

Design of a Bidirectional Wireless Charging Station for Electric Vehicles Using Road-Integrated Solar and Piezoelectric Energy Harvesting with Cantilever Technique

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Abstract

The increasing demand for sustainable transportation has accelerated research into innovative charging methods for electric vehicles (EVs). Conventional plug-in charging infrastructures are often limited by high installation costs, land usage, and charging downtime. To address these challenges, this project proposes a bidirectional wireless charging station integrated into roadways, powered by renewable energy sources. The system harnesses solar energy through photovoltaic modules and vibrational energy through piezoelectric crystals embedded within road surfaces, adopting the cantilever technique to maximize energy harvesting efficiency. The harvested energy is stored in roadside smart grid modules and later transmitted to EVs using wireless power transfer (WPT) technology. The bidirectional design ensures that energy can flow both from grid to vehicle (G2V) for charging and from vehicle to grid (V2G) to stabilize demand during peak load conditions. The wireless charging station eliminates the need for physical connectors, enabling dynamic charging while vehicles are in motion. The piezoelectric arrays convert mechanical vibrations from vehicle movement into usable electrical energy, complementing solar power to ensure continuous operation even under low sunlight conditions. The cantilever-based mechanism amplifies stress on piezoelectric materials, significantly improving energy output per unit area. A smart control system monitors energy flow, balances load distribution, and ensures maximum efficiency. Artificial intelligence algorithms are integrated to predict traffic density and optimize energy harvesting. The proposed system enhances the feasibility of on-road charging corridors, extending EV range and reducing dependence on conventional charging infrastructure. Moreover, the bidirectional feature supports energy recycling by allowing EVs to feed surplus power back into the smart grid. The combined use of renewable energy harvesting and wireless charging provides an eco-friendly, cost-effective, and scalable solution for future smart transportation networks. This project contributes to the development of green roadways, where roads themselves act as self-sustaining energy hubs that actively support electric mobility..

CHAPTER 1

1. Introduction

The rapid adoption of electric vehicles (EVs) worldwide has created an urgent need for reliable, efficient, and sustainable charging infrastructure. Traditional plug-in charging stations, while effective, are hindered by long charging times, high dependency on external power grids, and limited accessibility during transit. To overcome these limitations, the concept of wireless charging embedded in roadways has emerged as a futuristic solution to enable seamless charging while vehicles are in motion. At the same time, roads represent an untapped resource for energy harvesting, as they are continuously exposed to sunlight and mechanical vibrations from vehicle movement. Solar panels integrated into road surfaces can capture abundant renewable energy, while piezoelectric crystals embedded beneath the pavement can convert vehicular pressure and vibrations into electricity. The cantilever technique further enhances the efficiency of piezoelectric energy harvesting by amplifying the applied stress on crystals. By combining these technologies, roadways can transform into active energy-generating hubs that not only power charging stations but also contribute excess electricity to nearby smart grids. Wireless power transfer (WPT) technology eliminates the need for physical connectors, ensuring safety, convenience, and reduced maintenance. Furthermore, a bidirectional design allows energy to flow both ways—grid-to-vehicle (G2V) for charging and vehicle-to-grid (V2G) for stabilizing demand and enhancing grid resilience. This innovative integration of renewable energy harvesting and wireless charging infrastructure supports the vision of green transportation corridors, reducing carbon emissions and dependency on fossil fuels. With intelligent control systems, the solution dynamically adapts to traffic flow and power demand, making it highly efficient and scalable for urban as well as highway environments. Ultimately, this project introduces a revolutionary approach to road design, where highways evolve from being passive infrastructures to becoming smart, self-sustaining energy platforms that actively power the future of electric mobility..

1.2. Overview

The proposed **Bidirectional Wireless Charging Station for Electric Vehicles Using Road-Integrated Solar and Piezoelectric Energy Harvesting with Cantilever Technique** integrates multiple renewable energy sources into a single intelligent system to achieve efficient, contactless, and sustainable EV charging. The system harnesses solar energy through embedded photovoltaic panels on the road surface and converts mechanical vibrations from passing vehicles into electrical energy using piezoelectric cantilever transducers. Both energy sources are conditioned using advanced power electronics—MPPT controllers for solar energy and synchronized switching circuits for piezoelectric harvesting—and are fed into a common DC bus connected to hybrid energy storage consisting of supercapacitors and a battery bank. A bidirectional wireless power transfer (WPT) unit enables seamless power flow between the charging pad and the electric vehicle, supporting both grid-to-vehicle (G2V) and vehicle-to-grid (V2G) operations. The energy management system (EMS) coordinates harvesting, storage, charging, and discharging operations based on energy availability and vehicle demand while ensuring

maximum system efficiency, safety, and reliability. This integrated design not only reduces dependence on grid electricity but also enables dynamic energy recovery from the environment, contributing to greener transportation infrastructure.

1.3. Background

The rapid growth of electric vehicles (EVs) has created a pressing need for efficient, sustainable, and user-friendly charging infrastructure. Conventional wired charging systems often suffer from issues such as connector wear, safety hazards in wet or public environments, and the inconvenience of manual plug-in operations. To overcome these limitations, wireless power transfer (WPT) technology has emerged as a promising alternative, enabling contactless charging through inductive coupling between ground and vehicle coils. However, traditional charging stations still depend heavily on grid electricity, which may not always come from renewable sources. Integrating renewable energy harvesting into the charging infrastructure can significantly reduce carbon emissions and improve energy autonomy.

In this context, road-integrated solar panels provide a clean and consistent power source by converting sunlight directly into electrical energy, while piezoelectric cantilever energy harvesters convert mechanical vibrations from moving vehicles into additional electrical power. Although the power generated from piezoelectric systems is relatively small compared to solar energy, it can effectively supplement the system by powering sensors, controllers, and auxiliary components. Combining these energy sources with bidirectional wireless charging creates a self-sustaining, intelligent system capable of both charging EVs and returning excess energy to the grid through Vehicle-to-Grid (V2G) functionality. This holistic approach enhances energy efficiency, reduces operational costs, and supports the transition toward a more resilient and eco-friendly smart transportation network.

1.4 Objective

- To design and develop a road-integrated energy harvesting system using solar panels and piezoelectric crystals for sustainable EV charging.
- To implement the cantilever technique for enhancing piezoelectric energy conversion efficiency under vehicular loads.
- To integrate wireless power transfer (WPT) technology for seamless charging of EVs while stationary or in motion.
- To establish a bidirectional charging mechanism enabling both grid-to-vehicle (G2V) and vehicle-to-grid (V2G) energy flow.
- To develop an intelligent power management system that monitors, regulates, and distributes harvested energy efficiently.

- To optimize the system using AI/ML algorithms for predicting traffic density, charging demand, and energy utilization.
- To design a smart roadside grid storage module for buffering harvested energy and ensuring continuous power supply.
- To evaluate the system's performance, efficiency, and scalability under varying traffic and environmental conditions.
- To demonstrate the environmental benefits of reducing carbon emissions and fossil fuel dependency through renewable-powered EV charging.
- To propose a scalable model for smart green highways, transforming conventional roads into energy-generating and EV-supporting infrastructures.

CHAPTER 2

LITERATURE SURVEY

1) Self-Powered Synchronized Switching Interface Circuit for Piezoelectric Energy Harvesting — M. Ben Ammar, A. (et al.), **2023**.

Proposes and demonstrates a self-powered piezoelectric energy-management interface based on a phase-synchronized switching (P-SSHI) topology optimized for low-frequency, irregular excitations. The circuit increases harvested energy compared with standard rectifier approaches and is adaptable to different storage loads, making it suitable for road-vibration piezo harvesters feeding local electronics or supercaps.

2) Electric Vehicle-to-Grid (V2G) Technologies: Impact on the Power System and Market — M. R. H. Mojumder, **2022**.

Reviews V2G fundamentals, power-electronic interfaces, and control/market implications. Discusses how bidirectional charging can provide ancillary services (frequency regulation, peak shaving), operational constraints (battery cycling, standards), and EMS requirements—useful background for integrating V2G into a hybrid, harvest-augmented charging station.

3) Advances in EV Wireless Charging Technology: System Design, Topologies and Standards — B. Latha (et al.), **2024**.

Surveys recent developments in inductive power transfer (IPT) for EVs, covering compensation topologies, coil designs, alignment strategies, FOD detection, and efficiency tradeoffs across air-gaps. Also summarizes prototype systems and practical design recommendations for stationary and dynamic charging pads. This is directly applicable to designing the bidirectional WPT front-end.

4) Solar Energy Harvesting from Pavement-Integrated Photovoltaic/Thermal (PIPV/T) Systems — Y. Zhang (et al.), 2023.

Examines photovoltaic/thermal integration into pavements and road surfaces, modeling thermal and electrical performance under realistic loading and soiling conditions. Identifies key mechanical and thermal challenges for road-embedded PV (durability, optical losses, heat management) and provides performance estimates and design suggestions relevant to road-integrated solar panels for EV charging.

5) A Review of Piezoelectric Energy Harvesting: Materials, Design and Readout Circuits — (Review paper), 2023.

Comprehensive review of piezoelectric materials (PZT and lead-free alternatives), harvester geometries (cantilevered beams, stacks), and interface/readout circuits (rectifiers, SSHI/SECE). Highlights realistic power yields, tradeoffs in resonance tuning, and practical conditioning circuits—helpful when estimating how many cantilever units and which interface (SSHI/SECE) to use in a road application.

CHAPTER 3

3.1 Existing System

Currently, electric vehicle charging infrastructures are primarily based on fixed plug-in stations powered by conventional electrical grids. These systems require vehicles to stop and connect physically to charging ports, resulting in long charging times and reduced travel efficiency. Most of the existing stations rely heavily on fossil fuel-based electricity generation, indirectly contributing to greenhouse gas emissions. While renewable energy-based charging stations have been introduced in some regions, they are limited in number and often depend on large solar farms or wind energy installations rather than integrated road solutions. Wireless charging technologies are available in research prototypes and small-scale implementations, but they are restricted to static charging pads rather than dynamic, on-road charging. Piezoelectric energy harvesting from roads has been studied, yet most experiments produce low efficiency due to improper stress application techniques. Similarly, solar road projects exist in pilot phases, but challenges such as durability, cost, and efficiency hinder widespread adoption. The bidirectional charging concept (V2G and G2V) has been tested in limited urban areas, but integration with road-based wireless charging is still unexplored. Existing smart grid systems provide some support for renewable energy management, yet they do not incorporate real-time traffic-based adaptive control. Overall, present systems are fragmented, costly, and insufficient to meet the growing demand for continuous and sustainable EV charging. The lack of dynamic, self-sustaining, and renewable-powered charging infrastructures highlights the need for an innovative system that combines solar harvesting, piezoelectric energy, wireless power transfer, and bidirectional smart grid integration.

3.2 Existing System drawbacks

- Requires vehicles to stop for long durations at charging stations, reducing travel efficiency.
- Heavy dependence on conventional power grids, which are often powered by fossil fuels.
- Limited adoption of renewable-powered EV charging, leading to unsustainable practices.
- High installation and maintenance costs for traditional plug-in infrastructure.
- Lack of dynamic charging systems while vehicles are in motion.
- Wireless charging, where available, is restricted to small-scale static pads.
- Piezoelectric energy harvesting in roads is inefficient due to poor stress application techniques.
- Solar-integrated road projects face durability, weather resistance, and cost challenges.
- Absence of integrated bidirectional flow (G2V and V2G) in existing wireless charging networks.
- Current systems are fragmented and fail to provide a unified, scalable, and smart charging solution.

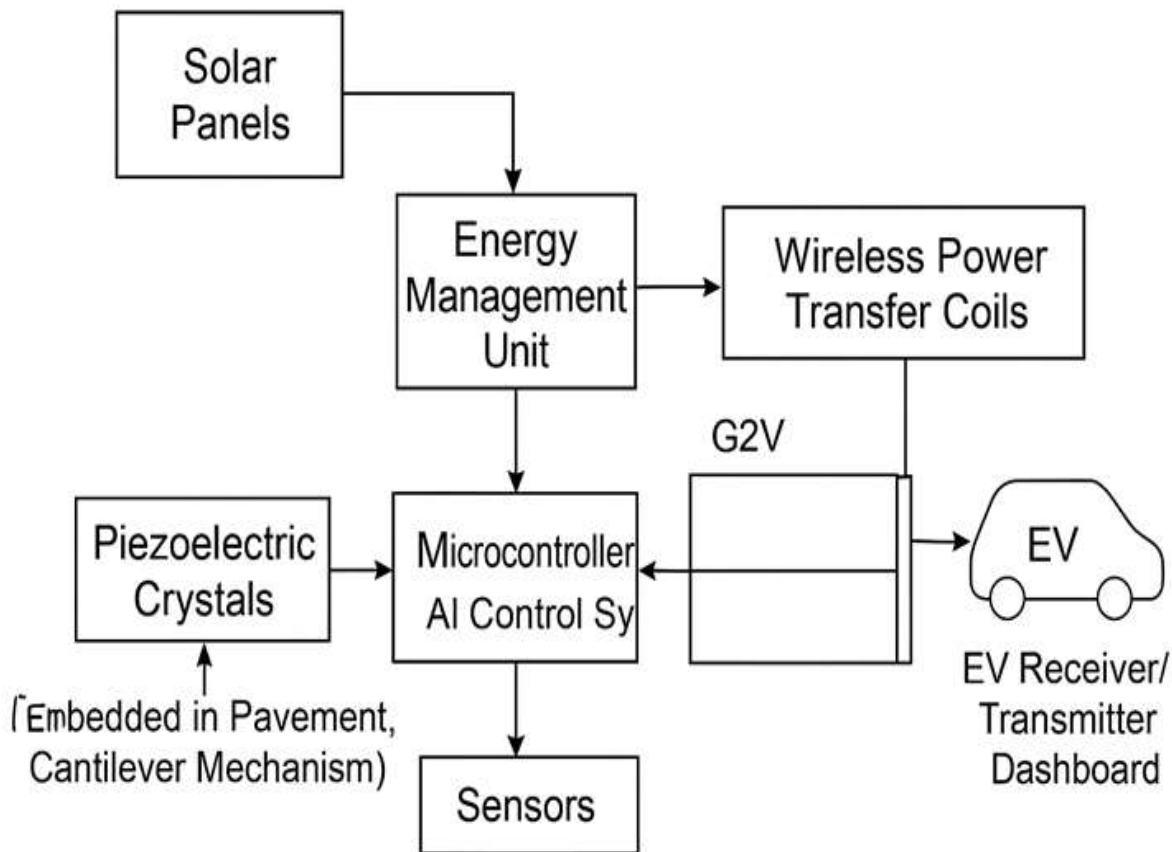
3.3 Proposed system

The proposed system introduces a road-integrated bidirectional wireless charging infrastructure for electric vehicles, leveraging both solar and piezoelectric energy harvesting. Solar panels embedded in the road surface capture sunlight, while piezoelectric crystals beneath the pavement convert vehicular vibrations into electrical energy, enhanced using the cantilever technique for higher efficiency. The harvested energy is stored in smart roadside grid modules, ensuring continuous availability even during low sunlight or traffic periods. Vehicles can charge wirelessly using dynamic wireless power transfer (WPT) as they pass over designated lanes, eliminating the need for physical connectors and reducing downtime. The bidirectional design allows energy to flow from the grid to vehicles (G2V) and from vehicles back to the grid (V2G) during peak demand, supporting grid stabilization. A centralized intelligent control system monitors traffic patterns, energy availability, and vehicle requirements, dynamically optimizing energy distribution. AI algorithms predict energy demand based on real-time traffic and adjust harvesting strategies for maximum efficiency. The system ensures scalability, enabling deployment on highways, urban roads, and parking areas. Renewable energy integration reduces carbon emissions, lowers dependency on conventional grids, and promotes sustainable transportation. Maintenance is simplified through wireless interfaces and modular design of energy-harvesting units. The combination of solar, piezoelectric, and wireless technologies creates a self-sustaining energy ecosystem on roads. Overall, this innovative approach transforms conventional roadways into active power sources, facilitating eco-friendly EV mobility and smart energy management.

3.4 Advantages

- 4 Enables dynamic wireless charging, allowing EVs to charge while in motion, reducing downtime.
- 5 Integrates renewable energy sources (solar and piezoelectric) for sustainable and eco-friendly operation.
- 6 Supports bidirectional energy flow (G2V and V2G), enhancing grid stability and efficiency.
- 7 Reduces dependency on conventional fossil-fuel-powered grids.
- 8 Cantilever-based piezoelectric design improves energy harvesting efficiency from road vibrations.
- 9 Eliminates the need for physical charging connectors, enhancing safety and convenience.
- 10 Scalable for urban roads, highways, and parking areas, making it adaptable to various infrastructures.
- 11 Intelligent control system with AI/ML optimizes energy distribution based on traffic patterns.
- 12 Promotes green transportation corridors, reducing carbon emissions and environmental impact.
- 13 Modular and smart design allows easier maintenance, monitoring, and system upgrades.

3.5 Block Diagram



3.6 Hardware Requirements

- **Solar panels** – Embedded in road surface for photovoltaic energy harvesting.
- **Piezoelectric crystals** – Installed beneath pavement to convert vehicular vibrations into electricity.
- **Cantilever mechanism** – To amplify stress on piezo crystals for improved energy output.
- **Wireless power transfer (WPT) coils** – For dynamic EV charging.
- **Smart roadside grid modules** – For energy storage and management.
- **Power electronics** – Including DC-DC converters, inverters, and rectifiers.
- **Microcontroller/Controller board** – For system control and energy distribution (Arduino).
- **Sensors** – Vehicle detection sensors, voltage/current sensors, and traffic flow sensors.
- **Communication modules** – Wi-Fi, LoRa, or Zigbee for data transfer between EVs and grid.
- **EV-compatible receiver modules** – For bidirectional energy transfer (charging and V2G).

3.7 Software Requirements

- **Embedded firmware** – For microcontroller control of energy flow, WPT operation, and sensor integration.
- **Energy management software** – To monitor, store, and distribute harvested energy efficiently.
- **AI/ML algorithms** – For traffic prediction, energy demand estimation, and optimization of energy harvesting.
- **Monitoring dashboard** – GUI for real-time visualization of energy generation, vehicle charging, and grid status.
- **Communication protocol software** – To enable secure data exchange between EVs, roadside modules, and central control.

CHAPTER 4

4.1 ARDUINO UNO:

The Arduino Uno is a microcontroller board. It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with a AC-to-DC adapter or battery to get started. The Uno differs from all preceding boards in that it does not use the FTDI USB-to-serial driver chip. "Uno" means one in Italian and is named to mark the upcoming release of Arduino 1.0. The Uno and version1.0 will be the reference versions of Arduino, moving forward. The Uno is the latest in a series of USB Arduino boards, and the reference model for the Arduino platform.

4.2 Technical Specifications:

Arduino Uno

Operating Voltage 5V

Input Voltage (recommended) 7-12V

Input Voltage (limits) 6-20V

Digital I/O Pins 14 (of which 6 provide PWM output)

Analog Input Pins 6

DC Current per I/O Pin 40 mA

DC Current for 3.3V Pin 50 mA

Flash Memory 32 KB of which 0.5 KB used by

bootloader

SRAM 2 KB

EEPROM 1 KB

Clock Speed 16 MHz

4.3 Power:

The Arduino Uno can be powered via the USB connection or with an external power supply. The power source is selected automatically. External (non-USB) power can come either from an AC-to-DC adapter (wall-wart) or battery. The adapter can be connected by plugging a 2.1mm center-positive plug into the board's power jack. Leads from a battery can be inserted in the Gnd and Vin pin headers of the POWER connector. The board can operate on an external supply of 6 to 20 volts. If supplied with less than 7V, however, the 5V pin may supply less than five volts and the board may be unstable. If using more than 12V, the voltage regulator may overheat and damage the board. The recommended range is 7 to 12 volts.

The power pins are as follows:

VIN: The input voltage to the Arduino board when it's using an external power source (as opposed to 5 volts from the USB connection or other regulated power source). You can supply voltage through this pin, or, if supplying voltage via the power jack, access it through this pin.

5V. The regulated power supply used to power the microcontroller and other components on the board. This can come either from VIN via an on-board regulator, or be supplied by USB or another regulated 5V supply.

3V3. A 3.3 volt supply generated by the on-board regulator. Maximum current draw is 50 mA.

GND - Ground pins.

4.4 Physical characteristics:

The maximum length and width of the Uno PCB are 2.7 and 2.1 inches respectively, with the USB connector and power jack extending beyond the former dimension. Three screw holes allow the board to be attached to a surface or case. Note that the distance between digital pins 7 and 8 is 160 mil (0.16"), not an even multiple of the 100 mil spacing of the other pins.

4.5 Hardware design:

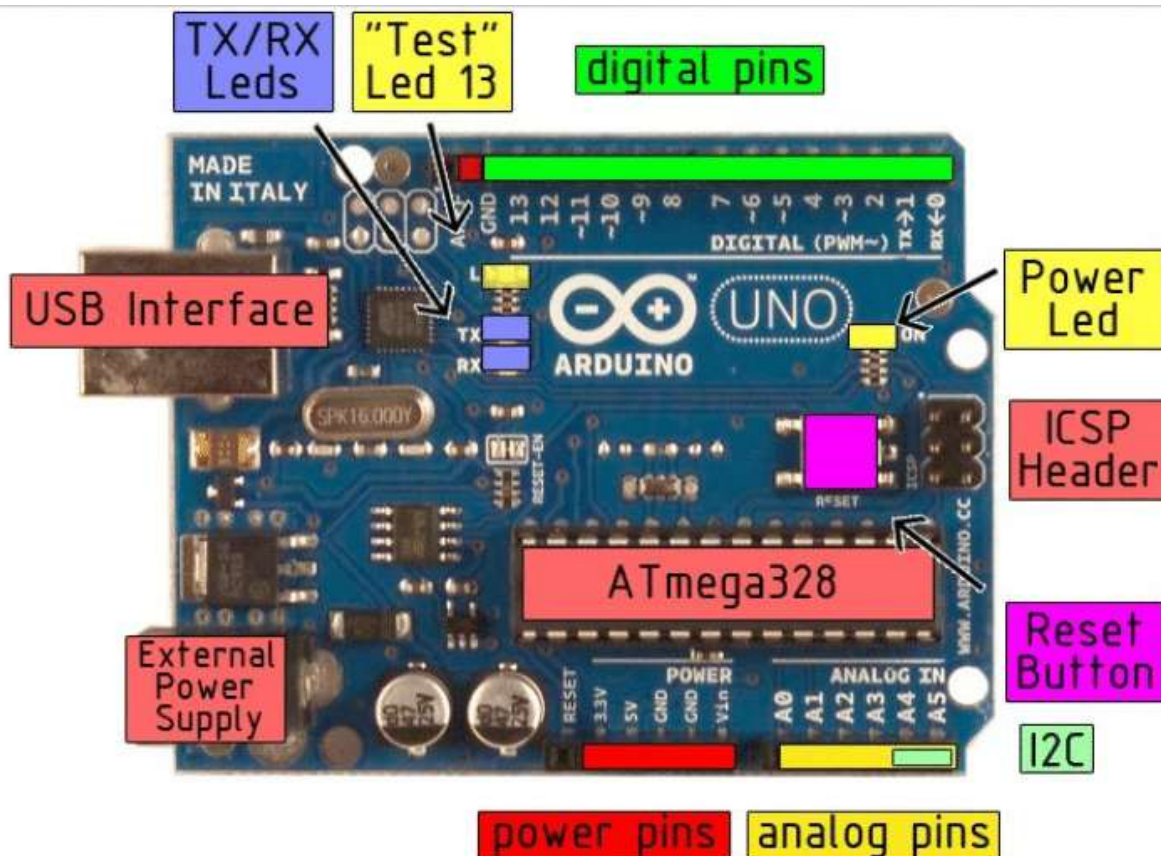


Figure 4.1 Arduino Uno hardware description

4.6 Hardware description:

1. Power USB

Arduino board can be powered by using the USB cable from your computer. All you need to do is connect the USB cable to the USB connection.

	Power (Barrel Jack) Arduino boards can be powered directly from the AC mains power supply by connecting it to the Barrel Jack (2).
	Voltage Regulator The function of the voltage regulator is to control the voltage given to the Arduino board and stabilize the DC voltages used by the processor and other elements.
	Crystal Oscillator The crystal oscillator helps Arduino in dealing with time issues. How does Arduino calculate time? The answer is, by using the crystal oscillator. The number printed on top of the Arduino crystal is 16.000H9H. It tells us that the frequency is 16,000,000 Hertz or 16 MHz.
	Arduino Reset You can reset your Arduino board, i.e., start your program from the beginning. You can reset the UNO board in two ways. First, by using the reset button (17) on the board. Second, you can connect an external reset button to the Arduino pin labelled RESET (5).
	Pins (3.3, 5, GND, Vin) 3.3V (6) – Supply 3.3 output volt 5V (7) – Supply 5 output volt

	Most of the components used with Arduino board works fine with 3.3 volt and 5 volt. GND (8)(Ground) – There are several GND pins on the Arduino, any of which can be used to ground your circuit. Vin (9) – This pin also can be used to power the Arduino board from an external power source, like AC mains power supply.
10	Analog pins The Arduino UNO board has six analog input pins A0 through A5. These pins can read the signal from an analog sensor like the humidity sensor or temperature sensor and convert it into a digital value that can be read by the microprocessor.
11	Main microcontroller Each Arduino board has its own microcontroller (11). You can assume it as the brain of your board. The main IC (integrated circuit) on the Arduino is slightly different from board to board. The microcontrollers are usually of the ATMEL Company. You must know what IC your board has before loading up a new program from the Arduino IDE. This information is available on the top of the IC. For more details about the IC construction and functions, you can refer to the data sheet.
12 *	ICSP pin Mostly, ICSP (12) is an AVR, a tiny programming header for the Arduino consisting of MOSI, MISO, SCK, RESET, VCC, and GND. It is often referred to as an SPI (Serial Peripheral Interface), which could be considered as an "expansion" of the output. Actually, you are slaving the output device to the master of the SPI bus.
13	Power LED indicator This LED should light up when you plug your Arduino into a power source to indicate that your board is powered up correctly. If this light does not turn on, then there is something wrong with the connection.

14	TX and RX LEDs On your board, you will find two labels: TX (transmit) and RX (receive). They appear in two places on the Arduino UNO board. First, at the digital pins 0 and 1, to indicate the pins responsible for serial communication. Second, the TX and RX led (13). The TX led flashes with different speed while sending the serial data. The speed of flashing depends on the baud rate used by the board. RX flashes during the receiving process.
15	Digital I/O The Arduino UNO board has 14 digital I/O pins (15) (of which 6 provide PWM (Pulse Width Modulation) output. These pins can be configured to work as input digital pins to read logic values (0 or 1) or as digital output pins to drive different modules like LEDs, relays, etc. The pins labeled “~” can be used to generate PWM.
16	AREF AREF stands for Analog Reference. It is sometimes, used to set an external reference voltage (between 0 and 5 Volts) as the upper limit for the analog input pins.

4.7 Pin configuration:

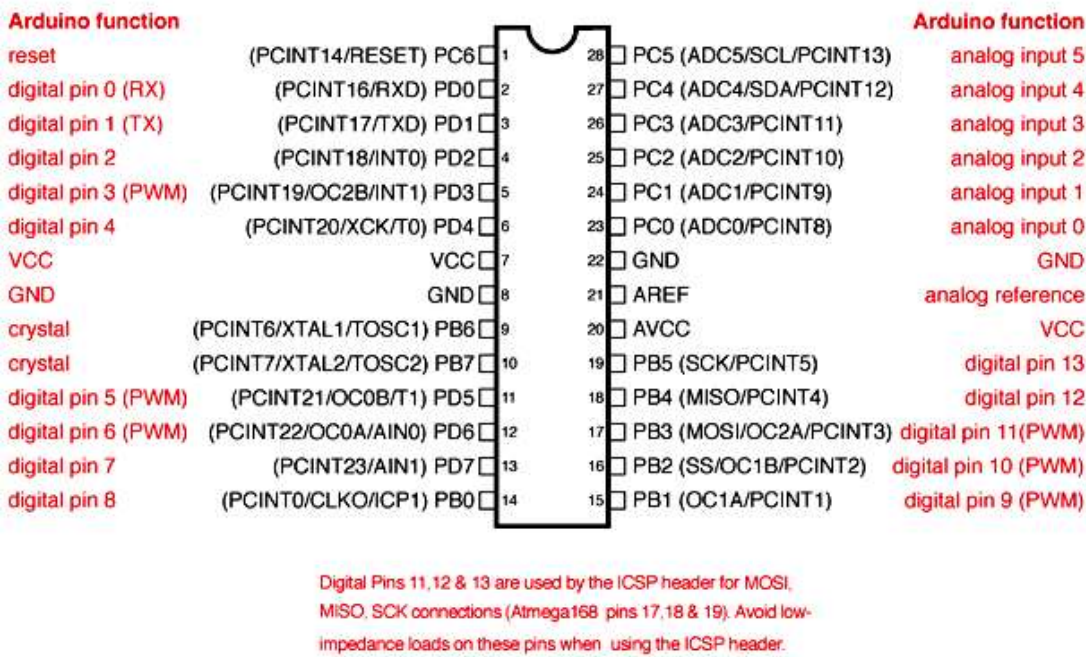


Figure 4.2 Pin configuration

4.8 Uses of microcontroller:

Like all good things, this powerful component is basically very simple. It is made by mixing tested and high-quality "ingredients" (components) as per following receipt:

The simplest computer processor is used as the "brain" of the future system. Depending on the taste of the manufacturer, a bit of memory, a few A/D converters, timers, input/output lines etc. are added. All that is placed in some of the standard packages. Simple software able to control it all and which everyone can easily learn about has been developed. On the basis of these rules, numerous types of microcontrollers were designed and they quickly became man's invisible companion. Their incredible simplicity and flexibility conquered us a long time ago and if you try to invent something about them, you should know that you are probably late, someone before you has either done it or at least has tried to do it. The following things have had a crucial influence on development and success of the microcontrollers:

Powerful and carefully chosen electronics embedded in the microcontrollers can independently or via input/output devices (switches, push buttons, sensors, LCD displays, relays etc.), control various processes and devices such as industrial automation, electric current, temperature, engine performance etc.

Very low prices enable them to be embedded in such devices in which, until recent time it was not worthwhile to embed anything. Thanks to that, the world is overwhelmed today with cheap automatic devices and various "smart" appliances.

Prior knowledge is hardly needed for programming. It is sufficient to have a PC (software in use is not demanding at all and is easy to learn) and a simple device (called the programmer) used for "loading" ready-to-use programs into the microcontroller.

So, if you are infected with a virus called electronics, there is nothing left for you to do but to learn how to use and control its power.

4.9 Working of microcontroller:

Even though there is a large number of different types of microcontrollers and even more programs created for their use only, all of them have many things in common. Thus, if you learn to handle one of them you will be able to handle them all. A typical scenario on the basis of which it all functions is as follows:

Power supply is turned off and everything is still...the program is loaded into the microcontroller, nothing indicates what is about to come...

Power supply is turned on and everything starts to happen at high speed! The control logic unit keeps everything under control.

Power supply voltage reaches its maximum and oscillator frequency becomes stable. SFRs are being filled with bits reflecting the state of all circuits within the microcontroller.

All pins are configured as inputs. The overall electronics starts operation in rhythm with pulse sequence. From now on the time is measured in micro and nanoseconds.

Program Counter is set to zero. Instruction from that address is sent to instruction decoder which recognizes it, after which it is executed with immediate effect.

The value of the Program Counter is incremented by 1 and the whole process is repeated...several million times per second.

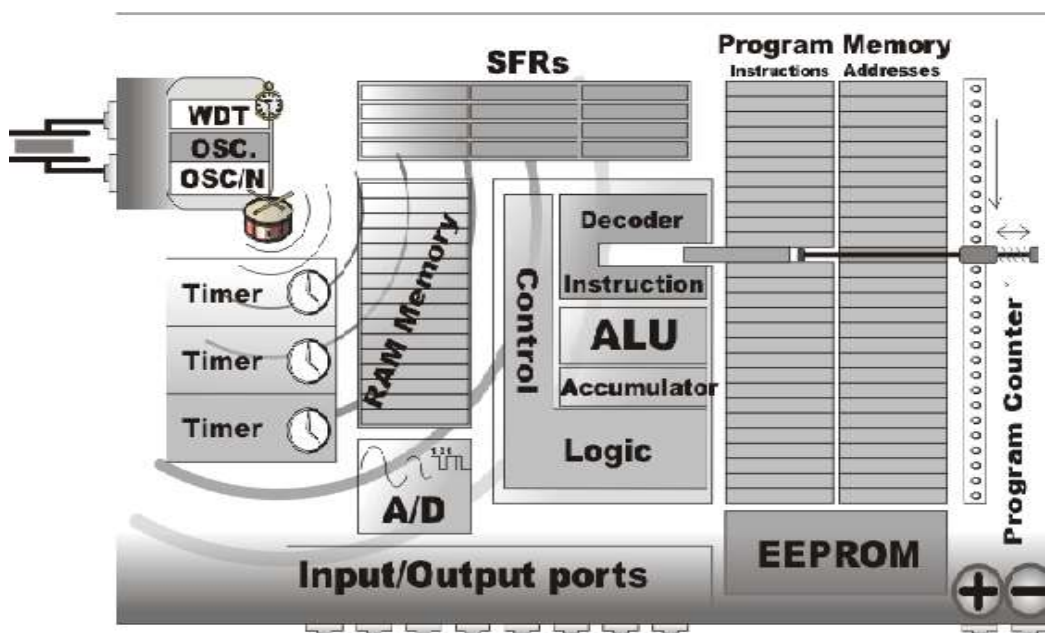


Figure 4.4 Internal description of a microcontroller

4.10 Inside a microcontroller:

As you can see, all the operations within the microcontroller are performed at high speed and quite simply, but the microcontroller itself would not be so useful if there are not special circuits which make it complete. In continuation, we are going to call your attention to them.

4.10.1 Read Only Memory (ROM):

Read Only Memory (ROM) is a type of memory used to permanently save the program being executed. The size of the program that can be written depends on the size of this memory. ROM can be built in the microcontroller or added as an external chip, which depends on the type of the microcontroller. Both options have some disadvantages. If ROM is added as an external chip, the microcontroller is cheaper and the program can be considerably longer. At the same time, a number of available pins is reduced as the microcontroller uses its own input/output ports for connection to the chip. The internal ROM is usually smaller and more expensive, but

leaves more pins available for connecting to peripheral environment. The size of ROM ranges from 512B to 64KB.

4.10.2 Random Access Memory (RAM):

Random Access Memory (RAM) is a type of memory used for temporary storing data and intermediate results created and used during the operation of the microcontrollers. The content of this memory is cleared once the power supply is off. For example, if the program performs an addition, it is necessary to have a register standing for what in everyday life is called the “sum”. For that purpose, one of the registers in RAM is called the "sum" and used for storing results of addition. The size of RAM goes up to a few KBs.

4.10.3 Electrically Erasable Programmable ROM (EEPROM):

The EEPROM is a special type of memory not contained in all microcontrollers. Its contents may be changed during program execution (similar to RAM), but remains permanently saved even after the loss of power (similar to ROM). It is often used to store values, created and used during operation (such as calibration values, codes, values to count up to etc.), which must be saved after turning the power supply off. A disadvantage of this memory is that the process of programming is relatively slow. It is measured in milliseconds.

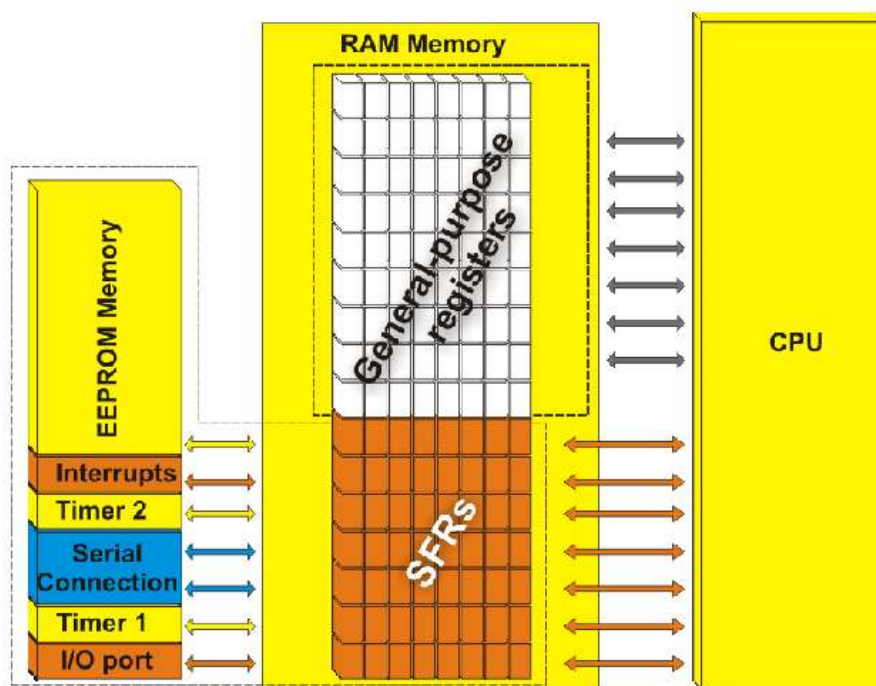


Figure 4.5 Memory description of a microcontroller

4.10.4 Special Function Registers (SFR):

Special function registers are part of RAM memory. Their purpose is predefined by the manufacturer and cannot be changed therefore. Since their bits are physically connected to particular circuits within the microcontroller, such as A/D converter, serial communication module etc., any change of their state directly affects the operation of the microcontroller or some of the circuits. For example, writing zero or one to the SFR

controlling an input/output port causes the appropriate port pin to be configured as input or output. In other words, each bit of this register controls the function of one single pin.

4.10.5 Program Counter:

Program Counter is an engine running the program and points to the memory address containing the next instruction to execute. After each instruction execution, the value of the counter is incremented by 1. For this reason, the program executes only one instruction at a time just as it is written. However the value of the program counter can be changed at any moment, which causes a “jump” to a new memory location. This is how subroutines and branch instructions are executed. After jumping, the counter resumes even and monotonous automatic counting +1, +1, +1...

4.10.6 Central Processor Unit (CPU):

As its name suggests, this is a unit which monitors and controls all processes within the microcontroller and the user cannot affect its work. It consists of several smaller subunits, of which the most important are:

Instruction decoder is a part of the electronics which recognizes program instructions and runs other circuits on the basis of that. The abilities of this circuit are expressed in the "instruction set" which is different for each microcontroller family.

Arithmetical Logical Unit (ALU) performs all mathematical and logical operations upon data.

Accumulator is an SFR closely related to the operation of ALU. It is a kind of working desk used for storing all data upon which some operations should be executed (addition, shift etc.). It also stores the results ready for use in further processing. One of the SFRs, called the Status Register, is closely related to the accumulator, showing at any given time the "status" of a number stored in the accumulator (the number is greater or less than zero etc.). A bit is just a word invented to confuse novices at electronics. Joking aside, this word in practice indicates whether the voltage is present on a conductor or not. If it is present, the appropriate pin is set to logic one (1), i.e. the bit's value is 1.

Otherwise, if the voltage is 0 V, the appropriate pin is cleared (0), i.e. the bit's value is 0. It is more complicated in theory where a bit is referred to as a binary digit, but even in this case, its value can be either 0 or 1.

4.10.7 Input/output ports (I/O Ports):

In order to make the microcontroller useful, it is necessary to connect it to peripheral devices.

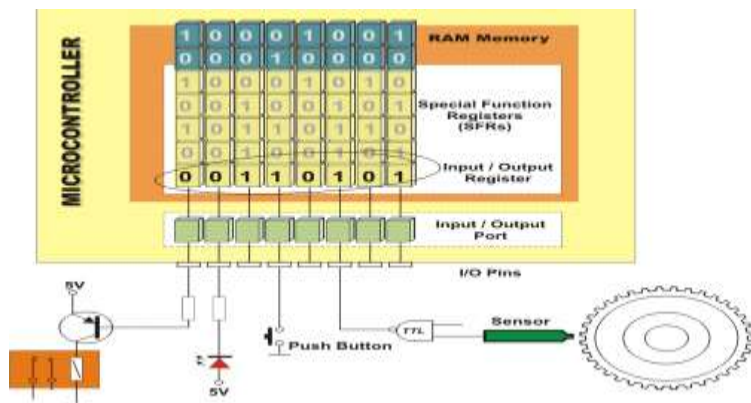


Figure 4.6 Overview of a microcontroller

Each microcontroller has one or more registers (called a port) connected to the microcontroller pins. Why do we call them input/output ports? Because it is possible to change a pin function according to the user's needs. These registers are the only registers in the microcontroller the state of which can be checked by voltmeter.

4.10.8 Oscillator:

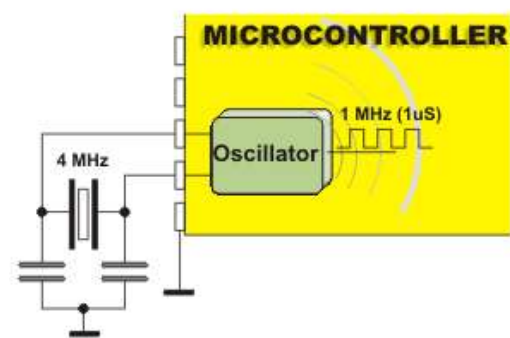


Figure4.7 Oscillator diagram

Even pulses generated by the oscillator enable harmonic and synchronous operation of all circuits within the microcontroller. It is usually configured as to use quartz-crystal or ceramics resonator for frequency stabilization. It can also operate without elements for frequency stabilization (like RC oscillator). It is important to say that program instructions are not executed at the rate imposed by the oscillator itself, but several times slower. It happens because each instruction is executed in several steps. For some microcontrollers, the same number of cycles is needed to execute any instruction, while it's different for other microcontrollers. Accordingly, if the system uses quartz crystal with a frequency of 20MHz, the execution time of an instruction is not expected 50nS, but 200, 400 or even 800 nS, depending on the type of the microcontroller.

4.10.9 Timers/Counters:

Most programs use these miniature electronic "stopwatches" in their operation. These are commonly 8- or 16-bit SFRs the contents of which is automatically incremented by each coming pulse. Once the register is completely loaded, an interrupt is generated. If these registers use an internal quartz oscillator as a clock source, then it is possible to measure the time between two events (if the register value is T1 at the moment measurement

has started, and T2 at the moment it has finished, then the elapsed time is equal to the result of subtraction $T2 - T1$). If the registers use pulses coming from external source, then such a timer is turned into a counter. This is only a simple explanation of the operation itself. It's somehow more complicated in practice.

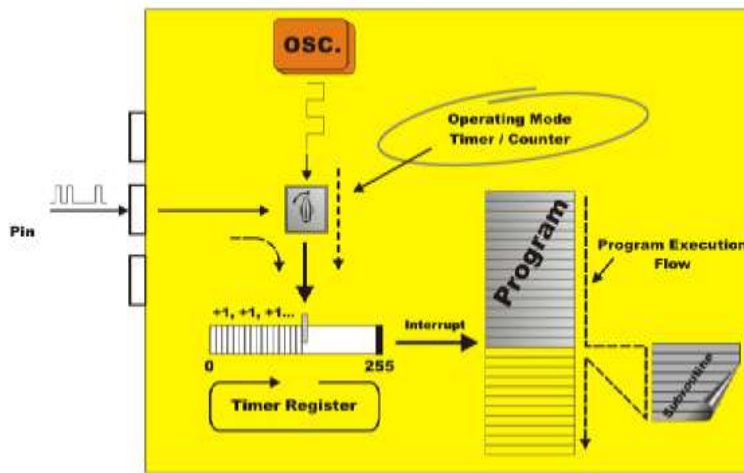


Figure4.8 Oscillator and timer circuit description

A register or a memory cell is an electronic circuit which can memorize the state of one byte. Besides 8 bits available to the user, each register has also a number of addressing bits. It is important to remember that:

All registers of ROM as well as those of RAM referred to as general-purpose registers are mutually equal and nameless. During programming, each of them can be assigned a name, which makes the whole operation much easier.

All SFRs are assigned names which are different for different types of the microcontrollers and each of them has a special function as their name suggests.

4.11 Power Supply Circuit:

There are two things worth attention concerning the microcontroller power supply circuit:

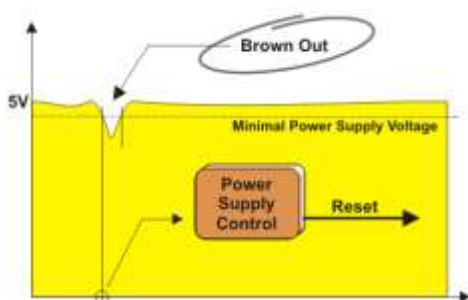


Figure 4.9 Optimisation of power supply unit

Brown out is a potentially dangerous state which occurs at the moment the microcontroller is being turned off or when power supply voltage drops to the lowest level due to electric noise. As the microcontroller consists

of several circuits which have different operating voltage levels, this can cause its out of control performance. In order to prevent it, the microcontroller usually has a circuit for brown out reset built-in. This circuit immediately resets the whole electronics when the voltage level drops below the lower limit. Reset pin is usually referred to as Master Clear Reset (MCLR) and serves for external reset of the microcontroller by applying logic zero (0) or one (1) depending on the type of the microcontroller. In case the brown out is not built in the microcontroller, a simple external circuit for brown out reset can be connected to this pin.

4.12 Serial communication:

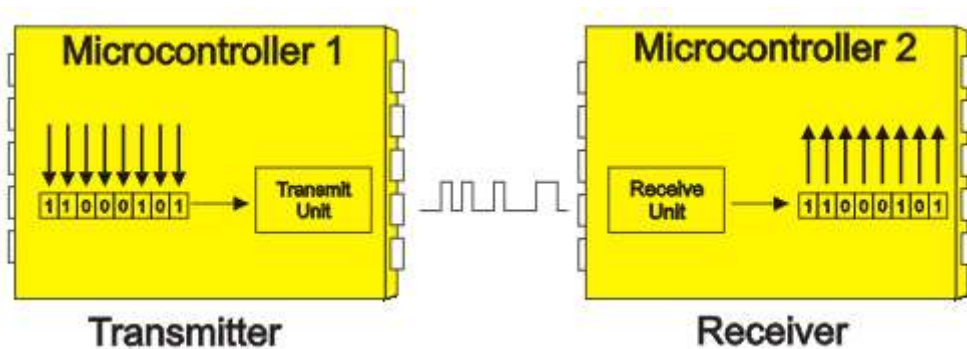


Figure 4.10 Serial communication between transmitter and receiver

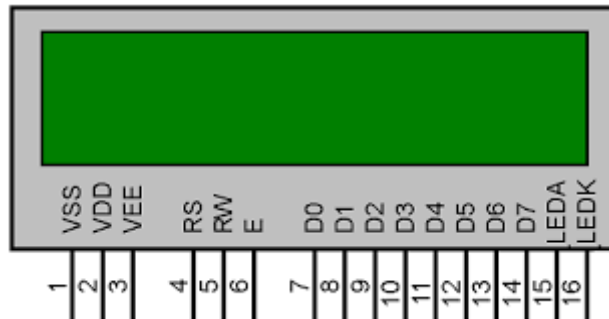
Parallel connections between the microcontroller and peripherals established over I/O ports are the ideal solution for shorter distances up to several meters. However, in other cases, when it is necessary to establish communication between two devices on longer distances it is obviously not possible to use parallel connections. Then, serial communication is the best solution. Today, most microcontrollers have several different systems for serial communication built in as a standard equipment. It is important to remember that byte digits are not of equal significance. The largest value has the leftmost bit called the most significant bit (MSB). The rightmost bit has the least value and is therefore called the least significant bit (LSB). Since 8 digits (zeros and ones) of one byte can be combined in 256 different ways, the largest decimal number which can be represented by one byte is 255 (one combination represents zero).

4.2 LCD

LCD (Liquid Crystal Display) screen is an electronic display module and find a wide range of applications. A 16x2 LCD display is very basic module and is very commonly used in various devices and circuits. These modules are preferred over seven segments and other multi segment LEDs. The reasons being: LCDs are economical; easily programmable; have no limitation of displaying special & even custom characters (unlike in seven segments), animations and so on.

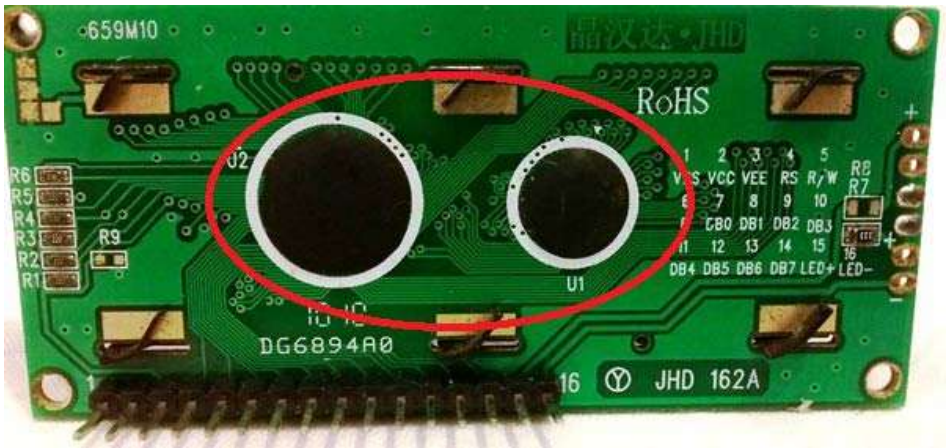
A 16x2 LCD means it can display 16 characters per line and there are 2 such lines. In this LCD each character is displayed in 5x7 pixel matrix. This LCD has two registers, namely, Command and Data.

The command register stores the command instructions given to the LCD. A command is an instruction given to LCD to do a predefined task like initializing it, clearing its screen, setting the cursor position, controlling display etc. The data register stores the data to be displayed on the LCD. The data is the ASCII value of the character to be displayed on the LCD. Click to learn more about internal structure of a LCD.



S. No	Pin No.	Pin Name	Pin Type	Pin Description	Pin Connection
1	Pin 1	Ground	Source Pin	This is a ground pin of LCD	Connected to the ground of the MCU/ Power source
2	Pin 2	VCC	Source Pin	This is the supply voltage pin of LCD	Connected to the supply pin of Power source
3	Pin 3	V0/VEE	Control Pin	Adjusts the contrast of the LCD.	Connected to a variable POT that can source 0-5V
4	Pin 4	Register Select	Control Pin	Toggles between Command/Data Register	Connected to a MCU pin and gets either 0 or 1. 0 -> Command Mode 1-> Data Mode

5	Pin 5	Read/Write	Control Pin	Toggles the LCD between Read/Write Operation	Connected to a MCU pin and gets either 0 or 1. 0 -> Write Operation 1-> Read Operation
6	Pin 6	Enable	Control Pin	Must be held high to perform Read/Write Operation	Connected to MCU and always held high.
7	Pin 7-14	Data Bits (0-7)	Data/Command Pin	Pins used to send Command or data to the LCD.	In 4-Wire Mode Only 4 pins (0-3) is connected to MCU In 8-Wire Mode All 8 pins(0-7) are connected to MCU
8	Pin 15	LED Positive	LED Pin	Normal LED like operation to illuminate the LCD	Connected to +5V
9	Pin 16	LED Negative	LED Pin	Normal LED like operation to illuminate the LCD connected with GND.	Connected to ground



These black circles consist of an interface IC and its associated components to help us use this LCD with the MCU. Because our LCD is a 16*2 Dot matrix LCD and so it will have (16*2=32) 32 characters in total and each character will be made of 5*8 Pixel Dots. A Single character with all its Pixels enabled is shown in the below picture.



So Now, we know that each character has (5*8=40) 40 Pixels and for 32 Characters we will have (32*40) 1280 Pixels. Further, the LCD should also be instructed about the Position of the Pixels. It will be a hectic task to handle everything with the help of MCU, hence an **Interface IC like HD44780** is used, which is mounted on LCD Module itself. The function of this IC is to get the **Commands and Data** from the MCU and process them to display meaningful information onto our LCD Screen. Let’s discuss the different type of mode and options available in our LCD that has to be controlled by our Control Pins.

4.2.1 4-bit and 8-bit Mode of LCD:

The LCD can work in two different modes, namely the 4-bit mode and the 8-bit mode. In **4 bit mode** we send the data nibble by nibble, first upper nibble and then lower nibble. For those of you who don’t know what a nibble is: a nibble is a group of four bits, so the lower four bits (D0-D3) of a byte form the lower nibble while the upper four bits (D4-D7) of a byte form the higher nibble. This enables us to send 8 bit data.

Whereas in **8 bit mode** we can send the 8-bit data directly in one stroke since we use all the 8 data lines. 8-bit mode is faster and flawless than 4-bit mode. But the major drawback is that it needs 8 data lines connected to the microcontroller. This will make us run out of I/O pins on our MCU, so 4-bit mode is widely used. No control pins are used to set these modes. It's just the way of programming that change.

4.2.2 Read and Write Mode of LCD:

As said, the LCD itself consists of an Interface IC. The MCU can either read or write to this interface IC. Most of the times we will be just writing to the IC, since reading will make it more complex and such scenarios are very rare. Information like position of cursor, status completion interrupts etc. can be read if required, but it is out of the scope of this tutorial.

The Interface IC present in most of the LCD is **HD44780U**, in order to program our LCD we should learn the complete datasheet of the IC. The [datasheet is given here](#).

4.2.3 LCD Commands:

There are some preset commands instructions in LCD, which we need to send to LCD through some microcontroller. Some important command instructions are given below:

Hex Code	Command to LCD Instruction Register
----------	-------------------------------------

0F	LCD ON, cursor ON
01	Clear display screen
02	Return home
04	Decrement cursor (shift cursor to left)
06	Increment cursor (shift cursor to right)
05	Shift display right
07	Shift display left
0E	Display ON, cursor blinking
80	Force cursor to beginning of first line
C0	Force cursor to beginning of second line
38	2 lines and 5×7 matrix
83	Cursor line 1 position 3
3C	Activate second line
08	Display OFF, cursor OFF
C1	Jump to second line, position 1
OC	Display ON, cursor OFF
C1	Jump to second line, position 1
C2	Jump to second line, position 2

4.3 Voltage Sensor

Introduction

The interface of various sensors to a controller like the BrainStem GP 1.0 module typically involves either conditioning or converting voltage levels into the range the controller requires. Many systems use A/D converters to make the sensor value relevant in a program or data logging configuration. These converters have a fixed range of voltages they can convert from with 0-5V being by far the most common.

Sensors often create voltages in different ranges than those required by the controllers they are being interfaced to which requires the conversion of one voltage to another. This conversion often breaks down into a combination one or more of three types, amplification, dividing, and shifting.



Dividing Voltages

Voltage dividing is probably the easiest transformation you can perform on sensor outputs to alter the value being connected to a microcontroller or other circuit.

The mathematical equivalent of what you are trying to achieve when dividing voltages is a simple division. For instance, say you have a sensor that outputs 0-100V and you want to convert this to 0-5V for interface to the A/D

input on your BrainStem. The goal would be to create a 20:1 ratio of voltage which means dividing the original sensor output voltage by a factor of 20. So we need a small circuit that will accomplish the following pictorially:

The easiest way to accomplish this division is using a few resistors to form a voltage divider. The resistors are wired up in series to create intermediate voltages based with the desired division. The above example could be accomplished as follows:

This voltage divider uses the input as the top of the resistor ladder and ground as the bottom. The actual division is defined by the proportion of resistance between the two resistors.

Notice the above circuit does not work out to an exact division by 20. This is because the resistors used are commonly found resistor values. Precision resistors with exact tolerances can be used but are often not needed since the original output of sensors typically varies. Here the resulting output voltage is slightly below the maximum of 5V but with a reasonable A/D converter like the 10-bit converters used in the BrainStem GP 1.0 module would still offer plenty of dynamic range in the sensor readings.

Amplifying Voltages

Voltage amplification is required for a class of sensors that create small voltages. Often sensors of this type are converting some sort of physical energy such as acceleration, temperature, or other minimal physical force into a voltage. This conversion is often an inefficient conversion and the measured energy is minimal which results in very small voltages generated by the sensor. To make these small voltages meaningful, they must be amplified to a usable level.

The equation for amplification is the exact opposite of dividing. You want to multiply the output voltage from a sensor to gain the full range of your A/D input or other interfaced circuit. Lets say you have an accelerometer which measures accelerations in g (gravity) units. A sensor like this may have a response of 312mV/g which means the sensor will generate 0.312V for each gravity unit of force it encounters. Now, say you would like to measure up to 2 gravity units (2g) with your detector with the full range of your 0-5V A/D converter. This means you need to multiply the output voltage of your accelerometer by a factor of about 16 to get the desired range and sensitivity in your measurements. So we want to accomplish the following pictorially:

Probably the most common way to multiply a voltage is using an amplifier. Here, we will use a common Operational Amplifier (Op Amp) to multiply the voltage. These Op Amp circuits are extremely common in electronics and there are volumes of literature devoted specifically to the various characteristics and performance

of each. We use one of the original versions which is widely available and easy to interface called the 741. Here is one circuit that will amplify the voltage by a factor of about 16:

There are some things to note about this circuit. Again, changing resistance values gives a different voltage amplification (multiplication). The small numbers indicate the pins of the 741 package that you would connect to for this circuit (it is an 8 pin chip). Also, notice the additional power supply which is both positive and negative. This is very common for Op Amp circuits. Since the Op Amp is powered by a plus/minus voltage of 9V, the absolute output can at best be 9V. In practice, the output voltage will probably be slightly less.

The gain for this amplifier may not be exactly linear, depending on the input and output voltages. This can often be hidden in the noise of the sensor and accuracy of the A/D conversion on the other end but it should be considered. The higher the gain of an amplifier, the larger the margin of error and noise.

Shifting Voltages

Shifting voltages can be a requirement for sensor data that are generated symmetrically about a common (often ground) voltage. A simple example of this would be a motor acting as a generator where spinning in one direction creates a positive voltage and spinning in the other direction creates a negative voltage. Since most common A/D converters in microcontrollers deal with a 0-VCC range for conversions, sensors that are symmetric about the ground voltage reference need to be shifted into the 0-VCC range.

The equation for shifting is then then the addition or subtraction of an offset from the original sensor's voltage. For example, if your sensor produces -2 to 2V, you would want to add 2V to the output for reading with a common 0-5V A/D converter. This addition would result in a final output of 0-4V which the A/D converter could then use. This conversion looks like this pictorially:

This circuit is a two-stage summing amplifier using an Op-Amp chip (the 1458) that houses two op-amps on a single chip. Notice there are some fixed values of resistors that essentially create a voltage summing circuit. The input on one side is a resistor network that creates a fixed voltage to sum with the input voltage. The variable resistor values change this resistor network's set voltage. You could substitute a potentiometer for R1 and R2 to make the addition variable, by twisting the potentiometer.

The addition circuit also requires a plus/minus 9V power supply for the op-amps. In addition, a tap from the 5V supply used for the logic is used although this could be done with the positive 9V side as well, provided the voltages are computed correctly.

Combining Conversions

So the above conversions define addition, subtraction, multiplication, and division of a voltage. Each of these conversions can be thought of in isolation as shown above or they can be combined to create composite conversions. We essentially have an algebra of blocks we can use to achieve a wide variety of overall conversions.

Say you have a sensor that creates -100 to 100V and you want to read the value with a 0-5V A/D converter. You would need to scale down the original voltage to -2.5 to 2.5V first and then offset the result by adding 2.5V to get the result into the desired range of 0-5V for your A/D converter. You can chain together the conversions for such an effect which would look like this pictorially:

Conversion Impurities

The above conversions all introduce impurities in the resulting signal in the form of noise, non-linearity, and other corruptions of the original input voltage. Care must be taken to minimize the number of stages and also to order them for reduced error. Testing and careful thought can typically reduce these impurities to a minimum but they cannot be disregarded.

There is a general rule of thumb with regard to these introduced impurities. The more you are changing the original voltage, the more impurities you will introduce. For instance, an amplification of 100x would be generally more noisy than one of 2x.

Power Supply Issues

Several of these circuits require a plus/minus 9V supply for the Op Amps. This can readily be accomplished using two standard 9V batteries. More sophisticated options include standard power supplies, charge pumps and inverters and several other options. The 9V battery is cheap, simple and it works well. Op Amp circuits tend to be pretty efficient so the batteries should last quite some time.

4.4 CURRENT SENSOR

A **current sensor** is a device that detects electrical current (AC or DC) in a wire, and generates a signal proportional to it.

The sensed current and the output signal can be:

- AC current input,
 - analog output, which duplicates the wave shape of the sensed current
 - unipolar output, which is proportional to the average or RMS value of the sensed current
- DC current input,
 - unipolar, with a unipolar output, which duplicates the wave shape of the sensed current

- bipolar output, which duplicates the wave shape of the sensed current
- digital output, which switches when the sensed current exceeds a certain threshold

CURRENT SENSOR:

NAME: CURRENT SENSOR/CS60 010

SHORT DESCRIPTION:

Current sensor is intended for measuring current from 1 to 10 Amps.

FEATURES:

Measures current from 1 to 10 *Amps*.

Tin-silver over copper terminations

0.5 mm minimum wall thickness of the hole

Sensitivity may be enhanced by increasing primary turns.

SPECIFICATIONS:

Ambient temperature: -40°C to $+85^{\circ}\text{C}$

Storage temperature: Component: -40°C to $+85^{\circ}\text{C}$

Packaging trays: -40°C to $+80^{\circ}\text{C}$

Vout tolerance $\pm 10\%$

APPLICATIONS:

Sensing branch circuit overload and detecting load drop or shutdown.



An AC line usually works at 50/60 Hz, meaning that the voltage changes within about 10ms between zero and peak. In addition, the drawn current will not usually have even a sinusoidal waveform (think of the modern switch-mode power supplies in so many consumer devices or of ballasts). And due to external sources of interference the waveform can be even more "dirty". So, except for very simple loads, the waveform of the current

drawn by a load does not resemble the voltage waveform. Besides the known phase shift and power factor, current flows in pulses, causing harmonics and subharmonics of the power frequency.

One way of avoiding this is to measure a ready integrated and averaged effective value delivered by a self-powered current transducer for example. The monitored line should also safely deliver the (low) power needed for the transmitter. As described in what follows, a wireless transmitter can be powered by a current transducer to send the measured values every time a primary current flows.

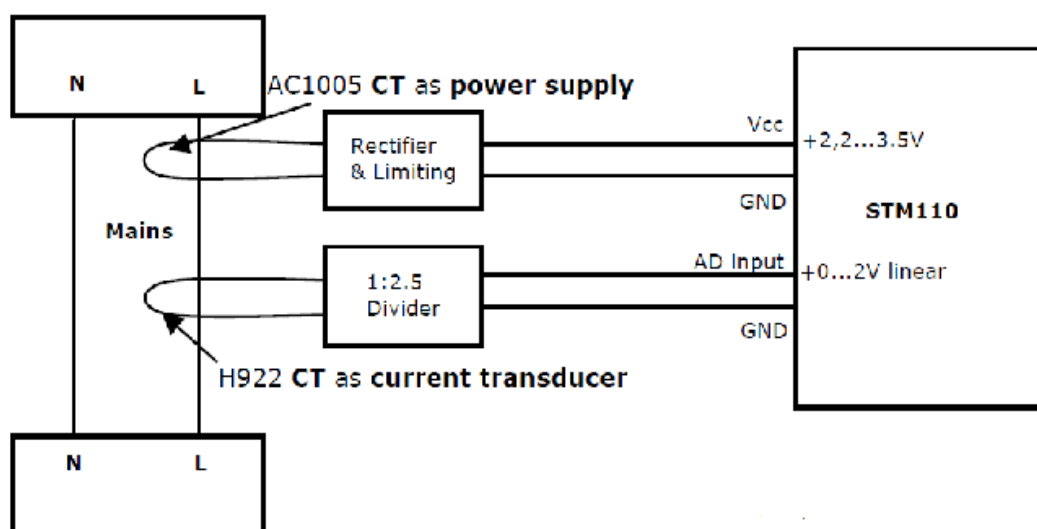
The only really suitable passive, ultra-low-power or self-powered current sensor is the current transducer (CT). CTs are generally used to measure AC amperage in an electrical circuit.

They are accurate, safe, easy to implement and reliable in tough environmental and thermal conditions. CTs are installed insulated around an energized conductor and sense the magnetic field generated by the primary current flowing in the circuit. Unlike other transducers, the primary winding current in a CT is independent of the secondary winding load.

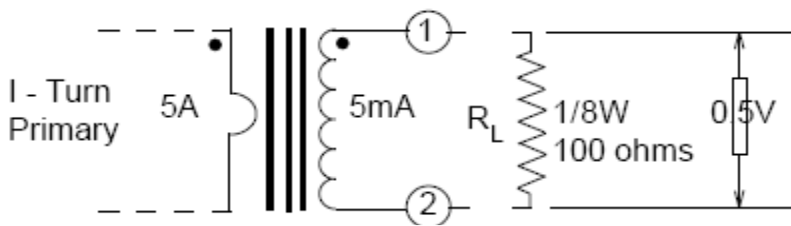
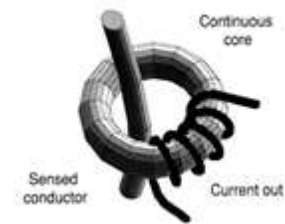
This primary winding current depends only on the circuit into which the primary winding is connected. The idea is not new. For example, a self-powered current transducer can also be loaded with a LED as a discrete current indicator to monitor the circuit condition in a remote location.

When the remote circuit current flows, the current transducer will generate enough "harvested" current to illuminate a LED to indicate the current flowing. When the remote current ceases to flow, the LED will be turned off.

BLOCK DIAGRAM OF THE CURRENT TRANSFORMER:



CT EQUIVALENT SCHEMATIC:



Current transducers provide a simple, low-cost but nevertheless accurate method of sensing current flow in power conductors. They are available mostly in two basic configurations:

1. Ring-core CTs with holes (power conductor opening size).
2. Split-core CTs have one end removable so that the load conductor or bus bar does not have to be disconnected to install the CT.

The ring-core style is the most readily used core geometry for current transducer application.

There is no air gap in the core, so the magnetizing current will always be small. Ringcore geometry fits perfectly with flux flow in the core; therefore the core material can be utilized efficiently giving you a small core and small core loss as a result.

They are the primary choice for new installations. However, to retrofit an existing installation, a split-core style could be the better alternative. Split-core CTs are very popular and suitable for fast retrofitting.

The split-core CT is smaller than the clamp-on probe style CT and is considerably less expensive. It works best in a crowded electrical panel where space is often limited.

Caution! :

A CT should never be open-circuited while main current is passing through the primary Winding. If the load (burden resistor or overvoltage protection) is removed from the secondary winding while the main circuit current is flowing, the flux in the core shoots up to a high level and a very high voltage appears across the open secondary circuit.

Due to the high turns ratio usually found in these transformers (e.g. 1:1000), the voltage can reach under this condition a dangerously high level, which can break down the insulation and damage the circuitry. It also becomes a hazard to personnel. It is strongly recommended to put a short or other overvoltage limitation device on the secondary winding before removing the secondary load while the main current is flowing through the primary winding.

Some specifications:

The mentioned transducer requires no external power supply; the device is parasitically powered from the line current through its integrated current transformer.

- 1.Range: 0 to 30, 60, 120 A, switch-selected (H922).
- 2.Output: 0 to 5 Vdc, proportionally to primary current.
- 3.Accuracy: better $\pm 2\%$ or $\pm 1\%$ FS.

Size: 2.9 x 2.58 x 1.04 in (LxWxH).

The delivered output voltage between 0 and 5 Vdc is available as long as the primary current flows and it only needs to be divided by 2.5 (i.e. 0 to 2 V range) and applied at the STM 1X0(C) AD input. This will detect the current flow and its changes and transmit the information.

An overvoltage protection, realized e.g. by two 2V7 Zener diodes connected between the corresponding STM 1X0(C) AD input and GND is recommended in order to prevent any damage.

Part Number Sensed current Irms Vout tolerance

CS60-010_ 1–10 A rms $\pm 10\%$

(For sensed current above 10 Arms, see CS60 data sheet)

- 1. When ordering, please specify termination code:

CS60-010L

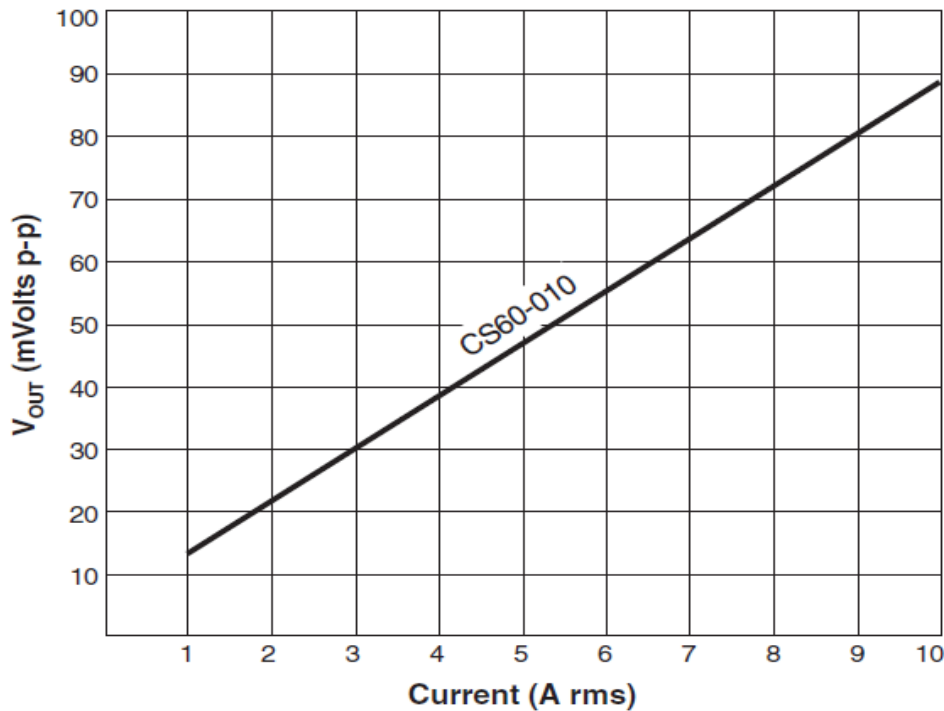
Termination: L= RoHS compliant tin-silver over copper.

Special order: T = RoHS tin-silver-copper (95.5/4/0.5)

or S = non-RoHS tin-lead (63/37).

- 2. Ambient temperature range -40°C to $+85^{\circ}\text{C}$.
- 3. Electrical specifications at 25°C .

Typical Response



Basic Principles of Operation:

This standard design uses an accurate and specific resistive termination on the secondary. By transformer action, the loading effect of this resistance is transferred to the primary and appears as a shunt resistance across the primary. The parallel combination of this shunt resistance and the impedance of the primary winding form the impedance through which the current flows.

THE FUNDAMENTALS OF CURRENT SENSE TRANSFORMER DESIGN:

Typically, the transformer is designed so that the impedance of the primary winding is much greater than the shunt resistance reflected into the primary side and thus the primary impedance is mostly resistive. This shunt resistance acts as a current viewing resistor for AC current and it is this AC voltage drop that gets transferred to the secondary.

It is this AC shunt resistance that the circuit sees and it is relatively easy to keep its value very low so as to have minimal effect on the circuit.

Because of the isolation feature of the current sense transformer, it can be placed at any desired location in a circuit, including above ground, to monitor current there.

Design Procedure:

Typical starting points, or inputs, to the design process are the following:

- Primary turns (N_p)
- Sensitivity (S)
- Desired series AC impedance (Z_{sac})
- Maximum current rating (I_{max})
- Minimum frequency response (f_{min})

Desired design results or outputs would include:

- Secondary turns (N_s)
- Secondary termination resistance (R_t)
- Minimum inductance factor (AL_{min})

The suggested design steps using the inputs listed above are as follows:

1. The desired series AC impedance (Z_{sac}) introduced into the circuit by the current transformer can be expressed in volts per ampere instead of ohms. Using this figure as the volts per ampere on the primary side of the transformer and using the desired sensitivity (S) in volts per ampere at the secondary, the turns ratio (n) is calculated..

$$n = \frac{S}{Z_{sac}}$$

2. Calculate secondary turns (N_s) using the primary turns (N_p) and the turns ratio.

$$N_s = n \cdot N_p$$

3. Calculate the secondary termination resistance (R_t) using the turns ratio and the series AC impedance at the primary.

$$R_t = Z_{sac} \cdot n^2$$

4. The minimum primary inductance required (L_p) is a function of how accurate and linear the volts per ampere versus current transfer function of the transformer needs to be. A good rule of thumb for an accurate and linear transformer is to design for minimum primary inductance whose inductive reactance is 100 times the primary Z_{sac} at the minimum low frequency (f_{min}) design point.

$$L_p \min = X_L (2\pi \cdot f_{\min})$$

5. Calculate the required inductance factor to obtain the required primary inductance (L_p) with the specified number of primary turns (N_p).

$$A_L = \frac{L_p \min}{N_p^2}$$

Design Example:

Following is an example of a design using the above approach:

INPUT/ OUTPUT

Primary turns (N_p) = 1 Secondary turns (N_s) = 100

Sensitivity (S) = 0.5 V/A Secondary termination resistance (R_t) = 50 Ω

Series AC impedance (Z_{sac}) = 0.005 Ω Minimum inductance factor ($AL_{\min}$) = 3981 nH/n²

Maximum current rating ($I_{\max}$) = 5 A

Minimum frequency response ($f_{\min}$) = 20 kHz.

Choosing a Core:

Quite often, a soft ferrite toroidal core is used for a current sense transformer. A core of surprisingly small cross section will be sufficient for current transformers handling multiple amperes at typical switch mode power frequencies. A toroidal core is well suited for a transformer with a single turn primary since it is desired to keep the primary to secondary coupling as good as possible.

The toroidal core works well here because the secondary turns are completely surrounding the single primary conductor passing through the hole.

Other shapes are also used, particularly at lower frequencies, where the required cross section is larger and higher numbers of both primary and secondary turns are used.

As seen in the equivalent circuit in Figure 1, the primary is in shunt across the primary side series AC impedance (Z_{sac}). If the primary is only one turn, the inductance factor of the core needs to be relatively large to provide sufficient inductive reactance at the low frequency end of the passband.

A toroidal shape is also efficient for this reason because the magnetic path length of a small toroid can be made small relative to the cross sectional area which will yield a high inductance factor per unit volume.

A high permeability material is also desirable in achieving a high inductance factor. However, one also has to take into account the required operating temperature range of the transformer.

The permeability of high permeability grade materials can drop significantly with decreasing temperature.

The required cross sectional area of the core is approached in essentially the same way as with any transformer. It is a function of the core material, the series AC impedance (Z_{sac}) on the primary side, the maximum ACrms current the primary will see, and the number of primary turns.

It will first be necessary to calculate the maximum voltage ($E_p \max$) that will appear across the primary.

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It will first be necessary to calculate the maximum voltage ($E_p \max$) that will appear across the primary.

$$E_p \max = I_p \max \cdot Z_{sac}$$

For a sinusoidal AC current with no DC component, the formula relating primary voltage (E_p), turns (N_p), frequency(f), and cross sectional area (A_e) is:

Solving for A_e , we have:

$$A_e = \frac{E_p}{4.44 \cdot f \cdot N_p \cdot B_{peak} \cdot 10^{-10}}$$

As with any transformer, determining a suitable B_{peak} is a function of core material and the maximum operating temperature of the transformer, as well as core losses. It is suggested to keep the maximum peak flux density at no more than 50% of the saturation flux density of the material at a particular temperature.

Designing for A DC Component:

As with any transformer, if the current in the circuit into which the current sense transformer will be inserted has a DC component, it must be taken into account in the transformer design. The DC component of the current in the primary will produce a DC component of flux density in the core material. An equation for calculating the approximate value of the DC component of flux density is as follows:

$$B_{dc \text{ peak}} = \mu_e \cdot H_{dc \text{ peak}}$$

$$H_{dc} = \frac{4\pi \cdot N_p \cdot I_{dc peak}}{l_e}$$

The units are B in gauss, I in amperes, l_e (the magnetic path length of the core) in mm, and H in oersteds. This is only an approximation because the permeability of the core material will decrease as DC current increases.

The μ_e in the B_{dc} formula above is the effective permeability of the magnetic circuit of the transformer. Of course, if an ungapped toroid core is used, the effective permeability is the permeability of the material. On the plus side, usually the primary of a current sense transformer has a small number of turns. Since H_{dc} is proportional to turns, this is desirable.

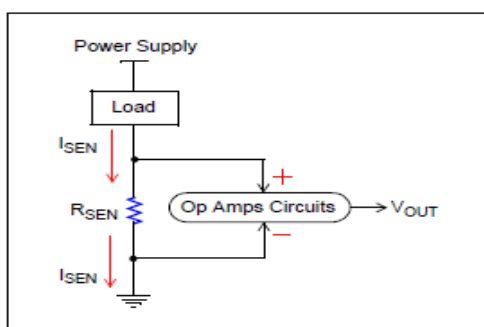
A gapped ferrite core or powdered metal core may be required for situations with high DC components.

CURRENT SENSING TECHNIQUES:

This section introduces two basic techniques for current sensing applications, low-side current sensing and high-side current sensing. Each technique has its own advantages and disadvantages, discussed in more detail in the following topics.

Low-Side Current Sensing:

As shown in Figure 1, low-side current sensing connects the sensing resistor between the load and ground. Normally, the sensed voltage signal ($V_{SEN} = I_{SEN} \times R_{SEN}$) is so small that it needs to be amplified by subsequent op amp circuits (e.g., non-inverting amplifier) to get the measurable output voltage (V_{OUT}).



a)Advantages:

- Low input Common mode voltage
- Ground referenced input and output
- Simplicity and low cost

b)Disadvantages:

- Ground path disturbance

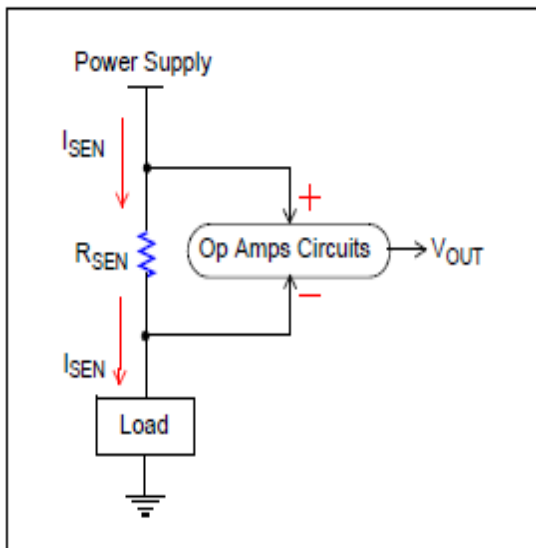
- Load is lifted from system ground since RSEN adds undesirable resistance to the ground path
- High load current caused by accidental short goes undetected
- Low VDD parts

In a single-supply configuration, the most important aspect of low-side current sensing is that the Common mode input voltage range (VCM) of the op amp must include ground. The MCP6H0X op amp is a good choice since its VCM is from $V_{SS} - 0.3V$ to $V_{DD} - 2.3V$.

Considering the advantages, choose low-side current sensing where short circuit detection is not required, and ground disturbances can be tolerated.

High-Side Current Sensing:

As shown in Figure 2, high-side current sensing connects the sensing resistor between the power supply and load. The sensed voltage signal is amplified by subsequent op amp circuits to get the measurable V_{OUT} .



a)Advantages:

- Eliminates ground disturbance
- Load connects system ground directly
- Detects the high load current caused by accidental shorts

b)Disadvantages:

- Must be able to handle very high and dynamic Common mode input voltages
- Complexity and higher costs
- High VDD parts.

In a single-supply configuration, the most important aspects of high-side current sensing are:

- The VCM range of the Difference amplifier must be wide enough to withstand high Common mode input voltages
- The Difference amplifier's ability to reject dynamic Common mode input voltages

The MCP6H0X op amp is a good fit for high-side current sensing, which will be discussed in more detail in the following section.

HIGH-SIDE CURRENT SENSING IMPLEMENTATION

High-side current sensing is typically selected in applications where ground disturbance cannot be tolerated, and short circuit detection is required, such as motor monitoring and control, overcurrent protection and supervising circuits, automotive safety systems, and battery current monitoring.

This section discusses three typical high-side current sensing implementations, with their advantages and disadvantages. Based on application requirements, one choice may be better than another.

4.5 PIEZOELECTRIC SENSOR

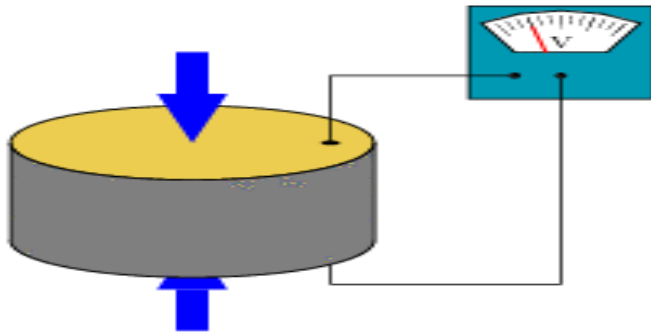
A piezoelectric sensor is a device that uses the piezoelectric effect to measure pressure, acceleration, strain or force by converting them to an electrical charge.

APPLICATIONS

Piezoelectric sensors have proven to be versatile tools for the measurement of various processes. They are used for quality assurance, process control and for research and development in many different industries. Although the piezoelectric effect was discovered by Pierre Curie in 1880, it was only in the 1950s that the piezoelectric effect started to be used for industrial sensing applications. Since then, this measuring principle has been increasingly used and can be regarded as a mature technology with an outstanding inherent reliability. It has been successfully used in various applications, such as in medical, aerospace, nuclear instrumentation, and as a pressure sensor in the touch pads of mobile phones. In the automotive industry, piezoelectric elements are used to monitor combustion when developing internal combustion engines. The sensors are either directly mounted into additional holes into the cylinder head or the spark/glow plug is equipped with a built in miniature piezoelectric sensor.[1]

The rise of piezoelectric technology is directly related to a set of inherent advantages. The high modulus of elasticity of many piezoelectric materials is comparable to that of many metals and goes up to 10^6 N/m. Even though piezoelectric sensors are electromechanical systems that react to compression, the sensing elements show almost zero deflection. This is the reason why piezoelectric sensors are so rugged, have an extremely high natural frequency and an excellent linearity over a wide amplitude range. Additionally, piezoelectric technology is insensitive to electromagnetic fields and radiation, enabling measurements under harsh conditions. Some

materials used (especially gallium phosphate [2] or tourmaline) have an extreme stability even at high temperature, enabling sensors to have a working range of up to 1000 °C. Tourmaline shows pyroelectricity in addition to the piezoelectric effect; this is the ability to generate an electrical signal when the temperature of the crystal changes. This effect is also common to piezoceramic materials.



A piezoelectric disk generates a voltage when deformed (change in shape is greatly exaggerated)

One disadvantage of piezoelectric sensors is that they cannot be used for truly static measurements. A static force will result in a fixed amount of charges on the piezoelectric material. While working with conventional readout electronics, imperfect insulating materials, and reduction in internal sensor resistance will result in a constant loss of electrons, and yield a decreasing signal. Elevated temperatures cause an additional drop in internal resistance and sensitivity. The main effect on the piezoelectric effect is that with increasing pressure loads and temperature, the sensitivity is reduced due to twin-formation. While quartz sensors need to be cooled during measurements at temperatures above 300 °C, special types of crystals like GaPO₄ gallium phosphate do not show any twin formation up to the melting point of the material itself.

However, it is not true that piezoelectric sensors can only be used for very fast processes or at ambient conditions. In fact, there are numerous applications that show quasi-static measurements, while there are other applications with temperatures higher than 500 °C.

Piezoelectric sensors are also seen in nature. The collagen in bone is piezoelectric, and is thought by some to act as a biological force sensor.^{[2][3]}

PRINCIPLE OF OPERATION

Depending on how a piezoelectric material is cut, three main modes of operation can be distinguished: transverse, longitudinal, and shear.

TRANSVERSE EFFECT

A force is applied along a neutral axis (y) and the charges are generated along the (x) direction, perpendicular to the line of force. The amount of charge depends on the geometrical dimensions of the respective piezoelectric element. When dimensions a, b, c apply,

$$C_x = d_{xy} F_y b / a,$$

where a is the dimension in line with the neutral axis, b is in line with the charge generating axis and d is the corresponding piezoelectric coefficient.[3]

LONGITUDINAL EFFECT

The amount of charge produced is strictly proportional to the applied force and is independent of size and shape of the piezoelectric element. Using several elements that are mechanically in series and electrically in parallel is the only way to increase the charge output. The resulting charge is

$$C_x = d_{xx} F_x n,$$

where d_{xx} is the piezoelectric coefficient for a charge in x-direction released by forces applied along x-direction (in pC/N). F_x is the applied Force in x-direction [N] and n corresponds to the number of stacked elements . force applied and the element dimension.

4.6 SOLAR PANEL



A **photovoltaic module** or **photovoltaic panel** is a packaged interconnected assembly of photovoltaic cells, also known as solar cells. The photovoltaic module, known more commonly as the **solar panel**, is then used as a component in a larger photovoltaic system to offer electricity for commercial and residential applications.

Because a single photovoltaic module can only produce a certain amount of wattage, installations intended to produce larger electrical power capacity require an installation of several modules or panels and this is known as a photovoltaic array. A photovoltaic installation typically includes an array of photovoltaic modules or panels, an inverter, batteries and interconnection wiring. Photovoltaic systems are used for either on- or off-grid applications, and for solar panels on spacecraft.

Solar Panels use light energy (photons) from the sun to generate electricity through photovoltaic effect (this is the photo-electric effect). The majority of modules use wafer-based crystalline silicon cells or a thin-film cell based on cadmium telluride or silicon. Crystalline silicon, which is commonly used in the wafer form in photovoltaic (PV) modules, is derived from silicon, a commonly used semi-conductor.

Special Features:

- 85W solar panel, for 12V DC applications
- Made of multi-crystalline solar silicone cells
- Peak power: 85 Watts (day time with fully sun shine)
- Open voltage circuit (Voc): 22V
- Maximum power voltage (Vmp): 17.5V
- Maximum power current (Imp): 4.9A
- Short circuit current (Isc): 5.3A
- Cells in series: 36 pieces
- Nominal working temperature: 43±2 degrees C
- Dimensions: less 1,172 x 541 x 35mm
- Installation: solar panel face directly to the sun
- Weight: less than 5.0kg
- Working life: more than 25 years
- Standard testing condition: 25 degrees C, AM1.5 spectrum, 1,000W/m² irradiance
- Insulation: ≥ 100MΩ
- Voltage standoff: AC 2,000V, DC 3,000V
- Wind pressure: 60m/s (200kg/m²)

4.7 WIRELESS POWER TRANSFER DC

GENERAL DESCRIPTION

The term “wireless charging” usually refers to inductive charging. This technology uses a charging station that creates an alternating magnetic field. A device with the proper induction coil will receive energy from that field when it is placed nearby, making it receive power without a physical connection. An important issue associated with all wireless power systems is limiting the exposure of people and other living things to potentially injurious electromagnetic fields. Wireless power transfer is the transmission of DC power from a power source to an electrical load, without the use of discrete human made conductors.

PRODUCT DESCRIPTION

The Wireless Power Transfer and Charging Module can be used in electronic equipments in common use for close wireless charging. This module uses an electromagnetic field to transfer electric energy between a transmitter circuit and a receiver circuit. An induction coil creates an alternating electromagnetic field from within the transmitter circuit powered with 12V. The second induction coil takes power from the electromagnetic field and converts it back into DC current to the receiver circuit. Increase the number of turns of the receiver coil to increase the transmission distance, when low current is suitable in your application. As distance increase current capacity of receiver will drop.



FEATURES

- Transmitter input voltage: 12v DC
- Receiver output voltage: 5v DC regulated fixed
- Maximum receiver current capacity: 1000 mA
- Coil inductance: 30uH
- Transmit receive distance: 1-20mm

APPLICATIONS

- Power grid
- Power mesh
- Mobile charging
- LED power

CHAPTER 5

5.1 SOFTWARE REQUIREMENT

Arduino is a prototype platform (open-source) based on an easy-to-use hardware and software. It consists of a circuit board, which can be programmed (referred to as a microcontroller) and a ready-made software called Arduino IDE (Integrated Development Environment), which is used to write and upload the computer code to the physical board.

The key features are:

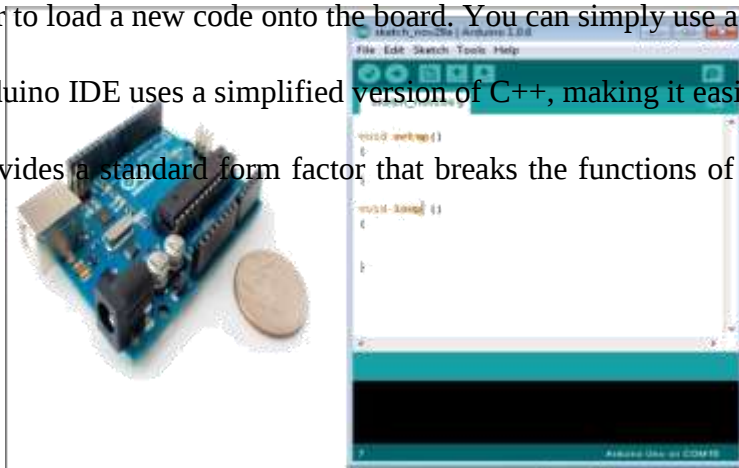
Arduino boards are able to read analog or digital input signals from different sensors and turn it into an output such as activating a motor, turning LED on/off, connect to the cloud and many other actions.

You can control your board functions by sending a set of instructions to the microcontroller on the board via Arduino IDE (referred to as uploading software).

Unlike most previous programmable circuit boards, Arduino does not need an extra piece of hardware (called a programmer) in order to load a new code onto the board. You can simply use a USB cable.

Additionally, the Arduino IDE uses a simplified version of C++, making it easier to learn to program.

Finally, Arduino provides a standard form factor that breaks the functions of the micro-controller into a more accessible package.



Step 1: First you must have your Arduino board (you can choose your favorite board) and a USB cable. In case you use Arduino UNO, Arduino Duemilanove, Nano, Arduino Mega 2560, or Diecimila, you will need a standard USB cable (A plug to B plug), the kind you would connect to a USB printer as shown in the following image.

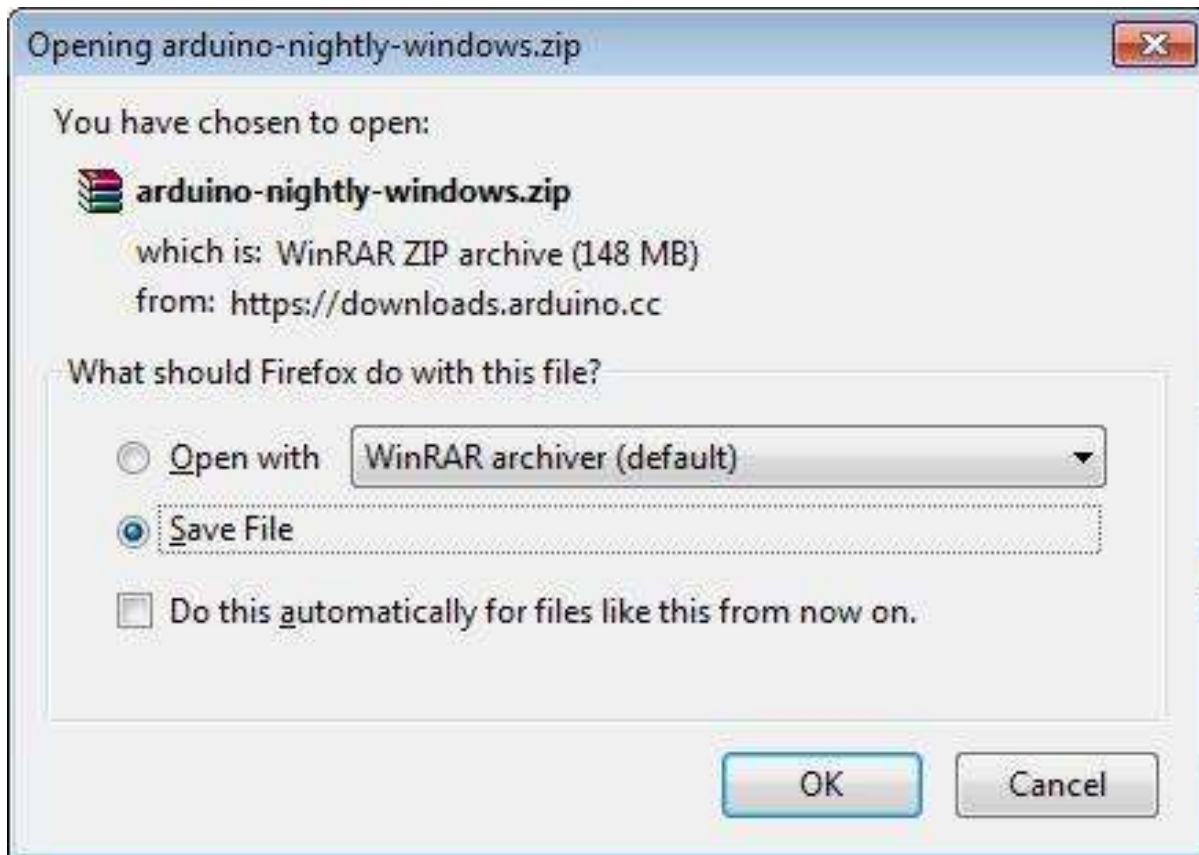


In case you use Arduino Nano, you will need an A to Mini-B cable instead as shown in the following image.



Step 2: Download Arduino IDE Software.

select your software, which is compatible with your operating system (Windows, IOS, or Linux). After your file download is complete, unzip the file.



Step 3: Power up your board.

The Arduino Uno, Mega, Duemilanove and Arduino Nano automatically draw power from either, the USB connection to the computer or an external power supply. If you are using an Arduino Diecimila, you have to make sure that the board is configured to draw power from the USB connection. The power source is selected with a jumper, a small piece of plastic that fits onto two of the three pins between the USB and power jacks. Check that it is on the two pins closest to the USB port.

Connect the Arduino board to your computer using the USB cable. The green power LED (labeled PWR) should glow.

Step 4: Launch Arduino IDE.

After your Arduino IDE software is downloaded, you need to unzip the folder. Inside the folder, you can find the application icon with an infinity label (application.exe). Double-click the icon to start the ID

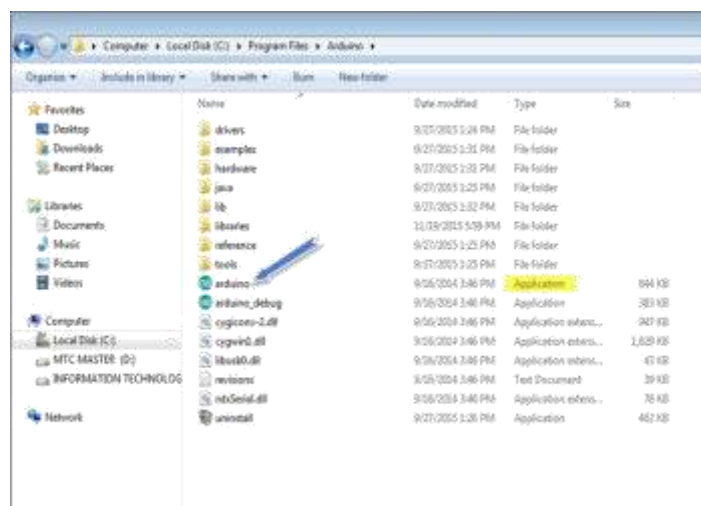
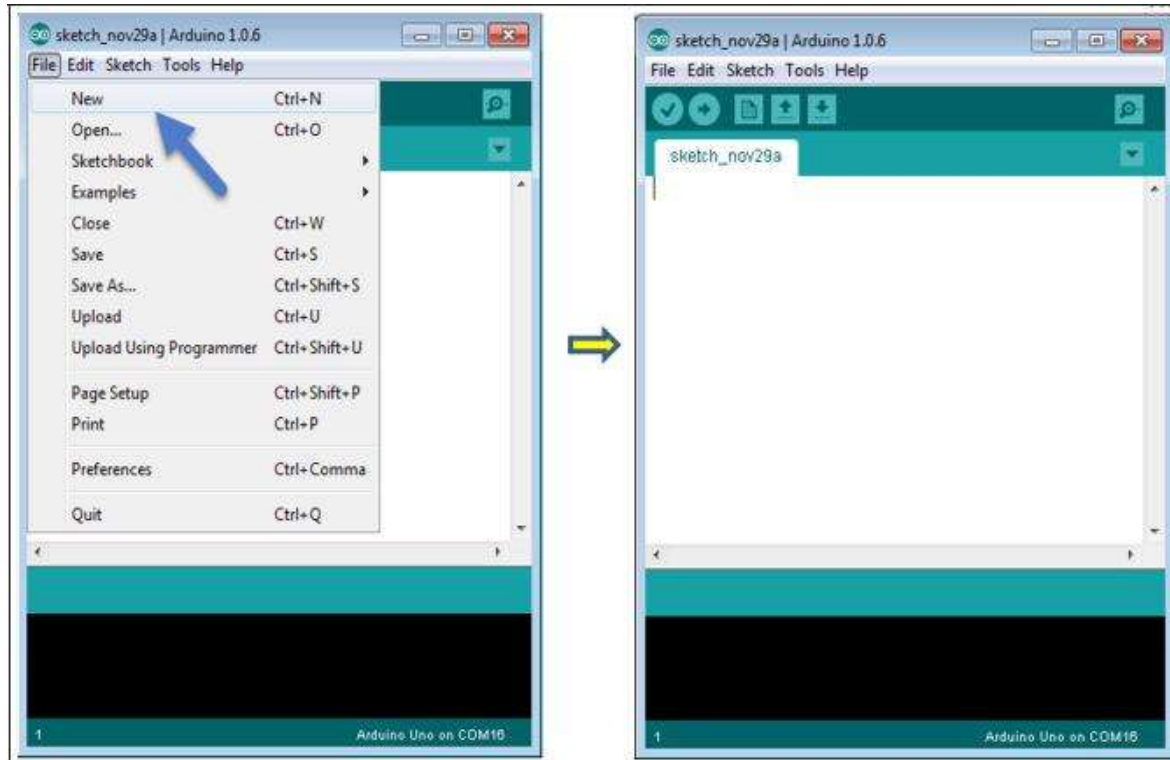
Step 5: Open your first project.

Once the software starts, you have two options:

Create a new project.

Open an existing project example.

To create a new project, select File --> New.



EMBEDDED C

The C programming language is a general-purpose, programming language that provides code efficiency, elements of structured programming, and a rich set of operators. C is not a *big* language and is not designed for any one particular area of application. Its generality combined with its absence of restrictions, makes C a convenient and effective programming solution for a wide variety of software tasks. Many applications can be solved more easily and efficiently with C than with other more specialized languages. The **Cx51** Optimizing C Compiler is a complete implementation of the American National Standards Institute (ANSI) standard for the C

language. **Cx51** is not a universal C compiler adapted for the 8051 target. It is a ground-up implementation dedicated to generating extremely fast and compact code for the 8051 microprocessor. **Cx51** provides you the flexibility of programming in C and the code efficiency and speed of assembly language. Since **Cx51** is a cross compiler, some aspects of the C programming language and standard libraries are altered or enhanced to address the peculiarities of an embedded target processor.

5.2.1 Compiling with Cx51

This explains how to use **Cx51** to compile C source files and discusses the control directives you may specify. These directives allow you to perform several functions. For example:

- Direct **Cx51** to generate a listing file
- Control the information included in the object file
- Specify code optimization and memory models

5.2.2 Running Cx51 from the Command Prompt

To invoke the C51 or CX51 compiler, enter **C51** or **CX51** at the command prompt. On this command line, you must include the name of the C source file to be compiled, as well as any other necessary control directives required to compile your source file.

The format for the **Cx51** command line is shown below:

C51 source file _directives..._

CX51 source file _directives..._

or:

C51 @command file

CX51 @command file

where:

source file is the name of the source program you want to compile.

directives are the directives you want to use to control the function of the compiler.

Command file is the name of a command input file that may contain *sourcefile* and *directives*. A *command file* is used, when the Cx51 invocation line gets complex and exceeds the limits of the Windows command prompt.

The following command line example invokes C51, specifies the source file

SAMPLE.C, and uses the controls **DEBUG**, **CODE**, and **PREPRINT**.

C51 SAMPLe.C DEBUG CODE PREPRINT

The **Cx51** compiler displays the following information upon successful invocation and compilation.

C51 COMPILER V6.10

C51 COMPILATION COMPLETE. 0 WARNING(S), 0 ERROR(S).

MATLAB

Matlab is a software program that allows you to do data manipulation and visualization, calculations, math and programming. It can be used to do very simple as well as very sophisticated tasks. We will start very simple.

Starting/quitting

To start Matlab, click on the ‘Start’ button on the left bottom of the screen, and then click on ‘All Programs’, then ‘Math and Stats’, then ‘Matlab’. A window will pop up that will consist of three smaller windows. On the right there will be a big window entitled ‘Command Window’. On the left there will be two windows, one entitled ‘Workspace’ and another one ‘Command History’.

In addition, on the top there is a usual bar with ‘File’, ‘Edit’, etc. headings. You can use these as you would in any other software (Word for example). Click on ‘File’ and look at the available commands there. Do the same for all the other headings. Note that the last heading is ‘Help’ (very useful!). Therefore, if you are stuck you know where to look.

To use Matlab, you will mostly be typing in the ‘Command window’. Click on the Command window. Its outline will become dark grey (that’s how you know that you can type into that window). A cursor will start blinking on a line right after ‘>>’ (this is called a prompt).

Let's start using Matlab by quitting it. In the Command window type quit (the letters should appear after the prompt) and hit enter. Matlab will close. Start Matlab again. Let's explore the Help bar. Look at the third option under the Help heading 'Using the Desktop'. Click on it. A Help window will come up with a list of topics describing the Desktop. Click on 'What Desktop Is'. On the bottom of the page that will come up you will find explanations of the buttons, windows and options available on the desktop. Scroll to the bottom. You will see text 'Drag the separator bar to resize window'.

Let's try that. Switch to the Matlab window. (To do this, look at the taskbar on the bottom of the screen and find an icon with a little orange and green hill on it that says 'MATLAB'. Click on it.) Move your mouse to the space between the 'Command window' on the right and the windows on the left. The mouse should take a shape of an arrow with two points. Press the left mouse button down and move the mouse left and right. This should move the boundary between the windows.

If you have questions about the desktop in the future, you can go to Help/Using the Desktop for the answers. However, the most useful help option under the Help heading for you now is the second option called 'MATLAB Help'. Click on it. This will take you to the main page of Matlab help. The categories are on the left, the main text is on the right.

You can always go to this page if you have a question.

Two very useful features on this page are 'Index' and 'Search'. These are bars on top of the left window that contains the categories. In the 'Index' you can search for available functions in Matlab. In fact, the Index is like an index at the back of a Matlab manual book. For example, click on the Index bar. In the window under 'Search index for:' type logarithm. The text on the window below will jump to the entry under 'logarithm'. It has several subheadings. Double click on the subheading 'natural' in that window. On the right you will get the description of the log function in Matlab, with syntax and example. The Index bar is very useful to look up the syntax of a function or to see if a particular Matlab function exists. Another useful Help feature is the Search bar (located to the right of the Index bar). That allows you to search Matlab documentation more thoroughly.

Therefore, if you cannot find something in the Index, you might want to try using Search. Close the Help window, and get back to the main Matlab window. Matlab as a super-calculator Click on the Command window. Type 2+3 at the prompt and then hit enter. The following will come up below the prompt: ans = 5. As you can see, you can use Matlab as a basic calculator (although that's not the most efficient use for it). Notice that there is a new entry in the top left window entitled 'Workspace'. There is now an entry ans there of size 1x1. ans is a variable. This means that it's a string of text that

has a value (number) assigned to it. To see this, type `ans` at the prompt and then hit enter. As you can see Matlab again returns `ans = 5`, i.e. it remembers that `ans` holds a value of 5. `ans` is a special name for a variable in Matlab. It is assigned the value of the answer to the expression that you type at the prompt.

You can create your own variables. For example, type in `x=10`. Now Matlab has another entry in the ‘Workspace’ window called `x`. Now if you type `x`, Matlab will know that its value is 10. For example, type `x+5`. Matlab will give you the correct answer 15. Matlab has all the math functions that a calculator may have and many more. For example, you can find `x^2`. Here, we need to learn a bit of notation. To raise `x` to the power of 2 in Matlab you type `x.^2`. You will get, predictably, 100 since you assigned a value of 10 to `x`. Among the most familiar functions, Matlab has `sin`, `cos`, `exp`, `log` functions. For

example, to find `e^2`, you type `exp(2)`. You should get 7.3891. As you can see, to use a function, you put the argument of the function in the parentheses after the function name (without a space between them). Matlab as a mathematical tool

So far we have used common mathematical functions. However, Matlab allows you to define (and evaluate) your own functions as well. For example, let's define a function `f(x)=x^2+1`. To do this, simply type in `f=x.^2+1`. Since `x` has a value of 10, the answer is 101. You can now change the value of `x`. For example, type `x=5` and enter, then type

`f=x.^2+1` again. You should now get 26.

However, you don't want to type the expression for `f(x)` every time you want to change the value of `x`. You might want to define a function `f(x)` for a range of values of `x`. To do this in Matlab we need to make `x` be a range of values. For example, suppose we want to make `x` to go from 1 to 10. To do this in Matlab, you type `x=1:10`. You will get

`x =`

`1 2 3 4 5 6 7 8 9 10`

as a result. Now, `x` is a list of values from 1 to 10. If we now type `f=x.^2+1`, we will get 10 values of `f` for each value of `x`. In other words, we have defined `f` as a function of `x`.

Right now the difference between two consecutive values of `x` is 1. To change this, we put the step between two consecutive values between the maximum and minimum values,

i.e. type `x=1:0.5:10`. You will get

`x =`

Columns 1 through 8

1.0000 1.5000 2.0000 2.5000 3.0000 3.5000

4.0000 4.5000

Columns 9 through 16

5.0000 5.5000 6.0000 6.5000 7.0000 7.5000

8.0000 8.5000

Columns 17 through 19

9.0000 9.5000 10.0000

Now `x` still ranges from 1 to 10, but now it takes on 19 values with a step of 0.5. Since we redefined `x`, we now need to redefine `f(x)` as well. This means that we must again type `f=x.^2+1`. `f(x)` now has 19 values as well.

Plotting basics

One thing we want to do to with functions is plot them. Matlab is a very good tool for that. For example, to plot `f` as a function of `x`, type `plot(x,f)`. A new window will come up with a plot of `f(x)` as a function of `x`. Matlab has many features for plotting. We will now learn a few of them. First of all we want to define our axes. This is very simple to do. To define the `x`-axis, type `xlabel('x')` in the Command window. Now switch to the window with the figure. You will see a label on the `x`-axis. Let's do the same for the `y`-axis. Predictably, to do this you need to type `ylabel('f(x)')`. Now, if we want to put a title on our graph the command is `title('Function f')`. As you can see, a lot of the commands are quite intuitive.

Matlab as a tool for data analysis

What about looking at data in Matlab? Usually, data comes in tables. For example, you

could have some observation as a function of time, such as the average temperature as a function of a month. This data will have two columns, one for the month and another for the value of a temperature. Or you could have several replicates on an experiment where the average weight of some organisms was observed in environments with different food levels. This data can be recorded as a table with the number of rows equal to the number of replicate experiments and the number of columns equal to the food levels tested.

A mathematical term for a table is a matrix. (From now on you can understand the term matrix as table.) Matlab deals with matrices very well. Let's create a matrix of ones in Matlab. To do this, we need to know how many rows and columns we want in a matrix. Suppose we want to create a matrix of ones with 2 rows and 3 columns. To do this, type `ones(2,3)`. The Matlab will return

ans =

1 1 1

1 1 1

Suppose we want to store this matrix in a variable. To do this, type `M=ones(2,3)`. Now, M will appear in the Workspace window (notice that its size, 2 by 3, is also stated). The size of a matrix is often referred to as its dimensions. For example, M is 'a matrix of dimensions 2 by 3' or simply 'a 2 by 3 matrix'.

Whenever you want to change a variable or remove a variable, you can use command `clear`. If you type `clear M`, this will remove M from the Workspace. Try it. Anytime that you have made a mistake defining a variable or a function, or when you reuse the same variable name, it is a very good practice to use the `clear` command. If you want to get rid of all the variables in your Workspace, you can simply type `clear`.

You can also construct your own matrix by typing it in. For example, if you type

`M=[2,5;9,7; 4,3]`, you will get a 3 by 2 matrix:

2 5

7

9 7

4 3

As you can see, to define a matrix in Matlab, you surround the entries by square brackets. Commas separate column entries and semicolons separate row entries. To look at the whole first row of the matrix M, you type `M(1,:)`. Here, the colon means ‘show me all the entries in the row(s) indicated’. To look at the whole second column, you type `M(:,2)`. If you want to see only the second and third rows of M, you type `M(2:3,:)`.

Let’s work on an example. Suppose you have observations of average temperature as a function of month. Let’s generate the data to represent that. As we do this, we will learn several more useful function of Matlab. First, we need to generate a column of months. We already generated a row of numbers from 1 to 10 in the previous section. Now, we need to make a column. Notice that a row is just a matrix of dimensions 1 by n (where n is the length of the row). Similarly, a column is a matrix of dimensions n by 1. These are called vectors. Since we know how to make a row, let’s start with that. Type

```
month=1:12. You will see
```

```
month =
```

```
1 2 3 4 5 6 7 8 9 10
```

```
11 12
```

To make this row into a column, we will transpose it. To transpose a matrix means to flip the values in the matrix so that the first row becomes the first column, the second row becomes the second column etc. Therefore, if you transpose a row, you will get a column. To do this type `month=month’`. The apostrophe tells Matlab to transpose month. You will get

```
month =
```

```
1
```

```
2
```

```
3
```

4

5

6

8

7

8

9

10

11

12

This is what we wanted. Now, we need to generate values of average temperature for each month. For educational purposes, we will do this naively by picking random numbers between 0 and 80. Matlab provides a convenient function `rand` to generate random numbers between 0 and 1. Try it by typing `rand` at the prompt several times. You will get a different number from 0 to 1 every time. To generate random values between 0 and 80, we can multiply a random number between 0 and 1 by 80. To do this type `80*rand`. Now, we need to generate 12 of these numbers. There are several ways of doing this, we will learn two of them. (In fact, there are several ways of doing almost everything in Matlab. As long as you can do it any one way, it will suffice for most work that you will be doing in the course.)

We need to generate 12 random numbers between 0 and 80. We know how to generate one of them (the command is `80*rand`). Now, we need to string them together. To do this, we will use a new variable called `temp` (for temperature). `temp` should be a column. A column is a matrix of dimensions `n by 1`. Therefore, the first entry in the variable `temp` will be located in the first row and first (and only) column. To express this in Matlab type `temp(1,1)=80*rand`. The second entry in the column will be located in the 2nd row and 1st column, therefore type `temp(2,1)=80*rand`. You will get the answer giving

two random values stored in temp. MATLAB is started by clicking the mouse on the appropriate icon and is ended by typing exit or by using the menu option. After each MATLAB command, the "return" or "enter" key must be depressed.

A. Definition of Variables

Variables are assigned numerical values by typing the expression directly, for example, typing

```
a = 1+2
```

yields: **a = 3**

The answer will not be displayed when a semicolon is put at the end of an expression, for example type **a = 1+2;**.

MATLAB utilizes the following arithmetic operators:

+ addition

- subtraction

* multiplication

/ division

^ power operator

' transpose

A variable can be assigned using a formula that utilizes these operators and either numbers or previously defined variables. For example, since a was defined previously, the following expression is valid

```
b = 2*a;
```

To determine the value of a previously defined quantity, type the quantity by itself:

```
b
```

yields: **b = 6**

If your expression does not fit on one line, use an ellipsis (three or more periods at the end of the line) and continue on the next line.

c = 1+2+3+...

5+6+7;

There are several predefined variables which can be used at any time, in the same manner as user-defined variables:

i sqrt(-1)

j sqrt(-1)

pi 3.1416...

For example,

y= 2*(1+4*j)

yields: **y = 2.0000 + 8.0000i**

There are also a number of predefined functions that can be used when defining a variable. Some common functions that are used in this text are:

abs magnitude of a number (absolute value for real numbers)

angle angle of a complex number, in radians

cos cosine function, assumes argument is in radians

sin sine function, assumes argument is in radians

exp exponential function

For example, with y defined as above,

c = abs(y)

yields: **c = 8.2462**

c = angle(y)

yields: **c = 1.3258**

With $a=3$ as defined previously,

$$c = \cos(a)$$

yields: $c = -0.9900$

$$c = \exp(a)$$

yields: $c = 20.0855$

Note that $\exp$ can be used on complex numbers. For example, with $y = 2+8i$ as defined above,

$$c = \exp(y)$$

yields: $c = -1.0751 + 7.3104i$

which can be verified by using Euler's formula:

$$c = \exp(2)\cos(8) + je(\exp)2\sin(8)$$

Conclusion

The Bidirectional Wireless Charging Station for Electric Vehicles Using Road-Integrated Solar and Piezoelectric Energy Harvesting with Cantilever Technique represents a major step toward achieving sustainable and intelligent transportation infrastructure. By integrating renewable energy sources—specifically solar and piezoelectric harvesters—into the charging ecosystem, the system significantly reduces reliance on grid electricity while maximizing energy efficiency through smart energy management. The incorporation of bidirectional wireless power transfer (WPT) enables both convenient, contactless charging and Vehicle-to-Grid (V2G) energy exchange, enhancing grid stability and supporting renewable integration.

The use of road-embedded solar panels ensures a steady generation of clean energy throughout the day, while piezoelectric cantilever harvesters capture additional mechanical energy from vehicle-induced vibrations, supplementing the system's power requirements for sensors and control circuits. The Energy Management System (EMS) intelligently coordinates harvesting, storage, and power flow to maintain optimal performance and reliability. Although challenges remain—such as improving the durability of road-integrated modules, enhancing piezoelectric output, and minimizing WPT losses—this design offers a scalable and future-ready

solution for next-generation EV infrastructure. Overall, the proposed system promotes eco-friendly mobility, enhances energy self-sufficiency, and contributes to the development of a smart, resilient, and green transportation network.

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