Subject Name Solutions

4343204 – Summer 2024

Semester 1 Study Material

Detailed Solutions and Explanations

Embedded System (4343204) - Summer 2024 Solution

Question 1(a) [3 marks]

Draw AVR status register.

Solution

The AVR Status Register (SREG) contains information about the result of arithmetic operations and controls interrupts.
Diagram:

```
+-+-+-+-+-+-+-+-+
| I | T | H | S | V | N | Z | C |
+-+-+-+-+-+-+-+-+
  7   6   5   4   3   2   1   0
```

- **I (bit 7)**: Global Interrupt Enable
- **T (bit 6)**: Bit Copy Storage
- **H (bit 5)**: Half Carry Flag
- **S (bit 4)**: Sign Flag (S = N)
- **V (bit 3)**: Two's Complement Overflow
- **N (bit 2)**: Negative Flag
- **Z (bit 1)**: Zero Flag
- **C (bit 0)**: Carry Flag

Mnemonic

"I Take Health Seriously, Very Nice Zero Carry"

Question 1(b) [4 marks]

Explain Harvard Architecture in the AVR.

Solution

Harvard Architecture in AVR separates program and data memory, allowing simultaneous access to both.
Diagram:

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph TD
    CPU[CPU]
    PM[Program Memory]
    DM[Data Memory]
    CPU {-{-}{}|Instruction Bus| PM}
    CPU {-{-}{}|Data Bus| DM}
{Highlighting}
{Shaded}
```

- **Program Memory**: Stores instructions in Flash memory
- **Data Memory**: Contains SRAM, registers, and I/O registers

- **Separate Buses**: Different buses for program and data
- **Parallel Access**: Can fetch instruction and access data simultaneously

Mnemonic

"Separate Places for Data And Programs"

Question 1(c) [7 marks]

Discuss real time operating system.

Solution

Real-Time Operating System (RTOS) manages tasks with strict timing requirements, ensuring predictable response times.

Table 1: Key Features of RTOS

Feature	Description
Task Scheduling	Prioritizes tasks based on urgency
Deterministic	Guaranteed response times for events
Preemptive	Critical tasks can interrupt lower priority ones
Memory Management	Efficient memory allocation without fragmentation
Low Latency	Minimal delay between event and response
Multitasking	Handles multiple tasks concurrently

- **Task-based**: Divides program into independent tasks
- **Interrupt Handling**: Fast response to external events
- **Synchronization**: Provides semaphores and mutexes for task coordination
- **Resource Management**: Prevents resource conflicts
- **Small Footprint**: Optimized for limited hardware resources

Mnemonic

"Tasks Run On Strict Timelines"

Question 1(c OR) [7 marks]

Discuss criteria for choosing microcontroller for embedded system.

Solution

Selecting the right microcontroller requires evaluating several key factors to match application requirements.

Table 2: Microcontroller Selection Criteria

Criterion	Considerations
Processing Power	CPU speed, bit width (8/16/32-bit)
Memory	Flash, RAM, EEPROM sizes
Power Consumption	Sleep modes, operating voltage
I/O Capabilities	Number of ports, special functions
Peripherals	Timers, ADC, communication interfaces
Cost	Unit price, development tools cost
Development Support	Tools, documentation, community

- **Application Needs**: Match controller to task complexity
- **Real-time Requirements**: Response time constraints
- **Environmental Factors**: Temperature, noise, vibration
- **Form Factor**: Physical size and packaging
- **Future Expansion**: Room for feature growth

Mnemonic

"Power, Memory, I/O, Peripherals, Cost"

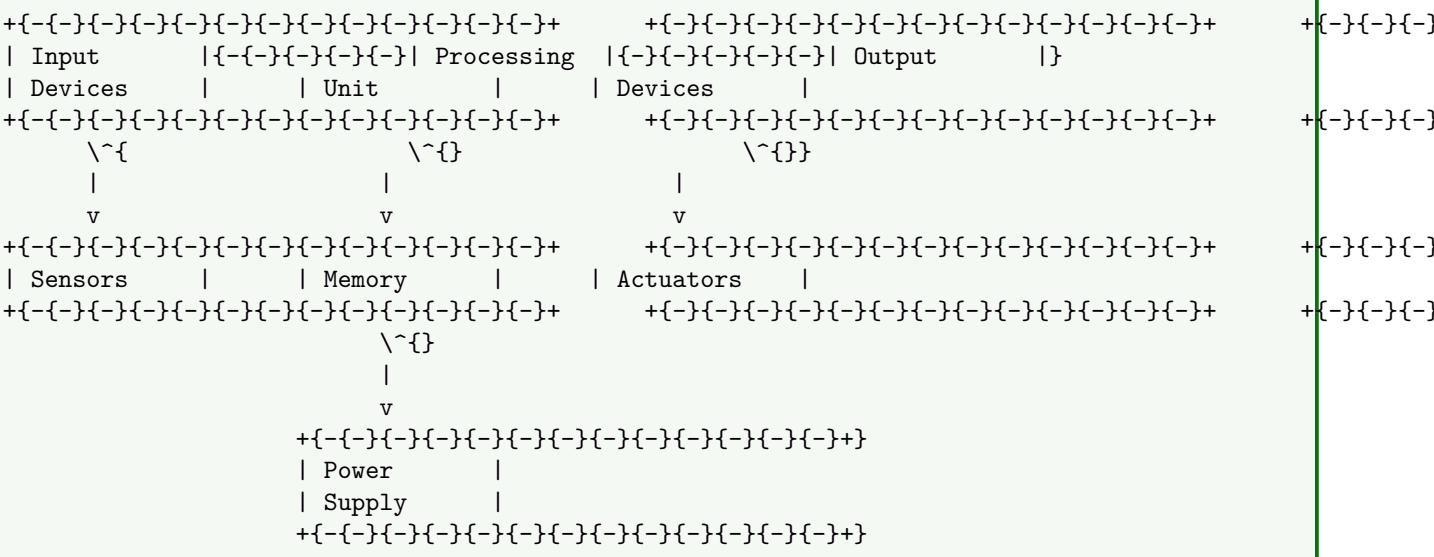
Question 2(a) [3 marks]

Define embedded system and draw its general block diagram.

Solution

An embedded system is a dedicated computer system designed for specific functions within a larger mechanical or electrical system.

Diagram:



- **Processing Unit**: Microcontroller/microprocessor
- **Memory**: Stores program and data
- **Input/Output**: Interfaces with external world

Mnemonic

"Processing Memory I/O Power"

Question 2(b) [4 marks]

List I/O registers associated with each port.

Solution

AVR microcontrollers have three primary registers for controlling each I/O port.

Table 3: I/O Port Registers

Register	Function	Description
PORTx	Data Register	Sets output values or pull-ups
DDRx	Data Direction Register	Sets pin direction (1=output, 0=input)
PINx	Port Input Pins	Reads actual pin status

- **x represents**: A, B, C, D (port letter)
- **Additional Special**: Some ports have PCMSK (Pin Change Mask) registers

Mnemonic

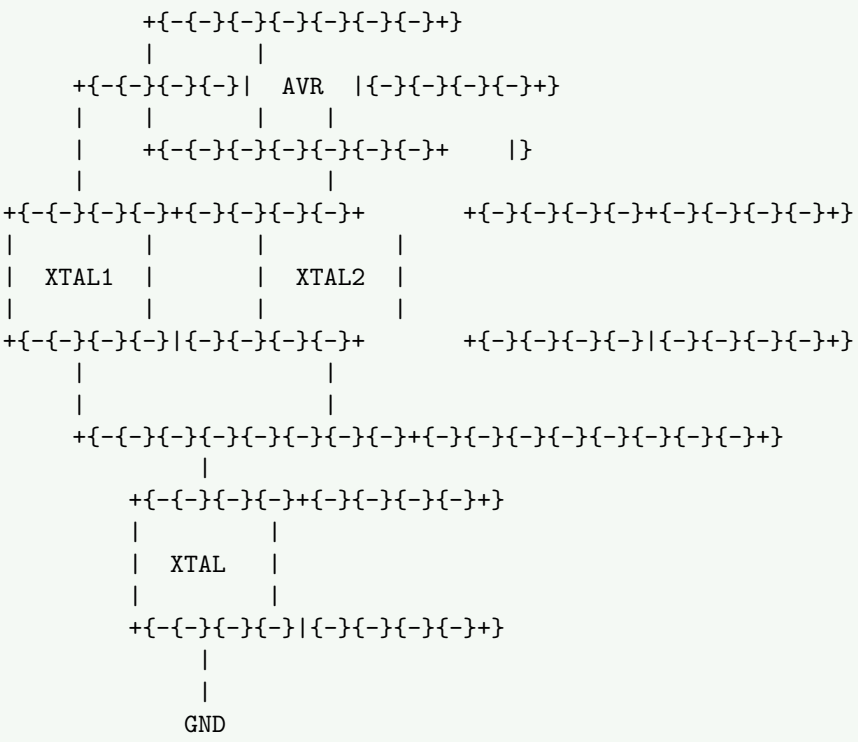
"Direction, Data, Pin reading"

Question 2(c) [7 marks]

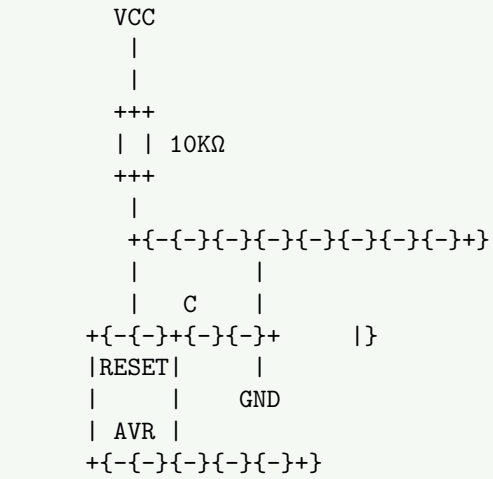
Explain clock and reset circuit for AVR.

Solution

The clock and reset circuits ensure proper initialization and timing of AVR operations.
Clock Circuit Diagram:



Reset Circuit:



- **Clock Source**: External crystal, RC oscillator, or internal oscillator
- **Crystal**: Provides accurate timing (1-16 MHz)
- **Reset Pin**: Active-low input for system restart
- **Power-on Reset**: Automatic reset when power applied
- **Brown-out Detection**: Reset if voltage drops below threshold

Mnemonic

"Crystal Oscillates, Reset Ensures Start"

Question 2(a OR) [3 marks]

Write characteristics of embedded system.

Solution

Embedded systems have unique characteristics that distinguish them from general-purpose computers.

Table 4: Embedded System Characteristics

Characteristic	Description
Single-Function	Dedicated to specific tasks
Real-time	Predictable response times
Resource Constrained	Limited memory, power, processing
Reliability	Must operate continuously without fail
Reactive	Responds to environmental changes

- **Long Life**: Often operates for years without intervention
- **Often Hidden**: Integrated within larger systems

Mnemonic

"Single, Real-time, Resource-limited, Reliable"

Question 2(b OR) [4 marks]

Discuss the role of DDRx in outputting and inputting data.

Solution

DDRx (Data Direction Register) configures each pin of port x as either input or output.

Table 5: DDRx Role in I/O Operations

DDRx Value	PORTx Value	Mode	Function
0	0	Input	High-impedance mode
0	1	Input	Pull-up enabled
1	0	Output	Output low (0V)
1	1	Output	Output high (VCC)

- **Direction Control**: 1 = output, 0 = input
- **Pin-specific**: Each bit controls individual pin
- **Initial State**: Default is input (all 0s)

Mnemonic

"Direction Determines Data flow"

Question 2(c OR) [7 marks]

Draw and explain ATmega32 pin diagram.

Solution

ATmega32 is a popular 8-bit AVR microcontroller with 40 pins providing various functionalities.
Diagram:

```
                +{-{-}{-}{-}{-}{-}{-}+}
    (XCK) PB0 {-|1   40|{-} PA0 (ADC0)}
          PB1 {-|2   39|{-} PA1 (ADC1)}
(INT2/AIN0)PB2{-|3   38|{-} PA2 (ADC2)}
(OC0/AIN1)PB3 {-|4   37|{-} PA3 (ADC3)}
       SS PB4 {-|5   36|{-} PA4 (ADC4)}
```

```
     MOSI PB5 {-|6   35|{-} PA5 (ADC5)}
     MISO PB6 {-|7   34|{-} PA6 (ADC6)}
      SCK PB7 {-|8   33|{-} PA7 (ADC7)}
       RESET  {-|9   32|{-} AREF}
         VCC  {-|10  31|{-} GND}
         GND  {-|11  30|{-} AVCC}
       XTAL2  {-|12  29|{-} PC7 (TOSC2)}
       XTAL1  {-|13  28|{-} PC6 (TOSC1)}
  (RXD) PD0   {-|14  27|{-} PC5}
  (TXD) PD1   {-|15  26|{-} PC4}
 (INT0) PD2   {-|16  25|{-} PC3}
 (INT1) PD3   {-|17  24|{-} PC2}
 (OC1B) PD4   {-|18  23|{-} PC1}
 (OC1A) PD5   {-|19  22|{-} PC0}
  (ICP) PD6   {-|20  21|{-} PD7 (OC2)}
              +{-{-}{-}{-}{-}{-}{-}+}
```

- **Port A (PA0-PA7)**: 8-bit bidirectional port with ADC inputs
- **Port B (PB0-PB7)**: 8-bit port with SPI, timers, and external interrupts
- **Port C (PC0-PC7)**: 8-bit bidirectional port with TWI support
- **Port D (PD0-PD7)**: 8-bit port with USART, external interrupts, and PWM
- **Power/Ground**: VCC, GND, AVCC, AREF
- **Clock**: XTAL1/XTAL2 for external oscillator
- **Reset**: Active-low reset input

Mnemonic

"ABCD Ports Around Power Clock Reset"

Question 3(a) [3 marks]

Explain Program Counter (PC) register for ATmega32.

Solution

Program Counter (PC) is a 16-bit register that tracks the address of the next instruction to execute.
Diagram:

```
+{-{-}{-}{-}{-}{-}{-}{-}{-}+{-}{-}{-}{-}{-}{-}{-}{-}+}
| PC High | PC Low |
+{-{-}{-}{-}{-}{-}{-}{-}{-}+{-}{-}{-}{-}{-}{-}{-}{-}+}
    15:8     7:0
```

- **Function**: Points to next instruction in program memory
- **Size**: 16-bit (can address up to 64K words)
- **Auto-increment**: Automatically increments after instruction fetch
- **Jump Control**: Modified by branch and jump instructions

Mnemonic

"Points to Code Execution"

Question 3(b) [4 marks]

Write an AVR C program to read the content of location 0x005F of EEPROM into PORTB.

Solution

```
\#include {avr/io.h}
\#include {avr/eeprom.h}
```

```
int main(void)
\{
    // Set PORTB as output
    DDRB = 0xFF;

    // Read from EEPROM location 0x005F and output to PORTB
    PORTB = eeprom\_read\_byte((uint8\_t*)0x005F);

    while(1) \{
        // Main loop
    \}
    return 0;
\}
```

- **DDRB = 0xFF**: Configure all PORTB pins as outputs
- **eeprom_read_byte()**: AVR library function to read EEPROM
- **while(1)**: Infinite loop to maintain output

Mnemonic

"Direction, Read EEPROM, Output to Port"

Question 3(c) [7 marks]

Draw and explain TCCR0 register in detail.

Solution

Timer/Counter Control Register 0 (TCCR0) controls the operation of Timer/Counter0.
Diagram:

```
+{-{-}{-}{-}{-}+{-}{-}{-}{-}{-}{-}+{-}{-}{-}{-}{-}{-}+{-}{-}{-}{-}{-}{-}+{-}{-}{-}{-}{-}{-}+{-}{-}{-}{-}{-}{-}+{
| FOC0| WGM00| COM01|COM00|WGM01| CS02| CS01| CS00|
+{-{-}{-}{-}{-}+{-}{-}{-}{-}{-}{-}+{-}{-}{-}{-}{-}{-}+{-}{-}{-}{-}{-}{-}+{-}{-}{-}{-}{-}{-}+{-}{-}{-}{-}{-}{-}+{
   7     6     5     4     3     2     1     0
```

Table 6: TCCR0 Bits Function

Bit(s)	Name	Function
7	FOC0	Force Output Compare
6,3	WGM01:0	Waveform Generation Mode
5,4	COM01:0	Compare Match Output Mode
2,1,0	CS02:0	Clock Select

- **WGM01:0**: Selects Normal, CTC, or PWM modes
- **COM01:0**: Defines OC0 pin behavior on compare match
- **CS02:0**: Sets clock source and prescaler (1, 8, 64, 256, 1024)

Mnemonic

"Forcing Waveforms, Comparing, Selecting Clock"

Question 3(a OR) [3 marks]

Explain AVR data memory.

Solution

AVR data memory consists of multiple sections for different types of data storage.
Diagram:

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph TD
    A[AVR Data Memory]
    A {-{-}{} B[Registers]}
    A {-{-}{} C[I/O Registers]}
    A {-{-}{} D[Internal SRAM]}
    A {-{-}{} E[EEPROM]}
{Highlighting}
{Shaded}
```

- **Registers**: 32 general-purpose registers (R0-R31)
- **I/O Memory**: Special function registers for peripherals
- **SRAM**: Internal RAM for variables (volatile)
- **EEPROM**: Non-volatile memory for persistent data

Mnemonic

"Registers I/O SRAM EEPROM"

Question 3(b OR) [4 marks]

Write an AVR C program to store 'G' into location 0x005F of EEPROM.

Solution

```
\#include {avr/io.h}
\#include {avr/eeprom.h}

int main(void)
\{
    // Store character {G to EEPROM location 0x005F}
    eeprom\_write\_byte((uint8\_t*)0x005F, {G});

    while(1) \{
        // Main loop
    \}
    return 0;
\}
```

- **eeprom_write_byte()**: AVR library function to write to EEPROM
- **'G'**: ASCII value 71 (0x47) stored in EEPROM
- **0x005F**: Target EEPROM address
- **while(1)**: Infinite loop after writing

Mnemonic

"Write Once, Remember Forever"

Question 3(c OR) [7 marks]

Draw and explain TIFR register in detail.

Solution

Timer/Counter Interrupt Flag Register (TIFR) holds flags that indicate timer events.
Diagram:

```
+{-{-}{-}{-}{-}+{-}{-}{-}{-}{-}+{-}{-}{-}{-}{-}+{-}{-}{-}{-}{-}+{-}{-}{-}{-}{-}+{-}{-}{-}{-}{-}+{-}{-}{
```

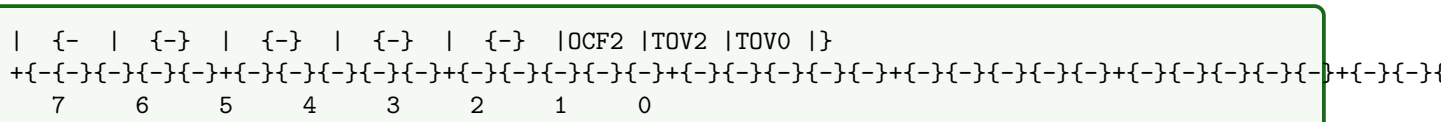


Table 7: TIFR Bits Function

Bit	Name	Function
0	TOV0	Timer/Counter0 Overflow Flag
1	TOV2	Timer/Counter2 Overflow Flag
2	OCF2	Output Compare Flag 2
3-7	-	Reserved bits

- **TOV0**: Set when Timer0 overflows, cleared when ISR executes
- **TOV2**: Set when Timer2 overflows
- **OCF2**: Set when Timer2 compare match occurs
- **Flag Clearing**: Write '1' to bit to clear flag

Mnemonic

"Timers Overflow, Comparisons Flag"

Question 4(a) [3 marks]

Write different ways of generating delay in AVR.

Solution

AVR microcontrollers offer multiple methods to generate time delays.

Table 8: Delay Generation Methods

Method	Description	Precision
Software Loops	CPU cycles counting	Low
Timer Interrupts	Hardware timers with ISR	High
Timer Polling	Hardware timers with flag checking	Medium
Delay Functions	Library functions (_delay_ms/_delay_us)	Medium

- **Software**: Simple but affected by optimizations
- **Hardware**: More accurate but requires timer setup
- **Library**: Convenient but limited to constant values

Mnemonic

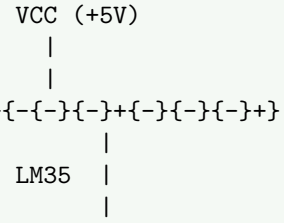
"Loops, Interrupts, Polling, Functions"

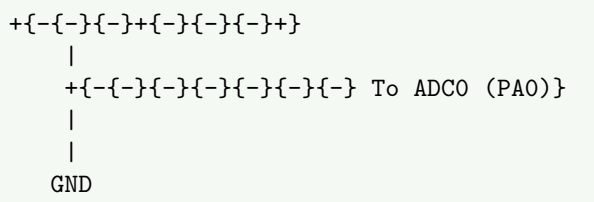
Question 4(b) [4 marks]

Draw and explain interfacing of LM35 with ATmega32.

Solution

LM35 is a temperature sensor that outputs an analog voltage proportional to temperature.
Circuit Diagram:





- **Connection**: LM35 output to ADC0 (PA0) of ATmega32
- **Scaling**: 10mV/$^{o}utput(0^{=}0V, 25^{=}250mV)$
- **ADC Setup**: Configure ADMUX to select ADC0
- **Calculation**: Temperature = (ADC_value * 5 * 100) / 1024

Mnemonic

"Analog Voltage Converts Temperature"

Question 4(c) [7 marks]

Explain interfacing of MAX7221 with ATmega32 in detail.

Solution

MAX7221 is an LED display driver IC that connects to AVR using SPI communication.
Circuit Diagram:

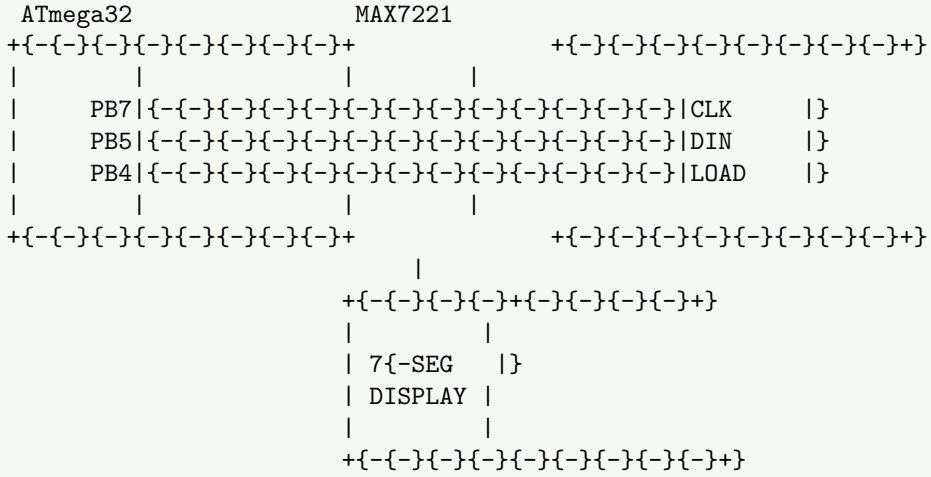


Table 9: Connections and Functionality

ATmega32 Pin	MAX7221 Pin	Function
PB7 (SCK)	CLK	Serial Clock
PB5 (MOSI)	DIN	Data Input
PB4 (SS)	LOAD	Chip Select

- **SPI Mode**: Master mode, MSB first
- **Initialization**: Set decode mode, intensity, scan limit
- **Data Transfer**: Send address byte followed by data byte
- **Multiplexing**: Can drive up to 8 digits
- **Brightness Control**: 16 levels through intensity register

Mnemonic

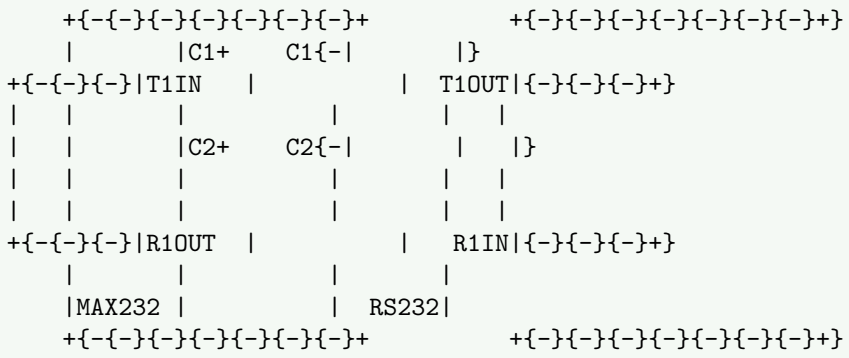
"Send Clock Data Load Display"

Question 4(a OR) [3 marks]

Explain MAX232 line driver.

Solution

MAX232 is an IC that converts TTL/CMOS logic levels to RS-232 voltage levels for serial communication.
Diagram:



- **Voltage Conversion**: TTL (0/5V) to RS-232 ($\pm 12V$)
- **Charge Pumps**: Uses capacitors to generate required voltages
- **Applications**: Serial communication with PC, modems
- **Bidirectional**: Handles both transmit and receive signals

Mnemonic

"TTL To RS-232 Conversion"

Question 4(b OR) [4 marks]

Explain ADMUX register.

Solution

ADC Multiplexer Selection Register (ADMUX) controls analog input channel selection and result format.
Diagram:

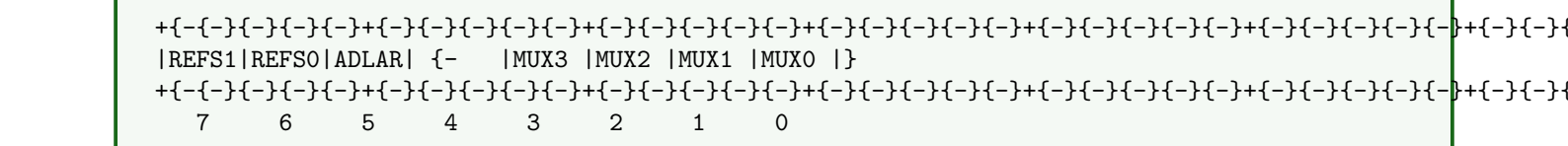


Table 10: ADMUX Bit Functions

Bits	Name	Function
7:6	REFS1:0	Reference Selection
5	ADLAR	ADC Left Adjust Result
3:0	MUX3:0	Analog Channel Selection

- **REFS1:0**: Select voltage reference (AREF, AVCC, Internal)
- **ADLAR**: Result alignment in ADC registers
- **MUX3:0**: Select input channel (ADC0-ADC7)

Mnemonic

"Reference, Alignment, Multiplexer"

Question 4(c OR) [7 marks]

Discuss Two Wire serial Interface (TWI) in AVR.

Solution

Two Wire Interface (TWI) is AVR's implementation of $I^2C protocol for communication with peripheral devices.$
Diagram:

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph LR
    A[Master AVR] {-{-} SDA {-}{-}{-} B[Slave 1]}
    A {-{-} SCL {-}{-}{-} B}
    B {-{-} SDA {-}{-}{-} C[Slave 2]}
    B {-{-} SCL {-}{-}{-} C}
{Highlighting}
{Shaded}
```

Table 11: TWI Characteristics

Feature	Description
Pins	SCL (Serial Clock) and SDA (Serial Data)
Speed	Standard (100kHz), Fast (400kHz)
Addressing	7-bit or 10-bit device addressing
Operation	Master or Slave mode
Bus Structure	Multi-master, multi-slave

- **Bidirectional**: Both devices can transmit and receive
- **Registers**: TWBR, TWCR, TWSR, TWDR, TWAR
- **ACK/NACK**: Acknowledgment for reliable transfers
- **Start/Stop**: Special conditions to begin/end transmission
- **Common Uses**: EEPROM, RTC, sensors, displays

Mnemonic

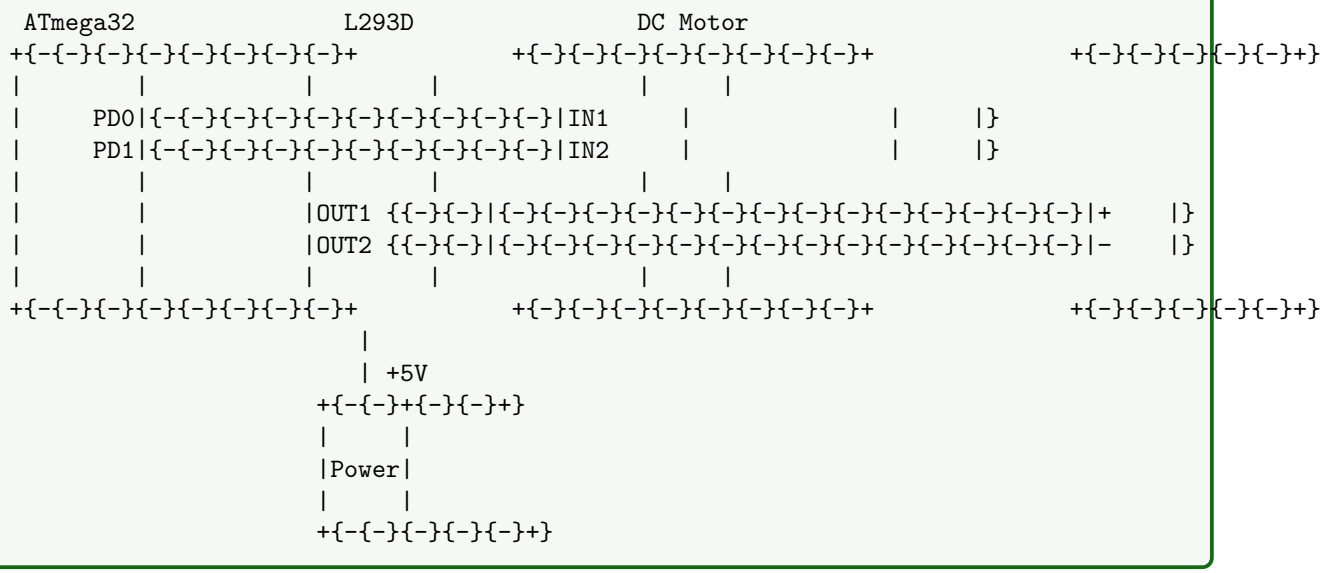
"Serial Clock And Data Transfers"

Question 5(a) [3 marks]

Draw circuit diagram to interface DC motor with ATmega32 using L293D motor driver.

Solution

L293D provides bidirectional drive current for controlling DC motors with microcontrollers.
Circuit Diagram:



- **Control Pins**: PD0, PD1 control motor direction
- **Driver Power**: Separate for logic and motor
- **H-Bridge**: Enables forward/reverse operation
- **Enable Pin**: Can be used for PWM speed control

Mnemonic

"Direction Control Through Bridge"

Question 5(b) [4 marks]

Write features of on chip ADC in ATmega32.

Solution

ATmega32 features a versatile analog-to-digital converter for measuring analog signals.

Table 12: ATmega32 ADC Features

Feature	Specification
Resolution	10-bit
Channels	8 single-ended inputs
Conversion Time	65-260 s
Reference Voltage	AREF, AVCC, or 2.56V internal
Accuracy	$\pm 2LSB$
Conversion Modes	Single and Free Running
Input Range	0V to VREF

- **Successive Approximation**: Conversion technique
- **Multiplexer**: Selects among 8 input channels
- **Interrupt**: Optional interrupt on completion
- **Sampling Rate**: Up to 15 KSPS at maximum resolution

Mnemonic

"Multiple Channels, Ten-bit Resolution"

Question 5(c) [7 marks]

Explain Smart Irrigation System.

Solution

Smart Irrigation System automates watering based on environmental conditions using microcontroller technology.

Diagram:

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph TD
    A[ATmega32] {-{-}{} B[Soil Moisture Sensor]}
    A {-{-}{} C[Temperature Sensor]}
    A {-{-}{} D[Humidity Sensor]}
    A {-{-}{} E[Water Pump Control]}
    A {-{-}{} F[Valve Control]}
    A {-{-}{} G[LCD Display]}
    H[RTC Module] {-{-}{} A}
{Highlighting}
{Shaded}
```

Table 13: System Components

Component	Function
Soil Moisture Sensor	Measures water content in soil
Temperature/Humidity	Monitors environmental conditions
Water Pump	Delivers water when needed
Valves	Controls water flow to different zones
LCD Display	Shows system status
RTC Module	Tracks time for scheduled irrigation

- **Adaptive Control**: Adjusts watering based on conditions
- **Water Conservation**: Uses only necessary amount of water
- **Remote Monitoring**: Optional WiFi/GSM connectivity
- **Data Logging**: Records moisture levels and watering events
- **Battery Backup**: Ensures operation during power outages

Mnemonic

"Sense Moisture, Control Water Automatically"

Question 5(a OR) [3 marks]

Draw and explain pin diagram of L293D motor driver IC.

Solution

L293D is a quadruple half-H driver IC used for controlling motors and other inductive loads.
Diagram:

```
      +{-{-}{-}{-}{-}{-}+}
      | 1  16 |
  EN1{-|      |{-}VCC1}
  IN1{-|      |{-}IN4}
 OUT1{-|      |{-}OUT4}
  GND{-| L293D|{-}GND}
  GND{-|      |{-}GND}
 OUT2{-|      |{-}OUT3}
  IN2{-|      |{-}IN3}
 VCC2{-|      |{-}EN2}
      +{-{-}{-}{-}{-}{-}+}
```

- **VCC1 (Pin 16)**: Logic supply voltage (5V)
- **VCC2 (Pin 8)**: Motor supply voltage (4.5V-36V)
- **EN1/EN2**: Enable inputs (can be PWM for speed control)
- **IN1-IN4**: Logic inputs to control direction
- **OUT1-OUT4**: Outputs to connect motors
- **GND**: Ground connections

Mnemonic

"Enable, Input, Output, Power"

Question 5(b OR) [4 marks]

List registers associated with ADC in AVR.

Solution

AVR's ADC system uses several registers to control its operation and store results.

Table 14: ADC Registers

Register	Function	Description
ADMUX	Multiplexer	Channel selection and reference options
ADCSRA	Control & Status	Control bits and flags
ADCH	Data High	High byte of conversion result
ADCL	Data Low	Low byte of conversion result
SFIOR	Special Function	ADC trigger source selection

- **ADMUX**: Channel and reference selection
- **ADCSRA**: Enable ADC, start conversion, prescaler
- **ADCH/ADCL**: Result registers (10-bit value)
- **SFIOR**: Auto-trigger sources (Timer, External)

Mnemonic

"Multiplexer Controls And Delivers Results"

Question 5(c OR) [7 marks]

Explain IoT based home automation system.

Solution

IoT home automation connects household devices to the internet for remote monitoring and control.
Diagram:

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph TD
    A[Internet] {-{-}{-} B[WiFi Gateway]}
    B {-{-}{-} C[AVR Controller]}
    C {-{-}{-} D[Light Control]}
    C {-{-}{-} E[Fan Control]}
    C {-{-}{-} F[Door Lock]}
    C {-{-}{-} G[Temperature Sensors]}
    C {-{-}{-} H[Motion Sensors]}
    B {-{-}{-} I[Mobile App]}
    B {-{-}{-} J[Cloud Services]}
{Highlighting}
{Shaded}
```

Table 15: System Components

Component	Function
Controller	Processes sensor data and commands
Sensors	Monitor environmental conditions
Actuators	Control appliances and systems
Communication	WiFi/Ethernet/Bluetooth connectivity
Gateway	Connects local network to internet
Mobile App	User interface for remote control

- **Remote Access**: Control home from anywhere
- **Scheduling**: Automate device operation based on time
- **Voice Control**: Integration with digital assistants
- **Energy Monitoring**: Track power consumption
- **Security**: Alerts for unusual activities
- **Scene Setting**: One-touch control of multiple devices

Mnemonic

"Connect, Control, Automate, Monitor"