Embedded System (4343204) - Winter 2024 Solution

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Question 1(a) [3 marks]

Write the size of RAM, Flash and EEPROM memory in ATmega32 and explain its need in microcontroller.

Solution

ATmega32 memory specifications and their importance in microcontroller operation:

Table 1. Memory Sizes in ATmega32

Memory Type	Size	Purpose
SRAM (RAM)	2 KB	Variables and stack storage
Flash	32 KB	Program storage
EEPROM	1 KB	Non-volatile data storage

- **RAM**: Temporary storage for variables during program execution
- **Flash**: Permanent storage for program instructions and constants
- **EEPROM**: Long-term storage for data that must survive power cycles

Mnemonic

"RAM for Run, Flash for Function, EEPROM for Eternity"

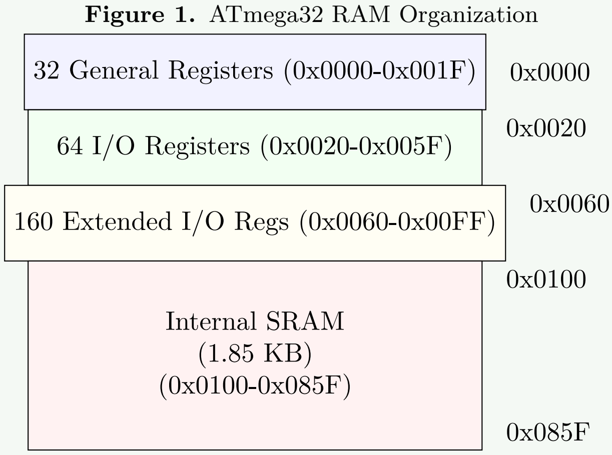
Question 1(b) [4 marks]

Discuss RAM memory of ATmega32.

Solution

ATmega32's RAM (SRAM) is organized into different sections for specific purposes.

Figure 1. ATmega32 RAM Organization



- **Register File**: First 32 locations (0x0000-0x001F)
- **I/O Registers**: Standard I/O space (0x0020-0x005F)
- **Extended I/O**: Additional peripheral registers (0x0060-0x00FF)
- **Data Memory**: General purpose SRAM (0x0100-0x085F)

Mnemonic

"Registers, I/O, Extended, Data - RAM's Efficient Design"

Question 1(c) [7 marks]

Define Real Time Operating System and Explain Characteristics of it.

Solution

A Real-Time Operating System (RTOS) is a specialized operating system designed to process data and events with precise timing constraints.

Table 2. Key Characteristics of RTOS

Characteristic	Description
Determinism	Guaranteed response times for tasks
Preemptive Scheduling	Higher priority tasks can interrupt lower ones
Low Latency	Minimal delay between event and response
Priority-Based	Tasks are assigned priorities for execution
Task Management	Provides mechanisms for task creation, deletion, and synchronization
Resource Management	Prevents resource conflicts and deadlocks
Reliability	Robust operation even under peak loads

- **Multitasking**: Supports concurrent execution of multiple tasks
- **Small Footprint**: Optimized for embedded systems with limited resources
- **Time Management**: Precise timing services with microsecond resolution
- **Kernel Services**: IPC, mutex, semaphores for task coordination

Mnemonic

"Deterministic Preemptive Tasks Run On Strict Timelines"

Question 1(c OR) [7 marks]

What is Embedded System? Draw and Explain General block diagram of Embedded system.

Solution

An Embedded System is a dedicated computer system designed to perform specific functions within a larger mechanical or electrical system, often with real-time constraints.

Figure 2. General Block Diagram of Embedded System

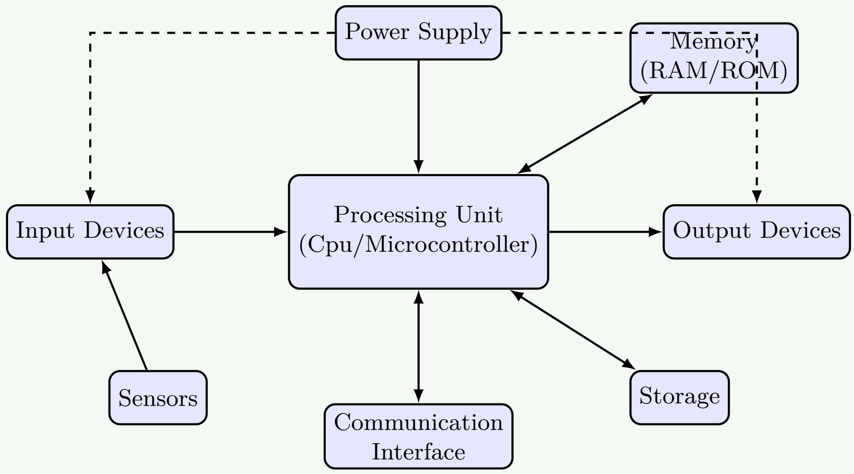


Table 3. Embedded System Components

Component	Function
Processing Unit	Executes program instructions (microcontroller/microprocessor)
Memory	Stores program and data (RAM, ROM, Flash)
Input/Output	Interfaces with external devices
Communication	Connects to other systems or networks
Power Supply	Provides regulated power
Sensors	Gather environmental data

- **Application-Specific**: Designed for dedicated tasks
- **Resource-Constrained**: Limited processing power and memory
- **Real-Time**: Responds to events within timing constraints
- **High Reliability**: Must operate continuously without failure

Question 2(a) [3 marks]

Write different Criteria for choosing microcontroller for any application design in embedded system.

Solution

Selecting the right microcontroller requires evaluating multiple criteria based on application requirements.

Table 4. Microcontroller Selection Criteria

Criterion	Considerations
Performance	CPU speed, MIPS, bit width (8/16/32)
Memory	Flash, RAM, EEPROM capacity
Power Consumption	Operating voltage, sleep modes
I/O Capabilities	Number of ports, special functions
Peripherals	ADC, timers, communication interfaces
Cost	Unit price, development tools
Form Factor	Size, package type, pin count

- **Application Requirements**: Specific features needed for the application
- **Development Environment**: Available compilers, debuggers, libraries
- **Future Expansion**: Scalability for future enhancements

Mnemonic

"Performance Memory Power I/O Cost"

Question 2(b) [4 marks]

Draw and Explain TCCR0 register.

Solution

Timer/Counter Control Register 0 (TCCR0) controls the operation of Timer/Counter0 in ATmega32.

Figure 3. TCCR0 Register

FOC0	WGM00	COM01	COM00	WGM01	CS02	CS01	CS00
7	6	5	4	3	2	1	0

Table 5. TCCR0 Bit Functions

Bits	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 (Prescaler)

- **WGM01:0**: Determines timer operating mode (Normal, CTC, PWM)
- **COM01:0**: Controls OC0 pin output behavior
- **CS02:0**: Selects clock source and prescaler value

Mnemonic

"Force Waveform Compare Clock Select"

Question 2(c) [7 marks]

List timers of ATmega32 and Explain working modes of any one timer in detail.

Solution

ATmega32 features multiple timers with various capabilities and operating modes.

Table 6. Timers in ATmega32

Timer	Type	Size	Features
Timer0	General Purpose	8-bit	Simple timing, PWM
Timer1	Advanced	16-bit	Input capture, dual PWM
Timer2	General Purpose	8-bit	Asynchronous operation

Timer0 Working Modes:

- **Normal Mode**:
  - Counter increments from 0 to 255 then overflows back to 0
  - Overflow interrupt can be generated
  - Used for simple timing and delay generation
- **CTC (Clear Timer on Compare) Mode**:
  - Counter resets when it reaches OCR0 value
  - Allows precise frequency generation
  - Compare match interrupt can be generated

- **Fast PWM Mode**:
  - Counter counts from 0 to 255
  - Output toggles at overflow and compare match
  - High frequency PWM generation
- **Phase Correct PWM Mode**:
  - Counter counts up then down (0→255→0)
  - Symmetric PWM waveform generation
  - Lower frequency but better resolution than Fast PWM

Mnemonic

"Normal Compares Fast Phase - Timer Modes Matter"

Question 2(a OR) [3 marks]

List various embedded system applications. Explain any one in brief.

Solution

Embedded systems are found in numerous applications across various domains.

Table 7. Embedded System Applications

Domain	Applications
Consumer	Smart appliances, entertainment systems
Automotive	Engine control, safety systems, infotainment
Industrial	Process control, automation, robotics
Medical	Patient monitoring, imaging, implantable devices
Communications	Routers, modems, network switches
Aerospace	Flight control, navigation, life support

Smart Home Automation System: A smart home system uses embedded controllers to monitor and control household devices. Sensors detect environmental conditions like temperature and motion, while microcontrollers process this data and control actuators such as HVAC systems, lighting, and security devices. The system can be programmed for autonomous operation or user control via smartphone apps, providing convenience, energy efficiency, and enhanced security.

Mnemonic

"Consumers Automate Industry Medical Communications Aerospace"

Question 2(b OR) [4 marks]

Explain the function of DDRA, PINA and PORTA registers in ATmega32 microcontroller.

Solution

The three registers control the operation of Port A in ATmega32, each serving a distinct purpose.

Table 8. Port A Registers

Register	Function	Operation
DDRA	Data Direction	Configures pins as input (0) or output (1)
PORTA	Data Register	Sets output values or enables pull-ups
PINA	Port Input Pins	Reads actual pin states

Example Configurations:

```
DDRA = 0xFF;  // All pins as output
PORTA = 0xA5; // Set alternating pattern (10100101)

DDRA = 0x00;  // All pins as input
PORTA = 0xFF; // Enable internal pull-ups on all pins
data = PINA;  // Read current pin states
```

- **Bit-Level Control**: Each bit controls corresponding pin
- **Atomic Operations**: Individual bits can be modified
- **Read-Modify-Write**: Common operation pattern

Mnemonic

"Direction Determines, Port Provides, PIN Perceives"

Question 2(c OR) [7 marks]

Draw Status Register of ATmega32 and explain it in detail.

Solution

The Status Register (SREG) in ATmega32 contains processor status flags affected by arithmetic operations and controls interrupts.

Figure 4. Status Register (SREG)

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

Table 9. SREG Bit Functions

Bit	Name	Function	Set When
7	I	Global Interrupt Enable	Programmatically enabled
6	T	Bit Copy Storage	Used for bit copy instructions
5	H	Half Carry Flag	Half-carry in BCD operations
4	S	Sign Flag	$N \oplus V$ (used for signed operations)
3	V	Two's Complement Overflow	Arithmetic overflow occurs
2	N	Negative Flag	Result is negative (MSB=1)
1	Z	Zero Flag	Result is zero
0	C	Carry Flag	Carry occurs in arithmetic

- **Arithmetic Feedback**: Indicates result status
- **Conditional Branches**: Used by branch instructions
- **Interrupt Control**: I-bit enables/disables all interrupts
- **Access Methods**: Directly addressable via IN/OUT instructions

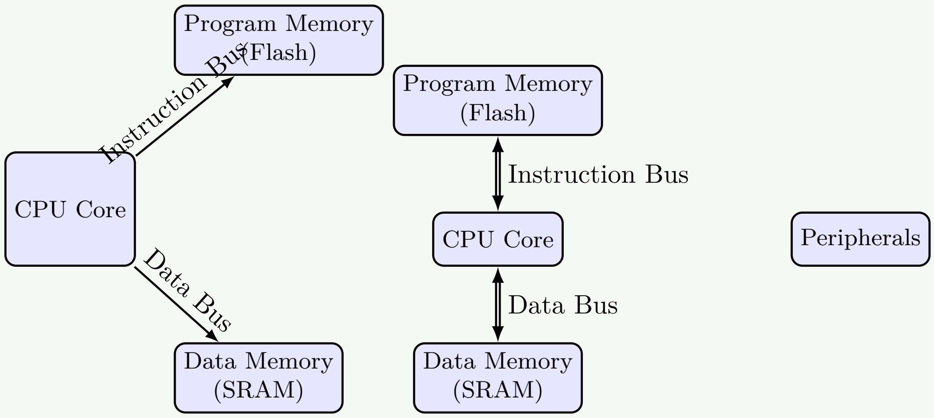
Question 3(a) [3 marks]

Write a short note on Harvard Architecture of AVR microcontroller.

Solution

Harvard Architecture is a fundamental design principle of AVR microcontrollers, separating program and data memory.

Figure 5. Harvard Architecture



- **Separate Buses**: Independent buses for program and data memory
- **Parallel Access**: Can fetch instructions and access data simultaneously
- **Performance**: Increases execution speed by eliminating memory bottlenecks
- **Different Widths**: Program memory is organized in 16-bit words, data memory in 8-bit bytes

Mnemonic

"Program and Data Paths Are Separate"

Question 3(b) [4 marks]

List Registers associated with Serial Communication (RS232) and explain steps to interface it with ATmega32.

Solution

ATmega32 uses USART (Universal Synchronous Asynchronous Receiver Transmitter) for serial communication.

Table 10. USART Registers

Register	Function
UDR	USART Data Register (transmit/receive)
UCSRA	USART Control and Status Register A
UCSRB	USART Control and Status Register B
UCSRC	USART Control and Status Register C
UBRRH/UBRRL	USART Baud Rate Registers

Steps to Interface RS232:

1. **Hardware Connection**:
   - Connect ATmega32's TXD (PD1) and RXD (PD0) to MAX232
   - Connect MAX232 to RS232 port or connector
2. **Initialize USART**:
   - Set baud rate (UBRR)
   - Set frame format (data bits, parity, stop bits)
   - Enable transmitter and/or receiver
3. **Data Transmission/Reception**:
   - Check status flags before operation
   - Write to UDR to transmit
   - Read from UDR to receive

Mnemonic

"Connect, Configure Baud, Enable, Transmit/Receive"

Question 3(c) [7 marks]

Explain Bit-wise logical operations in AVR C programming with necessary examples.

Solution

Bit-wise operations manipulate individual bits in a byte or word, essential for embedded programming.

Table 11. Bit-wise Operators in AVR C

Operator	Operation	Example	Result
&	AND	0xA5 & 0x0F	0x05
|	OR	0x50 | 0x0F	0x5F
^	XOR	0x55 ^ 0xFF	0xAA
~	NOT	~0x55	0xAA
<<	Left Shift	0x01 << 3	0x08
>>	Right Shift	0x80 >> 3	0x10

Example: Setting and Clearing Bits

```c
// Set bit 3 of PORTB
PORTB |= (1 << 3);    // PORTB = PORTB | 0b00001000

// Clear bit 5 of PORTB
PORTB &= ~(1 << 5);  // PORTB = PORTB & 0b11011111

// Toggle bit 2 of PORTB
PORTB ^= (1 << 2);    // PORTB = PORTB ^ 0b00000100

// Check if bit 4 is set
if (PINB & (1 << 4)) {
    // Bit 4 is set
}
```

Mnemonic

"AND clears, OR sets, XOR toggles, Shift multiplies/divides"

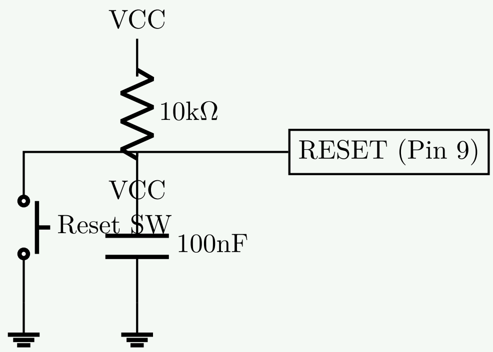
Question 3(a OR) [3 marks]

Explain RESET circuit for the ATmega32 microcontroller.

Solution

The reset circuit ensures proper initialization of ATmega32 when power is applied or during system reset.

Figure 6. Reset Circuit



- **Active-Low RESET**: Held low to reset the microcontroller
- **External Reset**: Manual reset button connects RESET pin to ground
- **Power-on Reset**: Auto-reset when power is first applied
- **Brown-out Detection**: Reset when voltage drops below threshold
- **Watchdog Timer**: Reset on software malfunction

Mnemonic

"Pull Up, Push Button, Power Starts, Voltage Drops"

Question 3(b OR) [4 marks]

List Registers associated with EEPROM and write steps to interface EEPROM of ATmega32.

Solution

ATmega32 has on-chip EEPROM with dedicated registers for access control.

Table 12. EEPROM Registers

Register	Function
EEARH/EEARL	EEPROM Address Registers
EEDR	EEPROM Data Register
EECR	EEPROM Control Register

Steps to Interface EEPROM:

1. **Wait for Completion**: Check if previous write operation is complete (EEWE bit in EECR)
2. **Set Address**: Load address into EEARH:EEARL (16-bit address)
3. **Read or Write Operation**:
   - For read: Set EERE bit in EECR, then read EEDR
   - For write: Write data to EEDR, then set EEMWE and EEWE bits in EECR
4. **Wait for Completion**: Poll EEWE bit until it becomes zero

Mnemonic

"Wait, Address, Data, Control, Wait"

Question 3(c OR) [7 marks]

Write a C program to generate square wave of 1KHz on the PORTC.2 pin continuously. Use Timer0, Normal mode, and 1:8 pre-scaler to create the delay. Assume XTAL = 8 MHz.

Solution

Code Implementation:

```c
#include <avr/io.h>

int main(void)
{
    // Configure PORTC.2 as output
    DDRC |= (1 << 2);  // Set PC2 as output

    // Timer0 configuration - Normal mode, 1:8 prescaler
    TCCR0 = (0 << WGM01) | (0 << WGM00) | (0 << CS02) | (1 << CS01) | (0 << CS00);

    // Calculate timer value for 1KHz (500us period, 250us half-period)
    // 8MHz/8 = 1MHz timer clock, 250 cycles for 250us
    // 256-250 = 6 (starting value for 250us)

    while (1)
    {
        // Toggle PORTC.2
        PORTC ^= (1 << 2);

        // Reset timer
        TCNT0 = 6;

        // Wait until timer overflows
        while (!(TIFR & (1 << TOV0)));

        // Clear overflow flag
        TIFR |= (1 << TOV0);
    }

    return 0;
}
```

- **Frequency Calculation**: 1KHz = 1000Hz = 1ms period = 500μs half-period
- **Timer Clock**: 8MHz $\div$ 8 = 1MHz = 1μs per tick
- **Timer Ticks**: 250μs $\div$ 1μs = 250 ticks
- **Initial Value**: 256 - 250 = 6 (for overflow after 250 ticks)

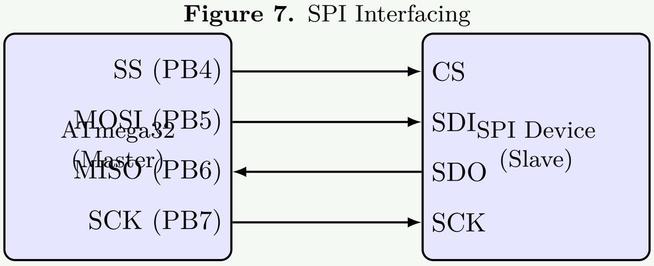
Question 4(a) [3 marks]

Draw and Explain SPI based device interfacing diagram with ATmega32.

Solution

SPI (Serial Peripheral Interface) is a synchronous serial communication protocol used to interface ATmega32 with peripheral devices.

Figure 7. SPI Interfacing



- **MOSI (Master Out Slave In)**: Data from master to slave
- **MISO (Master In Slave Out)**: Data from slave to master
- **SCK (Serial Clock)**: Synchronization clock provided by master
- **SS (Slave Select)**: Active-low signal to select specific slave device

Mnemonic

"Master Outputs, Slave Inputs, Clock Keeps Synchronization"

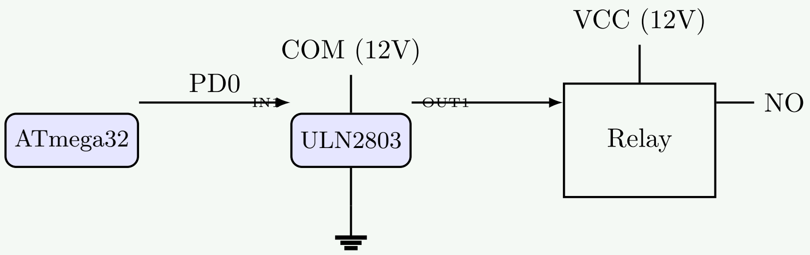
Question 4(b) [4 marks]

Draw and explain interfacing of Relay using ULN2803 with ATmega32.

Solution

ULN2803 is an array of Darlington transistor pairs used to drive high-current devices like relays from microcontroller pins.

Figure 8. Relay Interfacing using ULN2803



- **Current Amplification**: ULN2803 can sink up to 500mA per channel
- **Voltage Isolation**: Built-in diodes protect against inductive kickback
- **Multiple Channels**: 8 Darlington pairs in one package
- **High Voltage Rating**: Can handle up to 50V at outputs

Mnemonic

"Low Current Controls High Current Loads"

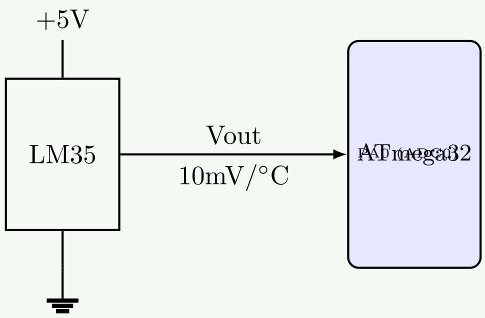
Question 4(c) [7 marks]

Draw an interfacing diagram of LM35 connected on ADC0 (pin 40) of ATmega32 and write AVR C program to display digital result on Port B. (use ADC in 8-bit mode).

Solution

LM35 is a precision temperature sensor that outputs an analog voltage proportional to temperature.

Figure 9. LM35 Interfacing



C Program:

```
#include <avr/io.h>
#include <util/delay.h>

```

```c
int main(void)
{
    // Configure PORTB as output for displaying result
    DDRB = 0xFF;

    // Configure ADC
    // REFS0=1: AVCC reference
    // ADLAR=1: Left adjust for 8-bit reading from ADCH
    // MUX=00000: ADC0
    ADMUX = (0 << REFS1) | (1 << REFS0) | (1 << ADLAR) |
            (0 << MUX4) | (0 << MUX3) | (0 << MUX2) | (0 << MUX1) | (0 << MUX0);

    // Enable ADC and set prescaler to 128
    ADCSRA = (1 << ADEN) | (1 << ADPS2) | (1 << ADPS1) | (1 << ADPS0);

    while (1)
    {
        // Start conversion
        ADCSRA |= (1 << ADSC);

        // Wait for conversion to complete
        while (ADCSRA & (1 << ADSC));

        // Display result on PORTB (8-bit from ADCH)
        PORTB = ADCH;

        // Wait before next reading
        _delay_ms(500);
    }

    return 0;
}
```

- **Temperature Calculation**: LM35 outputs 10mV/°C
- **ADC Configuration**: Left-adjusted for easy 8-bit reading
- **Resolution**: Using 8-bit mode gives approximately 1°C resolution with 5V reference
- **Range**: Can measure 0-255°C range (limited by 8-bit register)

Mnemonic

"Connect, Configure, Convert, Capture, Display"

Question 4(a OR) [3 marks]

Write an AVR C program to continuous monitor PA0 pin of port A. If it is HIGH, send HIGH to PC0 pin of port C; otherwise, send LOW to PC0 pin of port C.

Solution

Code Implementation:

```c
#include <avr/io.h>

int main(void)
{
    // Configure PA0 as input
    DDRA &= ~(1 << PA0);

    // Enable pull-up resistor on PA0
    PORTA |= (1 << PA0);

    // Configure PC0 as output
    DDRC |= (1 << PC0);
```

```c

    while (1)
    {
        // Check if PA0 is HIGH
        if (PINA & (1 << PA0))
        {
            // Set PC0 HIGH
            PORTC |= (1 << PC0);
        }
        else
        {
            // Set PC0 LOW
            PORTC &= ~(1 << PC0);
        }
    }

    return 0;
}
```

- **Input Configuration**: Set as input with pull-up resistor
- **Continuous Monitoring**: Infinite loop checks pin state
- **Output Action**: PC0 mirrors PA0 state
- **Efficient Code**: Simple conditional statement for pin monitoring

Mnemonic

"Configure, Monitor, Mirror"

Question 4(b OR) [4 marks]

Draw ATmega32 pin diagram and write function of Vcc, AVcc and Aref pin.

Solution

ATmega32 has 40 pins organized in a DIP package, with power supply pins having distinct functions.

Figure 10. ATmega32 Pin Diagram

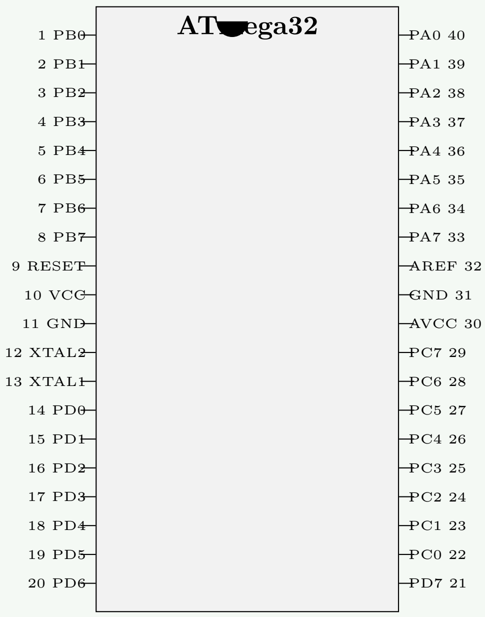


Table 13. Power Supply Pins

Pin	Function	Description
VCC	Digital Power	Main supply voltage for digital circuits (5V typical)
AVCC	Analog Power	Supply for analog circuitry, particularly ADC (5V typical)
AREF	Analog Reference	External reference voltage for ADC

- **VCC**: Powers digital logic and I/O ports
- **AVCC**: Must be within ±0.3V of VCC, even if ADC unused
- **AREF**: Optional external reference for ADC, otherwise connect to AVCC

Mnemonic

"VCC for Core Circuits, AVCC for Analog, AREF for Reference"

Question 4(c OR) [7 marks]

Draw and explain interfacing of MAX7221 with ATmega32.

Solution

MAX7221 is an LED display driver IC that interfaces with ATmega32 using SPI communication.

Figure 11. MAX7221 Interfacing

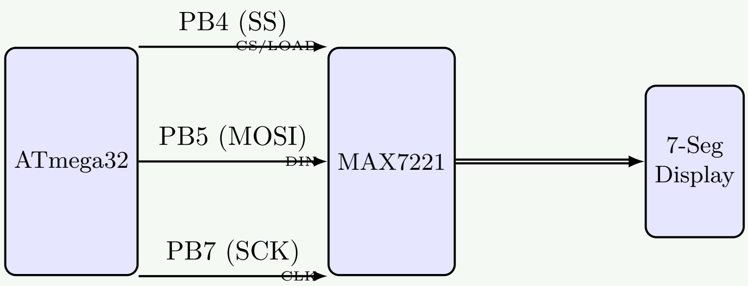


Table 14. Connection Details

ATmega32 Pin	MAX7221 Pin	Function
PB4 (SS)	CS/LOAD	Chip select/Load data
PB5 (MOSI)	DIN	Data input to MAX7221
PB6 (MISO)	DOUT	Data output (often unused)
PB7 (SCK)	CLK	Clock signal

Interfacing Steps:
- **Initialize SPI**: Configure Master mode, Clock Polarity/Phase, Set SS high.
- **Initialize MAX7221**: Set Decode mode, Scan limit, Intensity, Turn on display.
- **Send Data**: Pull SS low, send address/data, pull SS high.

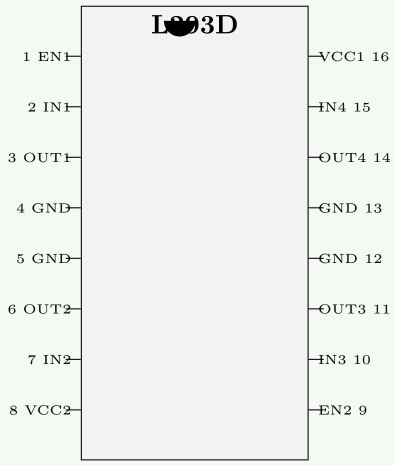
Question 5(a) [3 marks]

Draw and explain pin diagram of L293D motor driver IC.

Solution

L293D is a quadruple half-H driver designed for bidirectional control of DC motors.

Figure 12. L293D Pin Diagram



- **Dual H-Bridges**: Can control two DC motors independently
- **Heat Sink**: Ground pins provide heat dissipation
- **High Current**: Can drive up to 600mA per channel
- **Protection Diodes**: Internal flyback diodes for inductive loads

Mnemonic

"Enable, Input, Output, Power"

Question 5(b) [4 marks]

Draw and explain ADMUX register.

Solution

ADMUX (ADC Multiplexer Selection Register) controls analog channel selection and result format in ATmega32.

Figure 13. ADMUX Register

REFS1	REFS0	ADLAR	–	MUX3	MUX2	MUX1	MUX0
7	6	5	4	3	2	1	0

Table 15. ADMUX Bit Functions

Bits	Name	Function
7:6	REFS1:0	Reference voltage selection
5	ADLAR	ADC Left Adjust Result
3:0	MUX3:0	Analog channel selection

- **REFS1:0 Settings**: 00=AREF, 01=AVCC, 11=Internal 2.56V
- **Channel Selection**: MUX3:0 selects which ADC input to connect
- **Result Alignment**: ADLAR=1 shifts result left

Mnemonic

"Reference, Alignment, Multiplexer"

Question 5(c) [7 marks]

Explain Smart Irrigation System.

Solution

A Smart Irrigation System uses embedded technology to efficiently manage water for plant cultivation based on environmental conditions.

Figure 14. Smart Irrigation System Flowchart

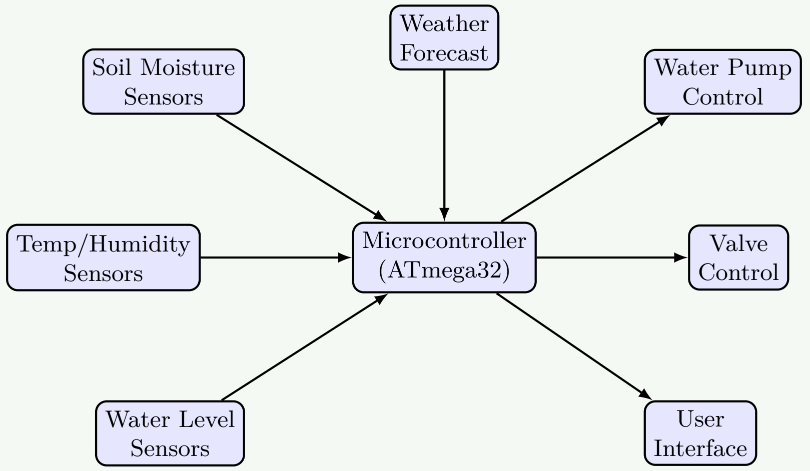


Table 16. Smart Irrigation Components

Component	**Function**
Soil Moisture Sensors	Measure water content in soil
Temperature/Humidity	Monitor environmental conditions
Valves	Control water flow to different zones
Pump Control	Activate water pumps when needed
Microcontroller	Process sensor data and control outputs
User Interface	Allow monitoring and manual control

Key Features:

- **Automated Watering**: Waters plants only when soil moisture falls below threshold
- **Weather Adaptation**: Adjusts watering schedule based on forecast
- **Zone Control**: Individual watering schedules for different areas
- **Water Conservation**: Uses minimum necessary water

Mnemonic

"Sense, Decide, Conserve, Grow"

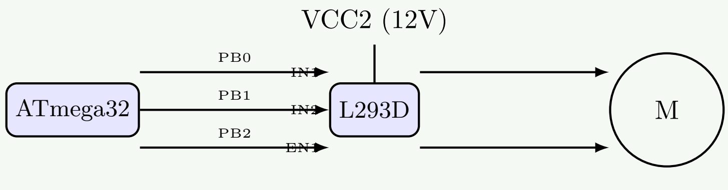
Question 5(a OR) [3 marks]

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

Solution

The circuit connects a DC motor to ATmega32 through L293D for bidirectional control.

Figure 15. DC Motor Interfacing



Control Logic:

Table 17. Motor Control Logic

IN1	IN2	EN1	Status
0	0	1	Stop
1	0	1	Clockwise
0	1	1	Counter-Clockwise
1	1	1	Stop

Mnemonic

"Enable and Direction Control Motor"

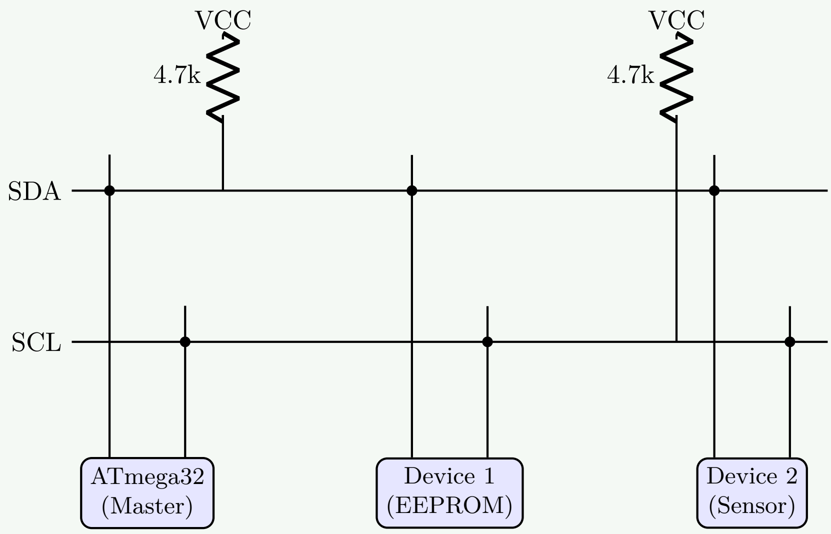
Question 5(b OR) [4 marks]

Draw and Explain I2C based device interfacing diagram with ATmega32.

Solution

I2C (Inter-Integrated Circuit) is a two-wire serial bus for connecting multiple devices to a microcontroller.

Figure 16. I2C Interfacing



- **SDA**: Serial Data Line (Bidirectional)
- **SCL**: Serial Clock Line (Master generated)
- **Pull-up Resistors**: Required on both lines

Mnemonic

"Start, Address, Acknowledge, Data, Stop"

Question 5(c OR) [7 marks]

Explain IoT based Home Automation System.

Solution

An IoT-based Home Automation System connects household devices to the internet for remote monitoring and control.

Figure 17. IoT Home Automation Architecture

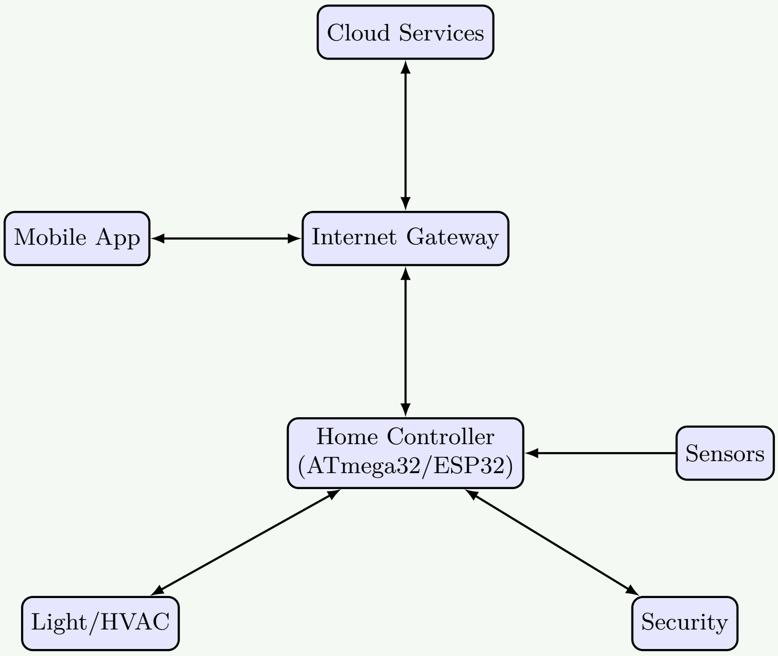


Table 18. Home Automation Components

Component	**Function**
Controller	Central processing unit
Sensors	Monitor environmental conditions
Actuators	Control lights, appliances, locks
Gateway	Connects local devices to internet
User Interface	App, voice control, dashboard
Cloud Services	Storage, processing, remote access

- **Remote Access**: Control from anywhere
- **Voice Control**: Integration with assistants
- **Energy Management**: Optimize consumption
- **Automation**: Scheduling and scene setting

Mnemonic

"Connect, Control, Monitor, Automate, Learn"