    set_address(start_address);

    // Control Byte
    start();
    write_high();
    write_low();
    write_high();
    write_low();
    write_low();
    write_low();
    write_low();
    write_low();
    write_high();
    int ack = check_ack();
    //Serial.println(ack);

    for (int i = 0; i < 63; i++)
    {
        int val = 0;
        val += read_bit()*1;
        val += read_bit()*2;
        val += read_bit()*4;
        val += read_bit()*8;
        val += read_bit()*16;
        val += read_bit()*32;
        val += read_bit()*64;
        val += read_bit()*128;
        Serial.println(val);
        write_low();
    }

    int val = 0;
    val += read_bit()*1;
    val += read_bit()*2;
    val += read_bit()*4;
    val += read_bit()*8;
    val += read_bit()*16;
    val += read_bit()*32;
    val += read_bit()*64;
    val += read_bit()*128;
    Serial.println(val);
    stop1();
}

void page_write(int start_address, int write_value) {
```

```

// Find binary address
int start_address_binary [15] = {0};
int i1 = 0;
while (start_address > 0) {
    start_address_binary[i1] = start_address % 2;
    start_address = start_address / 2;
    i1++;
}

// Find binary write_value
int write_value_binary [8] = {0};
int i2 = 0;
while (write_value > 0) {
    write_value_binary[i2] = write_value % 2;
    write_value = write_value / 2;
    i2++;
}

start();
write_high();
write_low();
write_high();
write_low();
write_low();
write_low();
write_low();
write_low();
int ack = check_ack();
//Serial.println(ack);

// Address High Byte
write_low();
for (int j = 14; j >= 8; j--) {
    if (start_address_binary[j] == 1)
        write_high();
    else
        write_low();
}
ack = check_ack();
//Serial.println(ack);

// Address Low Byte
for (int j = 7; j >= 0; j--) {
    if (start_address_binary[j] == 1)
        write_high();
    else
        write_low();
}
ack = check_ack();
//Serial.println(ack);

for (int i = 0; i < 63; i++)
{
    // Write Byte
    for (int j = 0; j < 8; j++) {
        if (write_value_binary[j] == 1)
            write_high();
        else
            write_low();
    }
    ack = check_ack();
    //Serial.println(ack);
}

// Write Byte
for (int j = 0; j < 8; j++) {
    if (write_value_binary[j] == 1)
        write_high();
    else
        write_low();
}

```



```

        ack = check_ack();
        //Serial.println(ack);
        stop1();
    }

void set_address(int start_address) {
    // Find binary address
    int start_address_binary [15] = {0};
    int i = 0;
    while (start_address > 0) {
        start_address_binary[i] = start_address % 2;
        start_address = start_address / 2;
        i++;
    }

    // Control Byte
    start();
    write_high();
    write_low();
    write_high();
    write_low();
    write_low();
    write_low();
    write_low();
    write_low();
    int ack = check_ack();
    //Serial.println(ack);

    // Address High Byte
    write_low();
    for (int i = 14; i >= 8; i--) {
        if (start_address_binary[i])
            write_high();
        else
            write_low();
    }
    ack = check_ack();
    //Serial.println(ack);

    // Address Low Byte
    for (int i = 7; i >= 0; i--) {
        if (start_address_binary[i])
            write_high();
        else
            write_low();
    }
    ack = check_ack();
    //Serial.println(ack);
}

int read_bit() {
    digitalWrite(s_clk, HIGH);
    delay(delay_time);
    int val = digitalRead(s_data);
    digitalWrite(s_clk, LOW);
    delay(delay_time);
    return val;
}

void start() {
    digitalWrite(s_data,HIGH);
    pinMode(s_data,OUTPUT);
    delay(delay_time);
    digitalWrite(s_clk, HIGH);
    delay(delay_time);
    digitalWrite(s_data,LOW);
    delay(delay_time);
    digitalWrite(s_clk,LOW);
    pinMode(s_data,INPUT);
}

```

```

    delay(delay_time);
}

void write_high() {
    digitalWrite(s_data,HIGH);
    pinMode(s_data,OUTPUT);
    delay(delay_time);
    digitalWrite(s_clk,HIGH);
    delay(delay_time);
    digitalWrite(s_clk,LOW);
    pinMode(s_data,INPUT);
    delay(delay_time);
}

void write_low() {
    digitalWrite(s_data,LOW);
    pinMode(s_data,OUTPUT);
    delay(delay_time);
    digitalWrite(s_clk,HIGH);
    delay(delay_time);
    digitalWrite(s_clk,LOW);
    pinMode(s_data,INPUT);
    delay(delay_time);
}

int check_ack() {
    digitalWrite(s_clk,HIGH);
    delay(delay_time);
    int ack = digitalRead(s_data);
    digitalWrite(s_clk,LOW);
    delay(delay_time);
    return ack;
}

void stop1(){
    digitalWrite(s_data,LOW);
    pinMode(s_data,OUTPUT);
    delay(delay_time);
    digitalWrite(s_clk, HIGH);
    delay(delay_time);
    digitalWrite(s_data,HIGH);
    delay(delay_time);
    digitalWrite(s_clk,LOW);
    delay(delay_time);
    pinMode(s_data,INPUT);
    delay(delay_time);
}

```

## Appendix 2 – FPGA Code

Can also be found here:

[https://github.com/tymcgreww/EEPROM\\_Data\\_Logger/tree/master/FPGA/eprom](https://github.com/tymcgreww/EEPROM_Data_Logger/tree/master/FPGA/eprom)

```
module eeprom(clk, rst, sdata, sclk, done, adcclock, din, dout, cs);

    input clk, rst;
    output sclk, done;
    inout sdata;
    output adcclock, dout, cs;
    input din;

    wire [7:0]adc_out;

    wire pagewriter_done;
    wire [31:0]samplecounter;

    reg [14:0]address = 15'd2048;
    reg [511:0]write_data;
    reg [511:0]page_buffer;
    reg [31:0]prev_samplecounter;
    reg [31:0]page_counter;
    reg firstpass = 1'b1;
    reg done;
    reg enable;

    pagewriter pagewriter1(clk, rst, sdata, sclk, write_data, address, pagewriter_done,
enable);
    adcreader adcreader1(clk, adcclock, din, dout, cs, rst, adc_out);
    samplecountertimer samplecountertimer1(clk, rst, samplecounter);

    always@(posedge clk or negedge rst)
    begin
        if (rst == 1'b0)
            begin
                address <= 15'd2048;
                write_data <= 512'd0;
                page_buffer <= 512'd0;
                prev_samplecounter <= 32'd0;
                page_counter <= 32'd0;
                firstpass <= 1'b1;
                done <= 1'b0;
                enable <= 1'b0;
            end
        else
            begin
                if (page_counter < 32'd16)
                    begin
                        if (prev_samplecounter == samplecounter)
                            enable <= 1'b0;
                        prev_samplecounter <= samplecounter;
                        if (samplecounter != prev_samplecounter)
                            begin
                                case(samplecounter)
                                    default: page_buffer[511:504] <= adc_out;
                                    32'd62: page_buffer[503:496] <= adc_out;
                                    32'd61: page_buffer[495:488] <= adc_out;
                                    32'd60: page_buffer[487:480] <= adc_out;
                                    32'd59: page_buffer[479:472] <= adc_out;
                                    32'd58: page_buffer[471:464] <= adc_out;
                                    32'd57: page_buffer[463:456] <= adc_out;
                                    32'd56: page_buffer[455:448] <= adc_out;
                                    32'd55: page_buffer[447:440] <= adc_out;
                                    32'd54: page_buffer[439:432] <= adc_out;
                                    32'd53: page_buffer[431:424] <= adc_out;
```

```

32'd52: page_buffer[423:416] <= adc_out;
32'd51: page_buffer[415:408] <= adc_out;
32'd50: page_buffer[407:400] <= adc_out;
32'd49: page_buffer[399:392] <= adc_out;
32'd48: page_buffer[391:384] <= adc_out;
32'd47: page_buffer[383:376] <= adc_out;
32'd46: page_buffer[375:368] <= adc_out;
32'd45: page_buffer[367:360] <= adc_out;
32'd44: page_buffer[359:352] <= adc_out;
32'd43: page_buffer[351:344] <= adc_out;
32'd42: page_buffer[343:336] <= adc_out;
32'd41: page_buffer[335:328] <= adc_out;
32'd40: page_buffer[327:320] <= adc_out;
32'd39: page_buffer[319:312] <= adc_out;
32'd38: page_buffer[311:304] <= adc_out;
32'd37: page_buffer[303:296] <= adc_out;
32'd36: page_buffer[295:288] <= adc_out;
32'd35: page_buffer[287:280] <= adc_out;
32'd34: page_buffer[279:272] <= adc_out;
32'd33: page_buffer[271:264] <= adc_out;
32'd32: page_buffer[263:256] <= adc_out;
32'd31: page_buffer[255:248] <= adc_out;
32'd30: page_buffer[247:240] <= adc_out;
32'd29: page_buffer[239:232] <= adc_out;
32'd28: page_buffer[231:224] <= adc_out;
32'd27: page_buffer[223:216] <= adc_out;
32'd26: page_buffer[215:208] <= adc_out;
32'd25: page_buffer[207:200] <= adc_out;
32'd24: page_buffer[199:192] <= adc_out;
32'd23: page_buffer[191:184] <= adc_out;
32'd22: page_buffer[183:176] <= adc_out;
32'd21: page_buffer[175:168] <= adc_out;
32'd20: page_buffer[167:160] <= adc_out;
32'd19: page_buffer[159:152] <= adc_out;
32'd18: page_buffer[151:144] <= adc_out;
32'd17: page_buffer[143:136] <= adc_out;
32'd16: page_buffer[135:128] <= adc_out;
32'd15: page_buffer[127:120] <= adc_out;
32'd14: page_buffer[119:112] <= adc_out;
32'd13: page_buffer[111:104] <= adc_out;
32'd12: page_buffer[103:96] <= adc_out;
32'd11: page_buffer[95:88] <= adc_out;
32'd10: page_buffer[87:80] <= adc_out;
32'd9: page_buffer[79:72] <= adc_out;
32'd8: page_buffer[71:64] <= adc_out;
32'd7: page_buffer[63:56] <= adc_out;
32'd6: page_buffer[55:48] <= adc_out;
32'd5: page_buffer[47:40] <= adc_out;
32'd4: page_buffer[39:32] <= adc_out;
32'd3: page_buffer[31:24] <= adc_out;
32'd2: page_buffer[23:16] <= adc_out;
32'd1: page_buffer[15:8] <= adc_out;
32'd0: page_buffer[7:0] <= adc_out;
endcase

case(samplecounter)
32'd0:
begin
    //if (firstpass == 1'b0)
    //begin
        write_data <= page_buffer;
        enable <= 1'b1;
    //end

end
32'd60:
begin
    firstpass <= 1'b0;
    if (firstpass == 1'b0)
    begin
        page_counter <= page_counter + 32'd1;
    end
end

```



```

stopcon stopcon1(clk, rst, sdata_stopcon, counter);
writehigh writehigh1(clk, rst, sdata_writehigh, counter);
writelow writelow1(clk, rst, sdata_writelow, counter);

//-----
//                -- Begin Declarations & Coding --
//-----

always@(posedge clk or negedge rst)    // Determine STATE
begin

    if (rst == 1'b0)
        STATE <= DATA;
    else
        STATE <= NEXT_STATE;

end

always@(posedge clk or negedge rst)    // Determine outputs
begin

    if (rst == 1'b0)
    begin
        sclk <= 1'b0;
        counter <= 32'd0;
        bit_counter <= 32'd0;
        data_bit_counter <= 32'd0;
        sdata <= 1'bz;
        NEXT_STATE <= (enable == 1'b1)? CONTROL : WAIT;
        secondpass <= 1'b0;
        done <= 1'b0;
    end

    else
    begin

        sclk <= sclk_internal;
        counter <= (counter >= SCLK_COUNTER_THRESH)? 32'd0 : counter + 32'd1;

        case(STATE)

            CONTROL:
            begin
                case (bit_counter)
                    32'd0:
                    begin
                        sdata <= (counter >= HIGH_THRESH || counter <=
LOW_THRESH)? sdata_startcon : 1'bz;
                        if (counter == LOW_THRESH)
                            secondpass <= 1'b1;
                        bit_counter <= (counter == LOW_THRESH && secondpass
== 1'b1)? bit_counter + 32'd1 : bit_counter;
                    end
                    32'd1:
                    begin
                        sdata <= (counter >= HIGH_THRESH || counter <=
LOW_THRESH)? sdata_writehigh : 1'bz;
                        bit_counter <= (counter == LOW_THRESH)? bit_counter
+ 32'd1 : bit_counter;
                    end
                    32'd2:
                    begin
                        sdata <= (counter >= HIGH_THRESH || counter <=
LOW_THRESH)? sdata_writelow : 1'bz;
                        bit_counter <= (counter == LOW_THRESH)? bit_counter
+ 32'd1 : bit_counter;
                    end
                    32'd3:
                    begin

```

```

LOW_THRESH)? sdata_writehigh : 1'bz;
+ 32'd1 : bit_counter;

end
32'd4:
begin
    sdata <= (counter >= HIGH_THRESH || counter <=
bit_counter <= (counter == LOW_THRESH)? bit_counter

LOW_THRESH)? sdata_writelow : 1'bz;
+ 32'd1 : bit_counter;

end
32'd5:
begin
    sdata <= (counter >= HIGH_THRESH || counter <=
bit_counter <= (counter == LOW_THRESH)? bit_counter

LOW_THRESH)? sdata_writelow : 1'bz;
+ 32'd1 : bit_counter;

end
32'd6:
begin
    sdata <= (counter >= HIGH_THRESH || counter <=
bit_counter <= (counter == LOW_THRESH)? bit_counter

LOW_THRESH)? sdata_writelow : 1'bz;
+ 32'd1 : bit_counter;

end
32'd7:
begin
    sdata <= (counter >= HIGH_THRESH || counter <=
bit_counter <= (counter == LOW_THRESH)? bit_counter

LOW_THRESH)? sdata_writelow : 1'bz;
+ 32'd1 : bit_counter;

end
32'd8:
begin
    sdata <= (counter >= HIGH_THRESH || counter <=
bit_counter <= (counter == LOW_THRESH)? bit_counter

LOW_THRESH)? sdata_writelow : 1'bz;
+ 32'd1 : bit_counter;

end
32'd9:
begin
    sdata <= 1'bz;
    bit_counter <= (counter == LOW_THRESH)? bit_counter

+ 32'd1 : bit_counter;

end
default:
begin
    NEXT_STATE <= AHIGH;
    bit_counter <= 32'd0;

end
endcase

end

AHIGH:
begin
    case (bit_counter)
        32'd0:
            begin
                sdata <= (counter >= HIGH_THRESH || counter <=
bit_counter <= (counter == LOW_THRESH)? bit_counter

            end
        32'd1:
            begin
                if (counter >= HIGH_THRESH || counter <= LOW_THRESH)
                    sdata <= (address[14] == 1'b1)?

                else
                    sdata <= 1'bz;

```

```

bit_counter <= (counter == LOW_THRESH)? bit_counter
+ 32'd1 : bit_counter;

end
32'd2:
begin
    if (counter >= HIGH_THRESH || counter <= LOW_THRESH)
        sdata <= (address[13] == 1'b1)?

    else
        sdata <= 1'bz;
    bit_counter <= (counter == LOW_THRESH)? bit_counter

end
3'd3:
begin
    if (counter >= HIGH_THRESH || counter <= LOW_THRESH)
        sdata <= (address[12] == 1'b1)?

    else
        sdata <= 1'bz;
    bit_counter <= (counter == LOW_THRESH)? bit_counter

end
32'd4:
begin
    if (counter >= HIGH_THRESH || counter <= LOW_THRESH)
        sdata <= (address[11] == 1'b1)?

    else
        sdata <= 1'bz;
    bit_counter <= (counter == LOW_THRESH)? bit_counter

end
32'd5:
begin
    if (counter >= HIGH_THRESH || counter <= LOW_THRESH)
        sdata <= (address[10] == 1'b1)?

    else
        sdata <= 1'bz;
    bit_counter <= (counter == LOW_THRESH)? bit_counter

end
32'd6:
begin
    if (counter >= HIGH_THRESH || counter <= LOW_THRESH)
        sdata <= (address[9] == 1'b1)?

    else
        sdata <= 1'bz;
    bit_counter <= (counter == LOW_THRESH)? bit_counter

end
32'd7:
begin
    if (counter >= HIGH_THRESH || counter <= LOW_THRESH)
        sdata <= (address[8] == 1'b1)?

    else
        sdata <= 1'bz;
    bit_counter <= (counter == LOW_THRESH)? bit_counter

end
32'd8:
begin
    sdata <= 1'bz;
    bit_counter <= (counter == LOW_THRESH)? bit_counter

end
default:
begin

```



```

NEXT_STATE <= ALLOW;
bit_counter <= 32'd0;
end
endcase
end

ALLOW:
begin
case (bit_counter)
32'd0:
begin
if (counter >= HIGH_THRESH || counter <= LOW_THRESH)
sdata <= (address[7] == 1'b1)?

sdata_writehigh : sdata_writelow;

else
sdata <= 1'bz;
bit_counter <= (counter == LOW_THRESH)? bit_counter

+ 32'd1 : bit_counter;

end
32'd1:
begin
if (counter >= HIGH_THRESH || counter <= LOW_THRESH)
sdata <= (address[6] == 1'b1)?

sdata_writehigh : sdata_writelow;

else
sdata <= 1'bz;
bit_counter <= (counter == LOW_THRESH)? bit_counter

+ 32'd1 : bit_counter;

end
32'd2:
begin
if (counter >= HIGH_THRESH || counter <= LOW_THRESH)
sdata <= (address[5] == 1'b1)?

sdata_writehigh : sdata_writelow;

else
sdata <= 1'bz;
bit_counter <= (counter == LOW_THRESH)? bit_counter

+ 32'd1 : bit_counter;

end
32'd3:
begin
if (counter >= HIGH_THRESH || counter <= LOW_THRESH)
sdata <= (address[4] == 1'b1)?

sdata_writehigh : sdata_writelow;

else
sdata <= 1'bz;
bit_counter <= (counter == LOW_THRESH)? bit_counter

+ 32'd1 : bit_counter;

end
32'd4:
begin
if (counter >= HIGH_THRESH || counter <= LOW_THRESH)
sdata <= (address[3] == 1'b1)?

sdata_writehigh : sdata_writelow;

else
sdata <= 1'bz;
bit_counter <= (counter == LOW_THRESH)? bit_counter

+ 32'd1 : bit_counter;

end
32'd5:
begin
if (counter >= HIGH_THRESH || counter <= LOW_THRESH)
sdata <= (address[2] == 1'b1)?

sdata_writehigh : sdata_writelow;

else
sdata <= 1'bz;
bit_counter <= (counter == LOW_THRESH)? bit_counter

+ 32'd1 : bit_counter;

end
32'd6:
begin

```

```

sdata_writehigh : sdata_writelow;

+ 32'd1 : bit_counter;

sdata_writehigh : sdata_writelow;

+ 32'd1 : bit_counter;

+ 32'd1 : bit_counter;

end
32'd7:
begin
    if (counter >= HIGH_THRESH || counter <= LOW_THRESH)
        sdata <= (address[1] == 1'b1)?
    else
        sdata <= 1'bz;
        bit_counter <= (counter == LOW_THRESH)? bit_counter
    end
end
32'd8:
begin
    if (counter >= HIGH_THRESH || counter <= LOW_THRESH)
        sdata <= (address[0] == 1'b1)?
    else
        sdata <= 1'bz;
        bit_counter <= (counter == LOW_THRESH)? bit_counter
    end
end
default:
begin
    NEXT_STATE <= DATA;
    bit_counter <= 32'd0;
end
endcase
end

DATA:
begin
    case (bit_counter)
        32'd0:
        begin
            if (counter >= HIGH_THRESH || counter <= LOW_THRESH)
                sdata <= (write_data[data_bit_counter] ==
1'b1)? sdata_writehigh : sdata_writelow;
            else
                sdata <= 1'bz;
                bit_counter <= (counter == LOW_THRESH)? bit_counter
                data_bit_counter <= (counter == LOW_THRESH)?
+ 32'd1 : bit_counter;
data_bit_counter + 32'd1 : data_bit_counter;
            end
            32'd1:
            begin
                if (counter >= HIGH_THRESH || counter <= LOW_THRESH)
                    sdata <= (write_data[data_bit_counter] ==
1'b1)? sdata_writehigh : sdata_writelow;
                else
                    sdata <= 1'bz;
                    bit_counter <= (counter == LOW_THRESH)? bit_counter
                    data_bit_counter <= (counter == LOW_THRESH)?
+ 32'd1 : bit_counter;
data_bit_counter + 32'd1 : data_bit_counter;
                end
                32'd2:
                begin
                    if (counter >= HIGH_THRESH || counter <= LOW_THRESH)
                        sdata <= (write_data[data_bit_counter] ==
1'b1)? sdata_writehigh : sdata_writelow;
                    else
                        sdata <= 1'bz;
                        bit_counter <= (counter == LOW_THRESH)? bit_counter
                        data_bit_counter <= (counter == LOW_THRESH)?
+ 32'd1 : bit_counter;
data_bit_counter + 32'd1 : data_bit_counter;
                    end
                end
            end
        end
    endcase
end

```

```

32'd3:
begin
    if (counter >= HIGH_THRESH || counter <= LOW_THRESH)
        sdata <= (write_data[data_bit_counter] ==
1'b1)? sdata_writehigh : sdata_writelow;
    else
        sdata <= 1'bz;
        bit_counter <= (counter == LOW_THRESH)? bit_counter
+ 32'd1 : bit_counter;
        data_bit_counter <= (counter == LOW_THRESH)?
data_bit_counter + 32'd1 : data_bit_counter;
    end
32'd4:
begin
    if (counter >= HIGH_THRESH || counter <= LOW_THRESH)
        sdata <= (write_data[data_bit_counter] ==
1'b1)? sdata_writehigh : sdata_writelow;
    else
        sdata <= 1'bz;
        bit_counter <= (counter == LOW_THRESH)? bit_counter
+ 32'd1 : bit_counter;
        data_bit_counter <= (counter == LOW_THRESH)?
data_bit_counter + 32'd1 : data_bit_counter;
    end
32'd5:
begin
    if (counter >= HIGH_THRESH || counter <= LOW_THRESH)
        sdata <= (write_data[data_bit_counter] ==
1'b1)? sdata_writehigh : sdata_writelow;
    else
        sdata <= 1'bz;
        bit_counter <= (counter == LOW_THRESH)? bit_counter
+ 32'd1 : bit_counter;
        data_bit_counter <= (counter == LOW_THRESH)?
data_bit_counter + 32'd1 : data_bit_counter;
    end
32'd6:
begin
    if (counter >= HIGH_THRESH || counter <= LOW_THRESH)
        sdata <= (write_data[data_bit_counter] ==
1'b1)? sdata_writehigh : sdata_writelow;
    else
        sdata <= 1'bz;
        bit_counter <= (counter == LOW_THRESH)? bit_counter
+ 32'd1 : bit_counter;
        data_bit_counter <= (counter == LOW_THRESH)?
data_bit_counter + 32'd1 : data_bit_counter;
    end
32'd7:
begin
    if (counter >= HIGH_THRESH || counter <= LOW_THRESH)
        sdata <= (write_data[data_bit_counter] ==
1'b1)? sdata_writehigh : sdata_writelow;
    else
        sdata <= 1'bz;
        bit_counter <= (counter == LOW_THRESH)? bit_counter
+ 32'd1 : bit_counter;
        data_bit_counter <= (counter == LOW_THRESH)?
data_bit_counter + 32'd1 : data_bit_counter;
    end
32'd8:
begin
    sdata <= 1'bz;
    bit_counter <= (counter == LOW_THRESH)? bit_counter
+ 32'd1 : bit_counter;
end
default:
begin
    if (data_bit_counter >= 32'd511)
    begin
        NEXT_STATE <= STOP;

```

```

                                data_bit_counter <= 32'd0;
                                end
                                bit_counter <= 32'd0;
                                end
                                endcase
                                end
                                STOP:
                                begin
                                    case(bit_counter)
                                        32'd0:
                                        begin
                                            sdata <= (counter >= HIGH_THRESH || counter <=
LOW_THRESH)? sdata_stopcon : 1'bz;
                                            bit_counter <= (counter == LOW_THRESH)? bit_counter
+ 32'd1 : bit_counter;
                                        end
                                        default:
                                        begin
                                            bit_counter <= 32'd0;
                                            NEXT_STATE <= WAIT;
                                        end
                                    endcase
                                end
                                default: //WAIT
                                begin
                                    if (enable == 1'b1)
                                    begin
                                        NEXT_STATE <= CONTROL;
                                        done <= 1'b0;
                                    end
                                    done <= 1'b1;
                                    sdata <= 1'bz;
                                end
                                endcase
                                end
                                end
                                endmodule

```

```

module adcreader(clk, adcclock, din, dout, cs, rst, out);

    input clk, rst, din;
    output adcclock;
    output reg dout, cs;
    downclock downclock1(clk, adcclock, rst);
    output reg [7:0]out;

    reg [31:0]state;
    reg [7:0]buffer;

    always@(posedge adcclock or negedge rst)
    begin
        if (rst == 1'b0)
        begin
            dout <= 1'b0;
            cs <= 1'b1;
            state <= 32'd0;
            buffer <= 8'd0;
            out <= 8'd0;
        end
    end
endmodule

```

```

else
begin

state <= (state > 32'd12)? 32'd0 : state + 32'd1;

case(state)
32'd0:
begin
cs <= 1'b0;
dout <= 1'b1;
buffer <= 8'd0;
end
32'd1:
begin
cs <= 1'b0;
dout <= 1'b0;
end
32'd2:
begin
cs <= 1'b0;
dout <= 1'b0;
end
32'd3:
begin
cs <= 1'b0;
dout <= 1'b1;
end
32'd4:
begin

end
32'd5:
begin
buffer[7] <= din;
end
32'd6:
begin
buffer[6] <= din;
end
32'd7:
begin
buffer[5] <= din;
end
32'd8:
begin
buffer[4] <= din;
end
32'd9:
begin
buffer[3] <= din;
end
32'd10:
begin
buffer[2] <= din;
end
32'd11:
begin
buffer[1] <= din;
end
32'd12:
begin
buffer[0] <= din;
cs <= 1'b1;
end
default:
begin
cs <= 1'b0;
dout <= 1'b1;
out <= buffer;
end
endcase

```

```

        end
    end

endmodule

module downclock(clk, adcclock, rst);

input clk, rst;
output reg adcclock;

reg [31:0]counter;
parameter threshold = 32'd128;    // 64
parameter half = 32'd64;        // 32

always@(posedge clk or negedge rst)
begin
    if (rst == 1'b0)
    begin
        counter <= 32'd0;
        adcclock = 1'b0;
    end
    else
    begin
        if (counter >= threshold)
            counter <= 32'd0;
        else
            counter <= counter + 32'd1;
            adcclock = (counter > half)? 1'b1 : 1'b0;
        end
    end
end
endmodule

module samplecountertimer(clk, rst, samplecounter);

input clk, rst;
output reg [31:0]samplecounter;

reg [31:0] counter;

parameter THRESHOLD = 32'd8192;    //2^15 // 64 of these needs to be at least 7
millisecons (8192), 128*64

always@(posedge clk or negedge rst)
begin
    if (rst == 1'b0)
    begin
        counter <= 32'd0;
        samplecounter <= 32'd0;
    end
    else
    begin
        if (counter >= THRESHOLD)
        begin
            counter <= 32'd0;
            samplecounter <= (samplecounter >= 32'd63)? 32'd0 : samplecounter +
32'd1;
        end
        else
        begin
            counter <= counter + 32'd1;
        end
    end
end
end

```

```

endmodule
module startcon(clk, rst, sdata, counter);

    input clk, rst;
    inout reg sdata;
    input [31:0]counter;

    always@(*)
    begin
        if (rst == 1'b0)
            sdata <= 1'bz;
        else
            sdata = (counter < 32'd3 || counter >= 32'd100)? 1'b0 : 1'b1;
        end
    end
endmodule

module stopcon(clk, rst, sdata, counter);

    input clk, rst;
    inout reg sdata;
    input [31:0]counter;

    always@(*)
    begin
        if (rst == 1'b0)
            sdata <= 1'bz;
        else
            sdata = (counter < 32'd3 || counter >= 32'd100)? 1'b1 : 1'b0;
        end
    end
endmodule

module writehigh(clk, rst, sdata, counter);

    input clk, rst;
    inout sdata;
    input [31:0]counter;

    assign sdata = (rst == 1'b1)? 1'bz : 1'b1;
endmodule

module writelow(clk, rst, sdata, counter);

    input clk, rst;
    inout sdata;
    input [31:0]counter;

    assign sdata = (rst == 1'b1)? 1'bz : 1'b0;
endmodule

```