SIGNBOT: Real-Time Speech to Gesture Converter

MINI PROJECT REPORT

Submitted in partial fulfillment of the
Requirements for the award of Bachelor of Technology Degree
In Electronics and Communication Engineering
Of APJ Abdul Kalam Technological University

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CERTIFICATE

This is to certify that this mini project report entitled **"SIGNBOT:Real-Time Speech to Gesture Converter"** is a bonafide record of work done by **Adwaith S. Kumar, Aiswarya V, Anand Prakash and Anaz Muhammad** of the sixth semester Electronics and Communication branch towards the partial fulfillment of the requirements for the award of Bachelor of Technology Degree in Electronics and Communication Engineering of APJ Abdul Kalam Technological University.

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ABSTRACT

Most bionic hands today rely on sign language interpreters or text-based software to convert sign language into text or speech. However, these systems have several drawbacks, including high costs, limited accessibility, delayed real-time responses, and a lack of physical gestures. Many existing solutions only display virtual gestures rather than producing actual hand movements, making communication less effective for individuals who rely on sign language. To address this issue, we propose a robotic hand that converts spoken words into sign language gestures. A mobile application captures voice input and converts it into text, which is then transmitted wirelessly to a control board. The control board processes the text and controls servo motors in the robotic hand, enabling it to replicate sign language gestures in real time. This approach offers a more accessible and interactive way to bridge communication gaps for the hearing and speech impaired.Our project met our expectations by successfully converting voice input into sign language gestures using a robotic hand. Clear, precise hand movements facilitated natural communication. This solution is both simple and affordable, and it could potentially help people who use sign language to communicate with others.

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CHAPTER-1

INTRODUCTION

Picture yourself attempting to communicate with others, but your inability to speak or listen makes it difficult to be understood. The daily routine of numerous individuals with deafness or speech difficulties is a challenge. The tools and technologies available may be helpful but are often too impersonal or inconvenient. Sign language interpreters and text-based systems are expensive, difficult to find or access, and may not provide the real-time connection needed for people to express themselves.

Although most systems attempt to translate sign language into spoken text or spoken language, they overlook the essential humanistic gestures of hand. The absence of this factor can cause communication to become distant and disconnected. This is where SignBot comes in.

The original idea behind SignBot was to help deaf and speech impaired people communicate more easily, naturally, and in real time. SignBot not only transforms words into text but also converts them into tangible sign language gestures, enabling people to communicate with anyone they desire. Communication should be more personal, inclusive, and authentic in nature, rather than being solely based on technology.

We created this tool to bring people closer together, ensuring that communication is effortless and inclusive. No one should feel unheard or disconnected—technology should break down barriers, not build them. By making interactions feel natural and engaging, we strive to bridge the gap between those who can hear or speak and those who may face challenges.

With SignBot, the aim is simple: to make people feel included, connected and understood without any barriers. Through the use of SignBot, a technology-enabled app that blends sign language with its aesthetic appeal, it seeks to revolutionize the way people with hearing or speech impairments can communicate.

1.1 Key Features and Benefits:

- **Quick Response Time:** The system reacts instantly to inputs, making communication feel natural and in sync**.**
- **Microcontroller-Based Control System:** At the heart of the system is a control board (like an ESP8266) that interprets signals and tells the hand what to do.
- **Real-Time Communication:** Converts spoken words into sign language gestures instantly, making conversations faster and more natural.
- **Cost Effective Solution:** Uses affordable components like ESP8266 and 3-D printed parts making it more accessible.
- **Precise Movement with Servo Motors:** Servo motors allow for accurate, controlled motion of the fingers, helping the bionic hand perform tasks similar to a human hand.
- **Customizable and Scalable:** SignBot isn't just a one-size-fits-all solution, it can grow and change as you need it to. Whether you need more accurate gestures or extra features for the app, it's easy to upgrade or customize. As you use it, it can evolve with you, ensuring it meets your needs and improves over time .
- **User-Friendly Interface:** The app is super easy to use! All you have to do is speak, and the system takes care of the rest. You don't need any technical knowledge, just talk into your phone, and watch the robotic hand sign your words in real time. It's simple, intuitive.
- **Promotes Social Interaction and Reduces Isolation:** SignBot helps you stay connected. When you can communicate easily, you feel more included in conversations and less isolated. It's great for socializing with friends or joining conversations at work or school. The more we understand each other, the stronger the community becomes.
- **Stable Power Supply:** A 12V power source keeps the system running, with a voltage regulator making sure each part gets just the right amount of power.

CHAPTER-2

TECHNOLOGY IN GENERAL

Our project uses simple technology to help people with hearing or speech impairments communicate easily. By turning spoken words into sign language gestures with a robotic hand, it makes conversations more natural and inclusive, helping users feel more confident and connected.

2.1.Block Diagram:

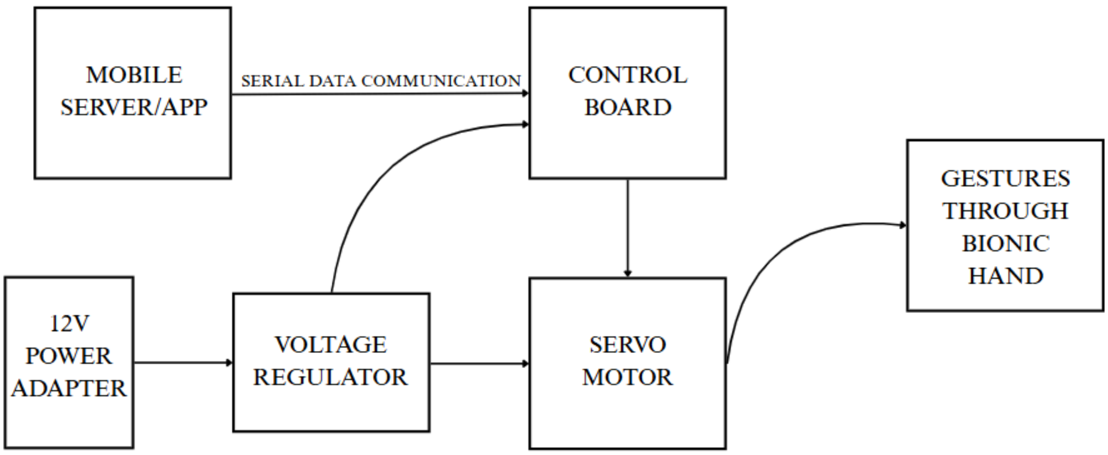

Fig 2.1: Block diagram of our bionic hand system

This diagram shows how a bionic hand system works in a simple and organized way. It all starts with a 12V power supply that gives energy to the system. Since not all parts can handle that much power directly, a voltage regulator steps in to adjust it to the right level. A mobile server, like an app or device ,sends commands to the control board using serial data communication. The control board acts like the brain, understanding the instructions and telling the servo motor what to do. The motor then moves the bionic hand based on those instructions.

2.2. Explanation

The SignBot system is a practical solution that bridges communication gaps for individuals with speech or hearing impairments by replicating sign language gestures in real time. It begins with a mobile server that takes spoken input and converts it into text using speech-to-text technology. This text is then transmitted to the ESP8266 microcontroller through a wireless connection.The microcontroller processes the received text and maps it to predefined gestures stored in its database. It then generates signals to control the servo motors that move different parts of the robotic hand, such as fingers and the wrist, allowing it to accurately replicate sign language gestures.

The ESP8266 microcontroller acts as the processing unit of the system. It interprets the text data and matches it to preconfigured sign language gestures stored in its database. Using servo motor control, the microcontroller sends precise instructions to the robotic hand, enabling it to perform the necessary gestures. Each servo motor manipulates specific parts of the hand, such as individual fingers or the wrist, ensuring accurate movements that replicate human sign language.

The robotic hand, made from lightweight and durable materials, serves as the system's output, performing precise gestures to convey the intended message. For enhanced accuracy, optional sensors in the robotic hand can verify the gestures and send feedback for fine-tuning if necessary. This system provides a reliable, real-time communication tool that helps individuals interact effectively in various situations.

- **Mobile Server:** It is the remote controller. It could be a smartphone, app, or computer that sends commands to the system. These commands are sent in the form of serial data, basically telling the bionic hand what action to perform.

- **Voltage Regulator:** The voltage regulator takes the 12V input and steps it down to a safer level that can be used by the control board and servo motor. It ensures that each component receives just the right amount of power it needs to function properly without getting damaged.

- **ESP8266 Control Board:** The ESP8266 microcontroller serves as the command hub. It interprets wireless input, like voice or text data received via Wi-Fi, and processes these commands to generate control signals. These signals direct the servo motors to move specific parts of the robotic hand. Additionally, it manages wireless communication for seamless interaction with external devices and coordinates power distribution and feedback from sensors.

- **Servomotor:** Servo motors in a bionic hand control precise movements of the fingers and wrist by responding to electrical signals from the control board. They ensure accurate and smooth gestures essential for mimicking natural hand motions. Their compact design and reliability make them ideal for real-time, responsive operation.

- **Power Supply:** The power supply offers an electric that enables the hand to operate.It powers the sensors,servo motors and microcontrollers. Typically a 12V DC power supply.

- **Bionic Hand:** The device that performs the required movements based on the input given.

CHAPTER-3

TECHNOLOGY IN SPECIFIC

A bionic hand is a robotic device designed to replicate human hand movements with precision, assisting individuals with disabilities. Technically, it integrates microcontrollers to process commands, sensors to detect inputs, and servo motors for precise movement control, all powered by a regulated energy source for seamless functionality.

3.1.Microcontroller

3.1.1 ESP8266: ESP8266 microcontroller is a 32 bit processor for task based processing, sensors and actuators and ability to efficiently process commands and control devices. The key features include:

- Operating frequency is 80MHz-160MHz
- Built in WiFi and Bluetooth connectivity
- Multiple GPIO pins for interfacing with sensors and actuators
- Includes up to 128KB RAM and 4MB Flash storage
- ADC(Analog to DigitalConverter)for reading analog signal

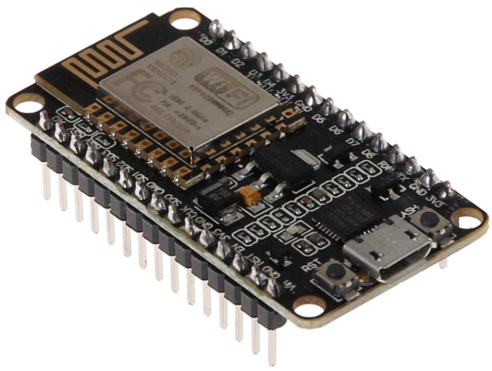

Fig. 3.1.1: ESP8266

3.2. Servo Motor

3.2.1 MG996R: MG996R servo motor makes it a popular choice for projects that require high-torque applications, such as robotics and automation. When it comes to designing precise, this is a perfect balance of strength and speed Key features include:

- Voltage range : Operates between 4.8V and 7.2V
- Rotation range: Supports 0° to 180° movement for precise control.
- Provides torque up to 11 kg/cm

Fig 3.2.1: MG996R Motor

3.3. LM2596S DC-DC Buck Converter

The LM2596S DC-DC buck converter is a device for regulating voltage, commonly used to step down a higher voltage to a stable lower voltage. Safety features like short-circuit protection and thermal shutdown make it reliable for various applications like battery management and power systems. Key features include:

- Input range of 3.2V to 40V
- High Efficiency

Fig 3.3.1: LM2596S DC-DC Buck Converter

3.4.Power Supply

The power supply offers an electric that enables the hand to operate.It powers the sensors,servo motors and microcontrollers. Typically a 12V DC power supply.A 12V adapter is used to power the devices. It converts AC power to DC power, providing a stable 12V output for reliable operation.

Fig 3.4.1: 12V Adapter

3.6. Data Communication

3.6.1 Wi-Fi connectivity: It has a built-in Wi- Fi module that connects the system to the internet. This wireless communication is important for monitoring and control.ESP8266 has a built-in Wi-Fi module that gives our system the ability to "talk" over WiFi. Our mobile app can communicate with the robotic hand without any cables or wires. It provides real-time communication by either connecting to the internet or creating its own hotspot. The wireless setup is beneficial for both preserving neatness and portability, as well as making it effortless to monitor and control the system from a phone or other device at any time. The whole thing feels seamless, cleverly designed and effortless to navigate

CHAPTER - 4

HARDWARE IMPLEMENTATION

The main purpose of a bionic hand is to help individuals with hand disabilities regain functionality and independence in their daily lives. Here is an overview of the components required for the system.

4.1. List of Components

- ESP8266: ESP8266 allows devices to connect to the internet and communicate without cables. The device's technical advantages include its small size, low power consumption, real-time data processing, making it a match for IoT and automation systems.

Applications-

Wireless Communication: Facilitates data transfer in real-time, such as in weather stations or health devices.

Security Systems: Supports remote control features in cameras, alarms, and other safety devices.

Web Server Functionality: Hosts interfaces for remote control and monitoring of devices.

Educational Projects: Popular among enthusiasts for learning embedded systems and IoT development.

- Servo Motor -MG996R: The servo motor MG996R is widely used for high torque.Its durability and reliable performance make it a good fit for projects that require controlled movement. It has a torque capacity of up to 11 kg/cm at 6V, supports rotation from 0° to 180°, and is constructed with long-lasting metal gears. Its ability to operate at a steady speed, even with higher loads, makes it an ideal choice for systems that are complex and dynamic.

- Voltage Regulator- LM2596S: The LM2596S ,it efficiently steps down voltage while maintaining stable output, which is crucial for powering sensitive components. Technically, its wide input range of 3.2V to 40V and adjustable output voltage from 1.5V to 35V make it versatile for various power sources. With a high efficiency of up to 92%, 3A current capacity, and built-in protections like thermal shutdown and short-circuit prevention, it ensures reliability and safety for powering the system.

- Power supply and Adapter: A 12V adapter is used to power the devices.They provide the necessary power to components, ensuring stable and reliable operation. The power supply must be chosen to match the voltage and current requirements of the system components.

- Connecting wires: Connecting wires are like the nerves of our bionic hand—they help all the parts talk to each other and work together. They carry signals and power between the microcontroller, motors, and other components, making sure everything moves and responds as it should. Without them, the hand simply wouldn’t work.

- Bionic Hand: The bionic hand brings the system to life by showing real-time sign language gestures. After the voice input is processed, the hand moves using servo motors to form the correct signs. It helps visually communicate words, making it easier for people with hearing or speech impairments to understand—almost like the hand is "speaking" through gestures.

- Foam Board: A foam board is a lightweight material used for organizing components in DIY electronics projects. It provides a stable platform to secure and display components,making the system more presentable and easier to manage.

4.2 Circuit Diagram

Our circuit brings the SignBot to life. It uses the ESP8266 to receive voice commands from a mobile app over Wi-Fi. These commands are then used to move servo motors that control a robotic hand, forming real-time sign language gestures. A power supply keeps everything running smoothly.

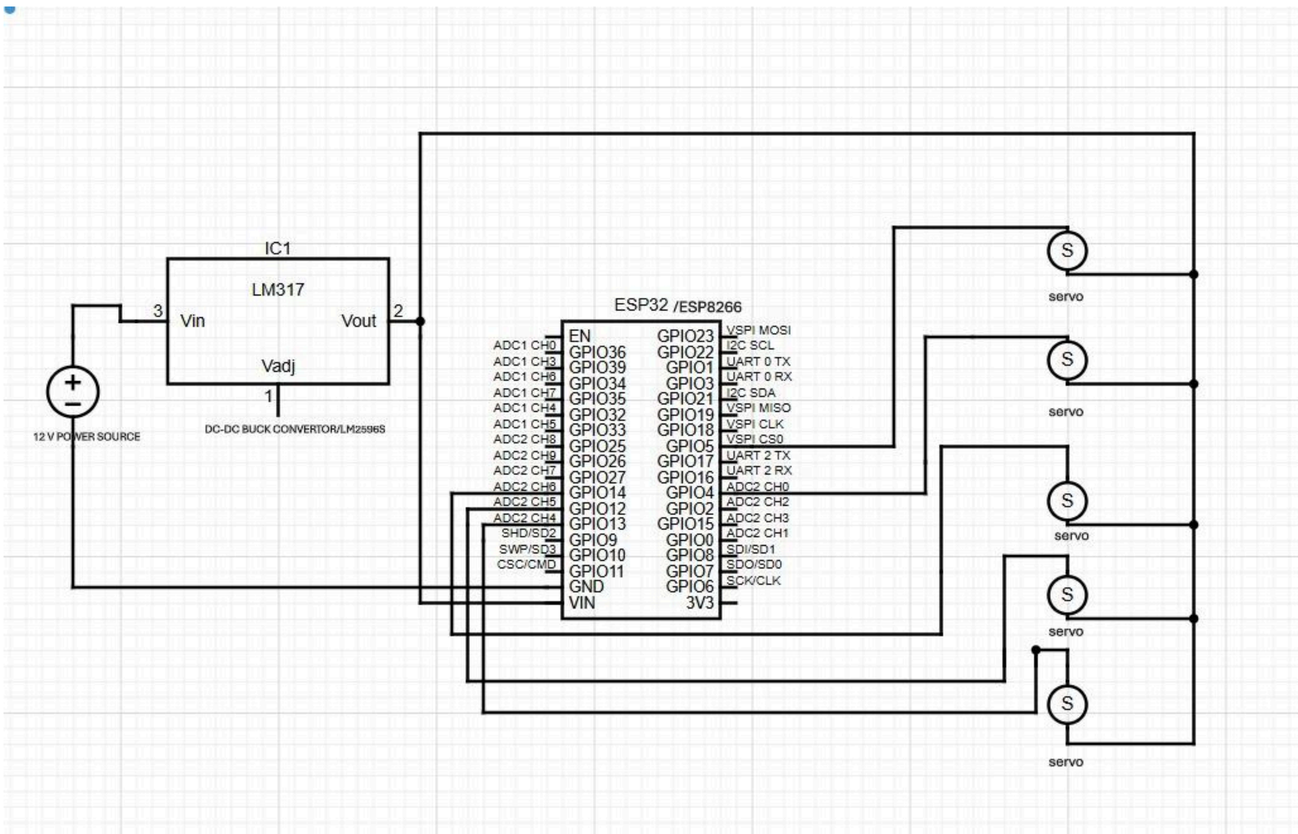

Fig 4.1: Circuit diagram of the Hardware

Connections:

4.2 Hardware Connections

- **ESP8266 (NodeMCU):**

  VIN Pin: Connect to the +5V output of the power supply board.

  GND Pin: Connect to the common ground (GND) of all components.

  D1 to D7 GPIO Pins: Used to control the five MG996R servo motors (Thumb, Index, Middle, Ring, Pinky).

  Each servo's signal wire is connected to one GPIO pin (e.g., D1 to D5).

  D6 and D7 can be used for additional fingers or future extensions.

- **WiFi Communication:** ESP8266 acts as a web server or access point to receive gesture/letter commands from the mobile app developed using MIT App Inventor.

- **Power Supply Board:**

  Input: Connected to the AC mains supply.

  Output Terminals:

  +5V Output: Powers ESP8266 and the servo motors.

  +12V Output (optional): Can be used for future expansions or relay modules.

  GND: Connects to all GND pins of components for a common ground.

- **MG996R Servo Motors:**

  Signal Wires : Connected to ESP8266 GPIO pins (D1–D5).

  Power Wires (VCC): Connected to +5V from the power supply board.

  Ground Wires (GND): Connected to the common GND of the power supply board.

- **MIT App Inventor Interface (Mobile App):**

- The mobile phone connects to ESP8266 via WiFi (ESP8266 in Access Point or Station mode).
- Commands (such as ASL letters) are sent as HTTP GET requests to ESP8266.
- ESP8266 parses the request and activates corresponding servo positions for sign language gestures.

4.3.Working:

4.3.1 Gesture Input and Data Collection

- The user interacts with a custom-built mobile application developed using MIT App Inventor.
- The app provides buttons or voice input that converts speech to text, corresponding to ASL letters.
- The selected letter is sent as a command string via WiFi to the ESP8266 module acting as a web server.

4.3.2 Data Reception and Processing

- The ESP8266 receives the command through HTTP GET requests sent by the mobile app.
- Upon receiving the letter, the ESP8266 maps it to a specific set of servo angles representing that letter in American Sign Language (ASL).
- These mappings are predefined in the firmware running on the ESP8266.

4.3.3 Servo Control and Gesture Display

- The servo motors (MG996R) embedded in the 3D-printed bionic hand receive angle values via PWM signals from ESP8266 GPIO pins.

- Each motor (for Thumb, Index, Middle, Ring, and Pinky) moves to a specific position to form the shape of the corresponding ASL letter.
- The hand physically displays the gesture based on the real-time command from the mobile app.

4.3.4 Real-Time Feedback and Looping

- The system shows one letter at a time with a delay for visibility.
- A serial monitor (optional) can be used to display which letter is being executed.
- The hand resets or continues to the next command as per the app's input.

4.3.5 Communication and Mobile Integration

- The ESP8266 runs in Access Point mode, creating a local WiFi network.
- The mobile device connects to this network and sends control data.
- The communication is wireless and real-time, offering flexibility and ease of use.
- No external internet is needed; communication is local through WiFi.

CHAPTER-5
SYSTEM IMPLEMENTATION

A compact 3D-printed robotic hand is paired with a user-friendly mobile app by our system. Users can input speech or text into the app, which is then transmitted to the ESP8266 via WiFi. The microcontroller is used to drive servo motors and display real-time sign language gestures. It's lightweight, easy to carry around and crafted for smooth, fluid flow.

5.1 Algorithm

5.1.1 System Initialization

ESP8266 Setup:

- Initialize WiFi in Access Point (AP) mode.
- Start a web server on ESP8266 (e.g, at 192.168.4.1).
- Initialize servo motors connected to D1-D7 (Thumb to Pinky).

5.1.2 Mobile App / Web Interface

- Connect mobile devices to ESP8266's WiFi.
- Open a web page hosted by ESP8266 to input or receive translated text.
- Use mobile mic - Google Voice Input - Convert to text.
- Send recognized text or individual letters to ESP8266 via HTTP (GET or POST).

5.1.3 Mobile Application

- On receiving HTTP requests.
- Parse the request for a valid letter (A-Z).
- Call a function to show the corresponding ASL gesture by controlling servos.

5.1.4 Robotic Hand Action

- Function shows ASL (letter) adjusts servo angles to mimic the ASL gesture of the received letter.
- Display each letter for a fixed delay (eg, 2 seconds).
- Optionally reset hand to neutral position after gesture.

5.1.5 Loop

- Loop for continuous letters (like in words), or wait for the next request if showing single letters.

5.2 Flowchart

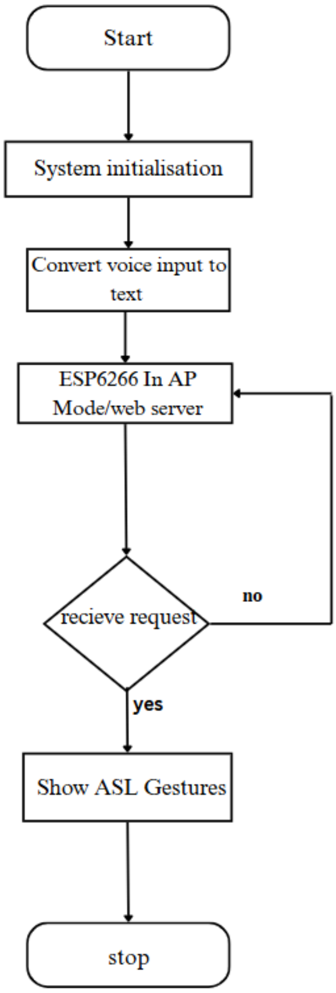

Fig 5.1: Flowchart of the Workflow

5.3 System UI Design

5.3.1 App Interface

The app has a simple, easy-to-use interface. Users press a microphone button to speak, and the app converts their speech into text. This text is then sent to the robotic hand via Wi-Fi, which performs the corresponding sign language gesture. The design is clean and straightforward, making communication quick and intuitive.

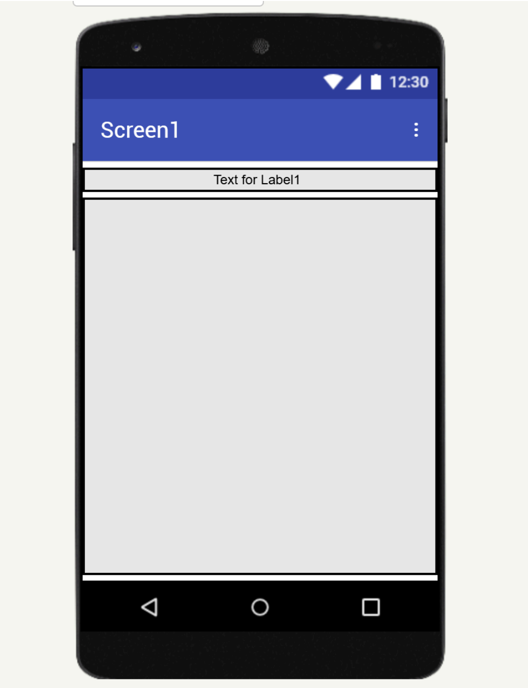

Fig 5.3.1 App interface

5.3.2 System Working

Our mobile app is designed to make communication easy and intuitive. When a user opens the app, they simply tap a button and speak a word or letter. The app listens, turns the speech into text, and sends it to the robotic hand through WiFi. The robotic hand interfaced with the ESP8266 chip, instantly understands the message and moves its fingers to show the right sign language gesture. It all happens in real time, helping people with hearing or speech difficulties connect with others in a smoother, more natural way.

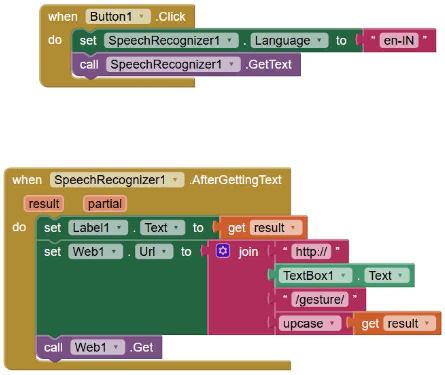

Fig 5.3.2 App Design Block code

5.4 Product Dimensions

5.4.1 Index Finger

Fig 5.4.1: Design of Index Finger

Dimensions: Length = 7 cm

Breadth = 2 cm

5.4.2 Middle Finger

Fig 5.4.2: Design of Ring Finger

Dimensions: Length = 9 cm
Breadth = 3 cm

5.4.3 Pinky Finger

Fig 5.4.3: Design of Pinky Finger

Dimensions: Length = 5 cm

Breadth = 1 cm

5.4.4 Ring Finger

Fig 5.4.4: Design of Ring Finger

Dimensions: Length = 7 cm

Breadth = 2 cm

5.4.5 Thumb

Fig 5.4.5: Design of Thumb

Dimensions: Length = 4 cm

Breadth = 3 cm

5.4.6 Right Hand Palm

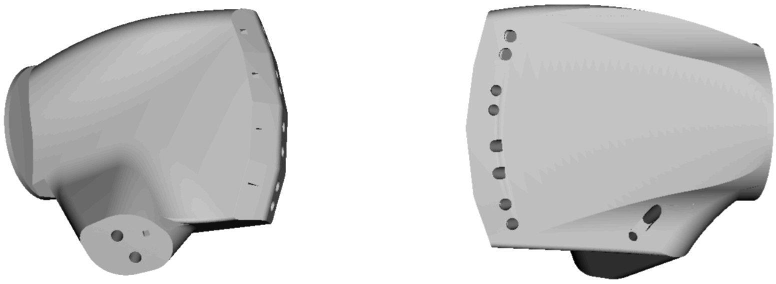

Fig 5.4.6: Design of Right hand palm

Dimensions: Length = 5 cm - 7 cm

Breadth = 10 cm

5.4.7 Foam Board

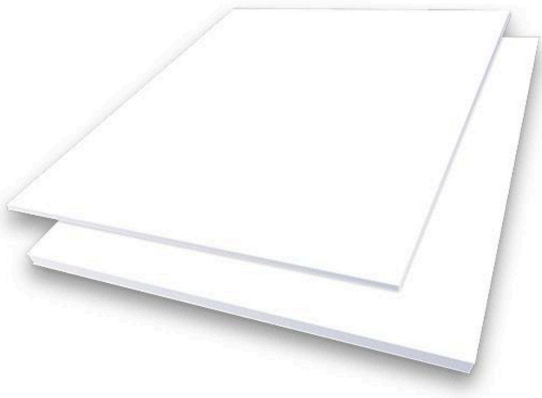

Fig 5.4.7: Foam Board

Dimensions: Length = 15 cm

Breadth = 10 cm

5.4.8 Final Product

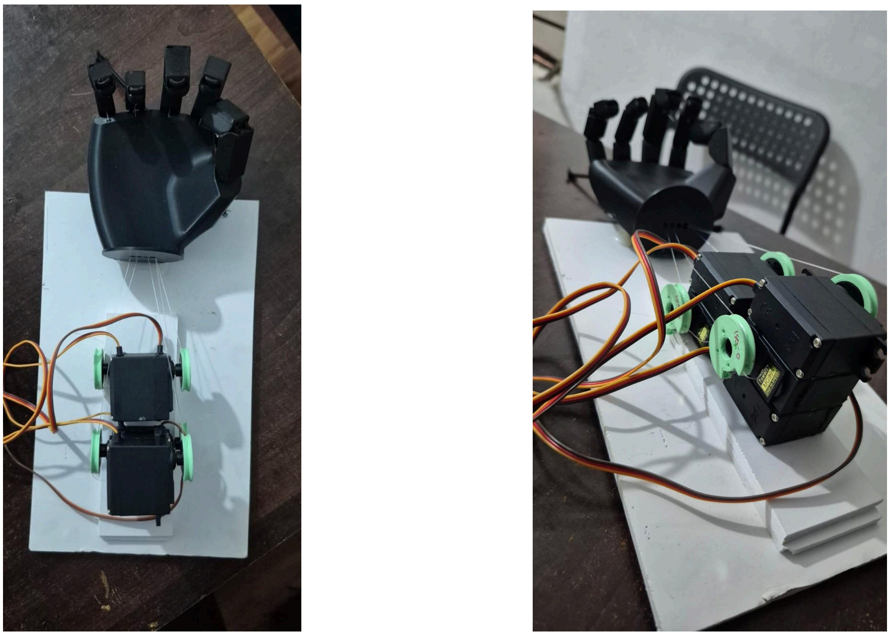

Fig 5.4.8: Image of Final Product

Dimensions: Length = 29 cm

Breadth = 10 cm

CHAPTER-6

DESIGN AND INTEGRATION

To avoid messy wires and unstable connections, we created a custom Printed Circuit Board (PCB) for our project. This helps keep everything organized and allows all components to be connected neatly in one place.

The PCB has a **c**ommon ground (GND) and common VCC (power) line. This means that all the parts , like the microcontroller, servos, and sensors , share the same power source and grounding. This setup avoids voltage issues and helps the system work smoothly.

To hold the ESP8266 on the board, we soldered header pins onto the PCB. This makes it easy to plug in or remove the microcontroller when needed. It's a clean and reusable way to mount the ESP8266.

Using a custom PCB makes our project look more professional, reduces errors, and keeps everything in place. It also makes it easier to fix or upgrade parts in the future. Overall, the PCB is a big help in making our SignBot reliable and user-friendly.

6.1 Desired Final Output

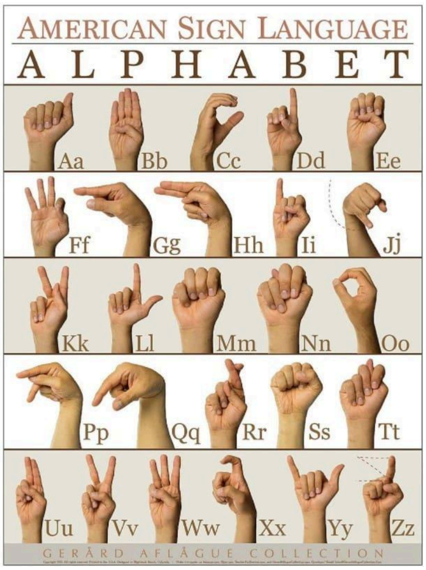

Fig 6.1: The desired output is above displayed alphabets in ASL

CHAPTER-7

RESULT

The results of our WiFi- enabled robotic hand project give a clear picture of how well the system performs and how useful it can be in real-life situations. The key outcomes highlight how effectively the hand responds to voice commands, how easy it is to control through a web interface, and how accurately it translates spoken words into sign language gestures- making communication more accessible and inclusive.

7.1. Key Outcomes

- **Smooth voice -to- sign translation:** We were able to successfully convert voice input into real-time American Sign Language (ASL) gestures using a 3D-printed robotic hand, making communication more inclusive and interactive.

- **Reliable WiFi - based control:** By using the ESP8266 to host a local web server, we replaced Bluetooth with a more flexible WiFi solution. This made it easier to send commands wirelessly from any device connected to the same network.

- **Accurate hand movements using servos:** The robotic hand, powered by five servo motors, was programmed to clearly show all 26 ASL alphabets. Each gesture was performed accurately.

- **Simple and accessible user interface:** We built a clean and easy-to-use web interface that lets users input text directly from their browser, without needing a separate app or complicated setup.

- **A meaningful step toward accessibility:** Most importantly, this project showed how technology can be used to support people with hearing and speech impairments by offering a low-cost, practical solution that could be improved and expanded in the future.

7.2 Final Output:

Fig 7.2.2: Gesture corresponding to A

Fig 7.2.3.: Gesture corresponding to B

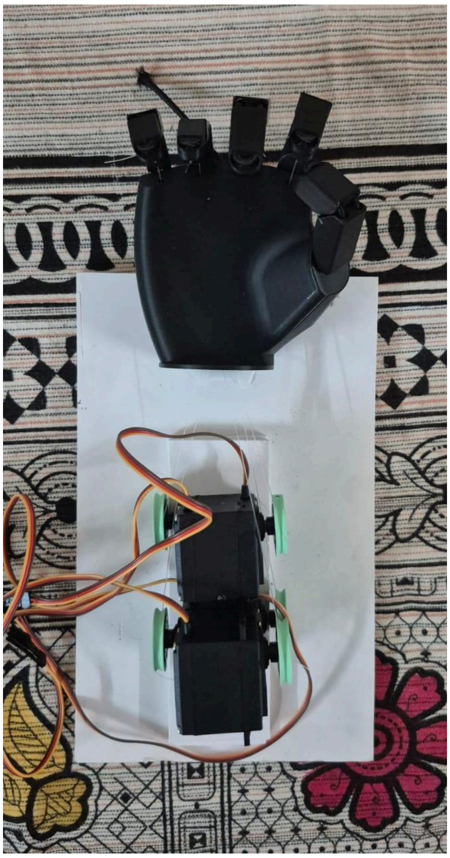

Fig 7.2.4: Gesture corresponding to C

7.2 Time response of the System:

Total time from the moment the input is given to getting the final output is given below.

Time for first loop	Time to Reset	Time for movement of one finger	Time for delay	Time for next Gesture	Time to Achieve final position	Total Time
2.7 s	0.8 s	2.7 s	10 s	1.565 s	1.1 s	18.8 s

Table 7.1 Time response of the System

CHAPTER-8
CONCLUSION

Our project, SignBot, is a WiFi-enabled robotic hand designed to convert voice input into American Sign Language (ASL), demonstrating how technology can enhance communication and promote inclusivity. SignBot uses an ESP8266 WiFi module for wireless connectivity, servo motors to control the movement of the fingers, and a simple mobile interface to input voice commands. When a user speaks, the system processes the voice input, translates it into text, and then maps that text to corresponding ASL gestures, which the robotic hand performs in real time. Switching from Bluetooth to WiFi was a key upgrade, it allowed for a wider range, faster response, and more reliable communication, making the system more practical for real-world environments where ease of access and mobility are important. Technically, this project brings together IoT, mechanical control, and real-time data processing, but its impact goes beyond that. SignBot aims to support the hearing and speech impaired community, offering a glimpse into how solutions can help bridge communication gaps and make a real difference in people’s lives.

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[4] B. Prashanth, C. Ramesh, and S. Varsha, “Wi-Fi Based Real-Time Gesture Controlled Robotic Hand Using ESP8266,” in Proc. Int. Conf. Electronics, Communication and Aerospace Technology (ICECA), 2020.

[5] N. Shah, A. Patel, and M. Joshi, “Design and Implementation of American Sign Language Interpreting Robotic Hand,” Int. J. Eng. Res. Technol. (IJERT), vol. 9, no. 4, pp. 15–19, 2020.

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APPENDIX

Program

```
#include <ESP8266WiFi.h>

#include <ESP8266WebServer.h>

#include <Servo.h>


// Servo Configuration

Servo s1, s2, s3, s4, s5;

const int servoPins[5] = {D1, D2, D5, D6, D7};




ESP8266WebServer server(80);


// Alphabet mapping (keep your original entries)

struct SignLanguageAlphabet {

  char letter;

  int angles[5];
```

```
};


SignLanguageAlphabet alphabetMap[] = {
  {'A', {180,180,180,0,0}},
  {'B', {180,0,0,180,180}},
  {'C', {45,90,90,90,90}},
  {'D', {0,180,0,180,180}},
  {'E', {0,0,0,0,0}},
  {'F', {45,180,180,180,180}},
  {'G', {180,180,0,180,180}},
  {'H', {180,180,180,0,0}},
  {'I', {0,0,0,0,180}},
  {'J', {90,0,0,0,180}},
  {'K', {90,180,0,0,0}},
  {'L', {0,180,0,180,180}},
  {'M', {0,0,0,0,180}},
  {'N', {0,0,0,180,180}},
  {'O', {90,90,90,90,90}},
  {'P', {90,180,180,0,0}},
  {'Q', {180,180,0,180,180}},
  {'R', {0,180,180,0,0}},
  {'S', {0,0,0,0,0}},
  {'T', {0,0,0,0,180}},
```

```
  {'U', {0,180,180,180,180}},
  {'V', {0,180,180,0,0}},
  {'W', {0,180,180,180,180}},
  {'X', {0,45,0,0,0}},
  {'Y', {180,0,0,0,180}},
  {'Z', {90,180,180,0,0}},
};

void setup() {
  Serial.begin(115200);

  // Attach servos
  for(int i=0; i<5; i++){
    switch(i){
      case 0: s1.attach(servoPins[i]); break;
      case 1: s2.attach(servoPins[i]); break;
      case 2: s3.attach(servoPins[i]); break;
      case 3: s4.attach(servoPins[i]); break;
      case 4: s5.attach(servoPins[i]); break;
    }
  }

  WiFi.mode(WIFI_STA);   // fun to set esp as wifi station
```

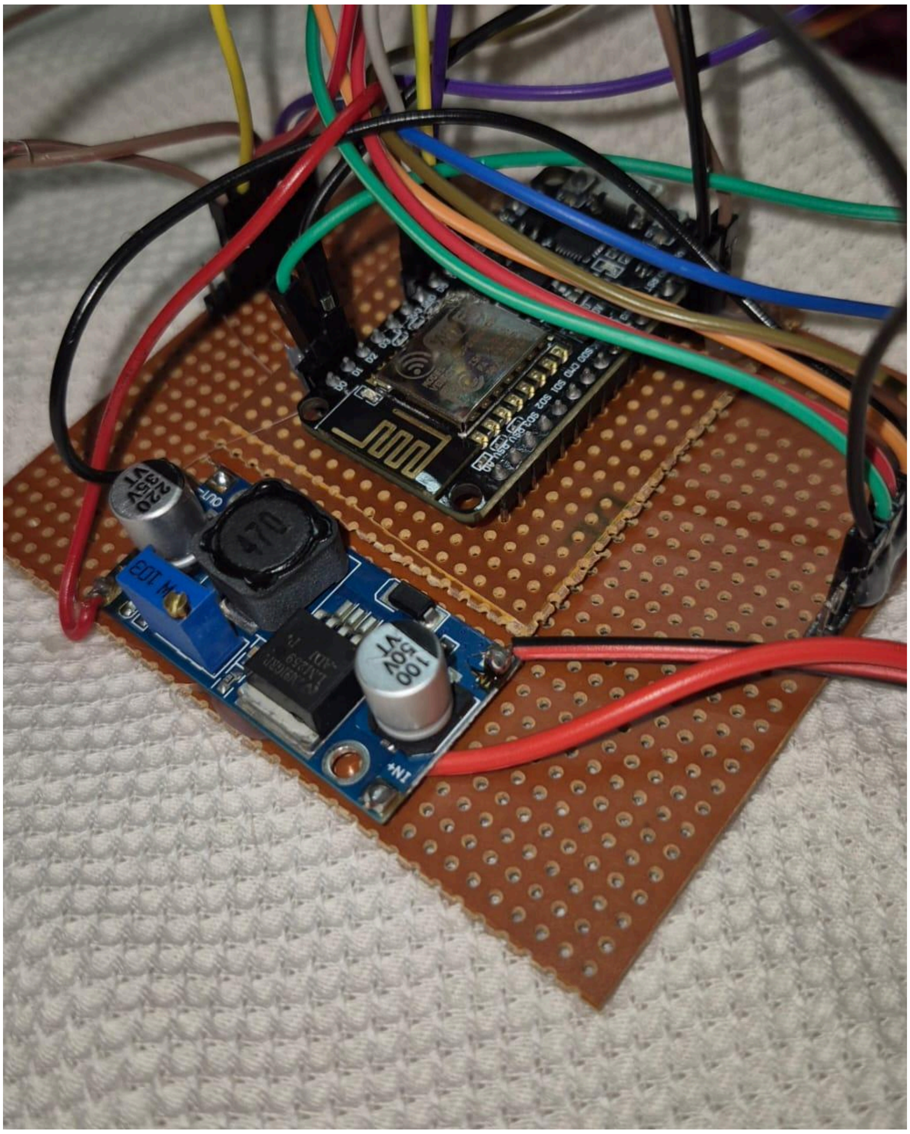
```
   WiFi.begin("iot","123456789"); // wifi credentials of hotspot
to which esp need to get connected

  Serial.println("connecting");

  while(WiFi.status() != WL_CONNECTED)

  {

    Serial.print(".");

    delay(100);

  }

  Serial.print(WiFi.localIP());

  delay(2000);

  s1.write(0);

  s2.write(0);

  s3.write(0);

  s4.write(180);

  s5.write(180);


  // Configure server

  server.onNotFound(handleGesture);

  server.begin();

}


void loop() {

  server.handleClient();
```

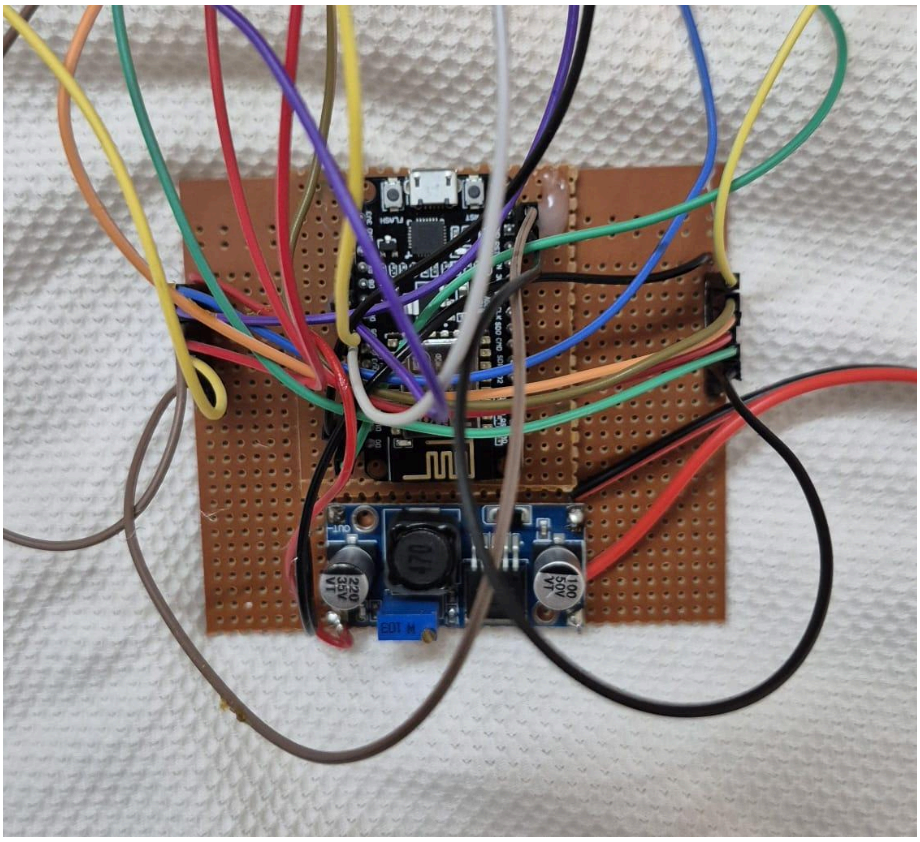
```
}

void handleGesture() {
  String path = server.uri();
  path.toLowerCase();

  if(path.startsWith("/gesture/")) {
    String inputText = path.substring(9); // Skip "/gesture/"
    inputText.replace("%20", " ");        // Decode spaces
    inputText.toUpperCase();

    Serial.print("Processing: ");
    Serial.println(inputText);

    processText(inputText);
    server.send(200, "text/plain", "Processed: " + inputText);
  }
  else {
    server.send(404, "text/plain", "Use /gesture/YOUR_TEXT");
  }
}

void processText(String text) {
```

```
  for(int i=0; i<text.length(); i++){
    char c = text[i];
    bool found = false;

    for(auto &entry : alphabetMap){
      if(entry.letter == c){
        moveServos(entry.angles);
        found = true;
        delay(2000); // 2s between letters
        break;
      }
    }

    if(!found) Serial.print("Unknown: "); Serial.println(c);
  }
}

void moveServos(int angles[5]) {
  s1.write(angles[0]);
  s2.write(angles[1]);
  s3.write(angles[2]);
  s4.write(angles[3]);
  s5.write(angles[4]);
```

```
  delay(300); // Servo stabilization
}
```

PCB DESIGN





LM2596 SIMPLE SWITCHER® Power Converter 150-kHz 3-A Step-Down Voltage Regulator

1 Features

- New product available:
  - LMR51430 4.5 to 36-V, 3-A, 500-kHz and 1.1-MHz synchronous converter
- For faster time to market:
  - TLVM13630 3 to 36-V, 3-A, 200-kHz to 2.2-MHz power module
- 3.3-V, 5-V, 12-V, and adjustable output versions
- Adjustable version output voltage range: 1.2-V to 37-V ±4% maximum over line and load conditions
- Available in TO-220 and TO-263 packages
- 3-A output load current
- Input voltage range up to 40 V
- Requires only four external components
- Excellent line and load regulation specifications
- 150-kHz fixed-frequency internal oscillator
- TTL shutdown capability
- Low power standby mode, I_Q, typically 80 μA
- High efficiency
- Uses readily available standard inductors
- Thermal shutdown and current-limit protection
- Create a custom design using the LM2596 with the WEBENCH® Power Designer

2 Applications

- Appliances
- Grid infrastructure
- EPOS
- Home theater

3 Description

The LM2596 series of regulators are monolithic integrated circuits that provide all the active functions for a step-down (buck) switching regulator, capable of driving a 3-A load with excellent line and load regulation. These devices are available in fixed output voltages of 3.3 V, 5 V, 12 V, and an adjustable output version.

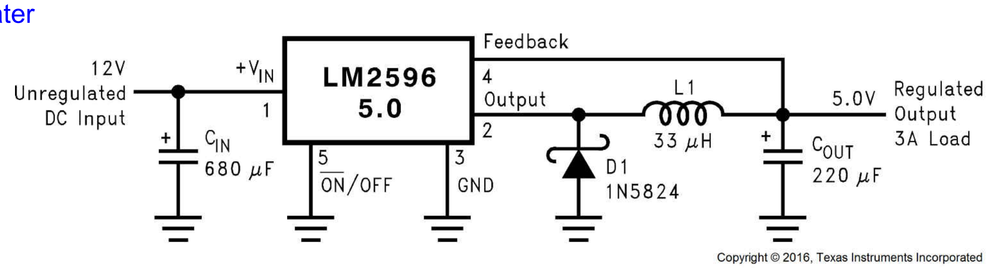
Requiring a minimum number of external components, these regulators are simple to use and include internal frequency compensation, and a fixed-frequency oscillator.

The LM2596 series operates at a switching frequency of 150 kHz, thus allowing smaller sized filter components than what can be required with lower frequency switching regulators. Available in a standard 5-pin TO-220 package with several different lead bend options, and a 5-pin TO-263 surface mount package.

Package Information

PART NUMBER	PACKAGE(1)	BODY SIZE (NOM)
LM2596	NDH (TO-220, 5)	14.986 mm × 10.16 mm
	KTT (TO-263, 5)	10.10 mm × 8.89 mm

(1) For all available packages, see the orderable addendum at the end of the data sheet.



(Fixed Output Voltage Versions)

Typical Application

Table of Contents

4 Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Revision F (April 2021) to Revision G (March 2023) **Page**

- Added link to LMR51430 and TLVM13630 product folders in the *Features* 1
- Updated trademark information..... 18

Changes from Revision E (February 2020) to Revision F (April 2021) **Page**

- Removed reference to device comparison table..... 1
- Updated the numbering format for tables, figures, and cross-references throughout the document. 1

Changes from Revision D (May 2016) to Revision E (February 2020) **Page**

- Added link to the LMR33630 product folder in the *Section 1* 1
- Updated *Section 3* to include the LMR33630 product page, device comparison table, and WEBENCH link 1
- Changed the package from 7 pins to 5 pins 1

Changes from Revision C (April 2013) to Revision D (February 2016) **Page**

- Added *ESD Ratings* table, *Feature Description* section, *Device Functional Modes*, *Application and Implementation* section, *Power Supply Recommendations* section, *Layout* section, *Device and Documentation Support* section, and *Mechanical, Packaging, and Orderable Information* section..... 1
- Removed all references to design software *Switchers Made Simple* 1

Changes from Revision B (April 2013) to Revision C (April 2013) **Page**

- Changed layout of National Semiconductor Data Sheet to TI format..... 11

6 Pin Configuration and Functions

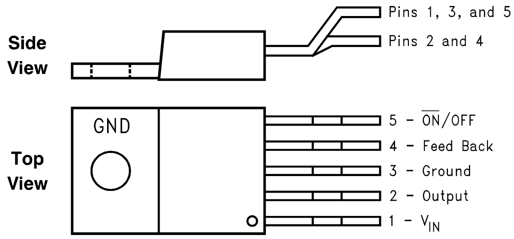


Figure 6-1. 5-Pin TO-220 NDH Package Top View

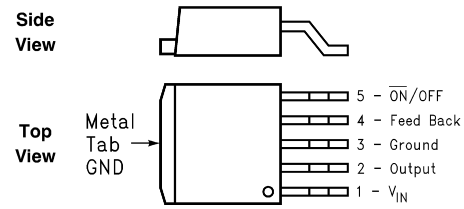


Figure 6-2. 5-Pin TO-263 KTT Package Top View

Table 6-1. Pin Functions

PIN		I/O	DESCRIPTION
NO.	NAME		
1	V_{IN}	I	This is the positive input supply for the IC switching regulator. A suitable input bypass capacitor must be present at this pin to minimize voltage transients and to supply the switching currents required by the regulator.
2	Output	O	Internal switch. The voltage at this pin switches between approximately ($+V_{IN} - V_{SAT}$) and approximately −0.5 V, with a duty cycle of V_{OUT} / V_{IN}. To minimize coupling to sensitive circuitry, the PCB copper area connected to this pin must be kept to a minimum.
3	Ground	—	Circuit ground
4	Feedback	I	Senses the regulated output voltage to complete the feedback loop.
5	$\overline{ON}$/OFF	I	Allows the switching regulator circuit to be shut down using logic signals thus dropping the total input supply current to approximately 80 µA. Pulling this pin below a threshold voltage of approximately 1.3 V turns the regulator on, and pulling this pin above 1.3 V (up to a maximum of 25 V) shuts the regulator down. If this shutdown feature is not required, the $\overline{ON}$/OFF pin can be wired to the ground pin or it can be left open. In either case, the regulator will be in the ON condition.

7 Specifications

7.1 Absolute Maximum Ratings

over operating free-air temperature range (unless otherwise noted)[1] [2]

			MIN	MAX	UNIT
Maximum supply voltage (V_{IN})				45	V
$\overline{SD}$/SS pin input voltage[3]				6	V
Delay pin voltage[3]				1.5	V
Flag pin voltage			–0.3	45	V
Feedback pin voltage			–0.3	25	V
Output voltage to ground, steady-state				–1	V
Power dissipation			Internally limited		
Lead temperature	KTW package	Vapor phase (60 s)		215	°C
		Infrared (10 s)		245	
	NDZ package, soldering (10 s)			260	
Maximum junction temperature				150	°C
Storage temperature, T_{stg}			–65	150	°C

(1) Stresses beyond those listed under *Absolute Maximum Ratings* may cause permanent damage to the device. These are stress ratings only, which do not imply functional operation of the device at these or any other conditions beyond those indicated under *Recommended Operating Conditions*. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.
(2) If Military/Aerospace specified devices are required, please contact the Texas Instruments Sales Office/ Distributors for availability and specifications.
(3) Voltage internally clamped. If clamp voltage is exceeded, limit current to a maximum of 1 mA.

7.2 ESD Ratings

			VALUE	UNIT
$V_{(ESD)}$	Electrostatic discharge	Human-body model (HBM), per ANSI/ESDA/JEDEC JS-001[1]	±2000	V

(1) JEDEC document JEP155 states that 500-V HBM allows safe manufacturing with a standard ESD control process.

7.3 Operating Conditions

	MIN	MAX	UNIT
Supply voltage	4.5	40	V
Temperature	–40	125	°C

7.4 Thermal Information

THERMAL METRIC[1]			LM2596		UNIT
			KTW (TO-263)	NDZ (TO-220)	
			5 PINS	5 PINS	
$R_{\theta JA}$	Junction-to-ambient thermal resistance[2] [3]	See[4]	—	50	°C/W
		See[5]	50	—	
		See[6]	30	—	
		See[7]	20	—	
$R_{\theta JC(top)}$	Junction-to-case (top) thermal resistance		2	2	°C/W

(1) For more information about traditional and new thermal metrics, see the *Semiconductor and IC Package Thermal Metrics* application report.
(2) The package thermal impedance is calculated in accordance to JESD 51-7.
(3) Thermal Resistances were simulated on a 4-layer, JEDEC board.
(4) Junction to ambient thermal resistance (no external heat sink) for the package mounted TO-220 package mounted vertically, with the leads soldered to a printed circuit board with (1 oz.) copper area of approximately 1 in^2.
(5) Junction to ambient thermal resistance with the TO-263 package tab soldered to a single sided printed circuit board with 0.5 in^2 of 1-oz copper area.

(6) Junction to ambient thermal resistance with the TO-263 package tab soldered to a single sided printed circuit board with 2.5 in^2 of 1-oz copper area.
(7) Junction to ambient thermal resistance with the TO-263 package tab soldered to a double sided printed circuit board with 3 in^2 of 1-oz copper area on the LM2596S side of the board, and approximately 16 in^2 of copper on the other side of the PCB.

7.5 Electrical Characteristics – 3.3-V Version

Specifications are for T_J = 25°C (unless otherwise noted)

PARAMETER		TEST CONDITIONS		MIN(1)	TYP(2)	MAX(1)	UNIT
SYSTEM PARAMETERS (3) (see Figure 9-13 for test circuit)							
V_{OUT}	Output voltage	4.75 V ≤ V_{IN} ≤ 40 V, 0.2 A ≤ I_{LOAD} ≤ 3 A	T_J = 25°C	3.168	3.3	3.432	V
			–40°C ≤ T_J ≤ 125°C	3.135		3.465	
η	Efficiency	V_{IN} = 12 V, I_{LOAD} = 3 A			73%		

(1) All room temperature limits are 100% production tested. All limits at temperature extremes are specified via correlation using standard Statistical Quality Control (SQC) methods. All limits are used to calculate Average Outgoing Quality Level (AOQL).
(2) Typical numbers are at 25°C and represent the most likely norm.
(3) External components such as the catch diode, inductor, input and output capacitors can affect switching regulator system performance. When the LM2596 is used as shown in Figure 9-13, system performance is shown in the test conditions column.

7.6 Electrical Characteristics – 5-V Version

Specifications are for T_J = 25°C (unless otherwise noted)

PARAMETER		TEST CONDITIONS		MIN(1)	TYP(2)	MAX(1)	UNIT
SYSTEM PARAMETERS (3) (see Figure 9-13 for test circuit)							
V_{OUT}	Output voltage	7 V ≤ V_{IN} ≤ 40 V, 0.2 A ≤ I_{LOAD} ≤ 3 A	T_J = 25°C	4.8	5	5.2	V
			–40°C ≤ T_J ≤ 125°C	4.75		5.25	
η	Efficiency	V_{IN} = 12 V, I_{LOAD} = 3 A			80%		

(1) All room temperature limits are 100% production tested. All limits at temperature extremes are specified via correlation using standard Statistical Quality Control (SQC) methods. All limits are used to calculate Average Outgoing Quality Level (AOQL).
(2) Typical numbers are at 25°C and represent the most likely norm.
(3) External components such as the catch diode, inductor, input and output capacitors can affect switching regulator system performance. When the LM2596 is used as shown in Figure 9-13, system performance is shown in the test conditions column.

7.7 Electrical Characteristics – 12-V Version

Specifications are for T_J = 25°C (unless otherwise noted)

PARAMETER		TEST CONDITIONS		MIN(1)	TYP(2)	MAX(1)	UNIT
SYSTEM PARAMETERS (3) (see Figure 9-13 for test circuit)							
V_{OUT}	Output voltage	15 V ≤ V_{IN} ≤ 40 V, 0.2 A ≤ I_{LOAD} ≤ 3 A	T_J = 25°C	11.52	12	12.48	V
			–40°C ≤ T_J ≤ 125°C	11.4		12.6	
η	Efficiency	V_{IN} = 25 V, I_{LOAD} = 3 A			90%		

(1) All room temperature limits are 100% production tested. All limits at temperature extremes are specified via correlation using standard Statistical Quality Control (SQC) methods. All limits are used to calculate Average Outgoing Quality Level (AOQL).
(2) Typical numbers are at 25°C and represent the most likely norm.
(3) External components such as the catch diode, inductor, input and output capacitors can affect switching regulator system performance. When the LM2596 is used as shown in Figure 9-13, system performance is shown in the test conditions column.

7.8 Electrical Characteristics – Adjustable Voltage Version

Specifications are for T_J = 25°C (unless otherwise noted)

PARAMETER		TEST CONDITIONS		MIN(1)	TYP(2)	MAX(1)	UNIT
SYSTEM PARAMETERS (3) (see Figure 9-13 for test circuit)							
V_{FB}	Feedback voltage	4.5 V ≤ V_{IN} ≤ 40 V, 0.2 A ≤ I_{LOAD} ≤ 3 A			1.23		V
		V_{OUT} programmed for 3 V (see Figure 9-13 for test circuit)	T_J = 25°C	1.193		1.267	
			–40°C ≤ T_J ≤ 125°C	1.18		1.28	
η	Efficiency	V_{IN} = 12 V, V_{OUT} = 3 V, I_{LOAD} = 3 A			73%		

(1) All room temperature limits are 100% production tested. All limits at temperature extremes are specified via correlation using standard Statistical Quality Control (SQC) methods. All limits are used to calculate Average Outgoing Quality Level (AOQL).
(2) Typical numbers are at 25°C and represent the most likely norm.

(3) External components such as the catch diode, inductor, input and output capacitors can affect switching regulator system performance. When the LM2596 is used as shown in Figure 9-13, system performance is shown in the test conditions column.

7.9 Electrical Characteristics – All Output Voltage Versions

Specifications are for T_J = 25°C, I_{LOAD} = 500 mA, V_{IN} = 12 V for the 3.3-V, 5-V, and adjustable version, and V_{IN} = 24 V for the 12-V version (unless otherwise noted).

PARAMETER		TEST CONDITIONS		MIN[1]	TYP[2]	MAX[1]	UNIT
DEVICE PARAMETERS							
I_b	Feedback bias current	Adjustable version only, V_{FB} = 1.3 V	T_J = 25°C		10	50	nA
			–40°C ≤ T_J ≤ 125°C			100	
f_O	Oscillator frequency[3]	T_J = 25°C		127	150	173	kHz
		–40°C ≤ T_J ≤ 125°C		110		173	
V_{SAT}	Saturation voltage[4] [5]	I_{OUT} = 3 A	T_J = 25°C		1.16	1.4	V
			–40°C ≤ T_J ≤ 125°C			1.5	
DC	Max duty cycle (ON)[5]				100%		
	Min duty cycle (OFF)[6]				0%		
I_{CL}	Current limit[4] [5]	Peak current	T_J = 25°C	3.6	4.5	6.9	A
			–40°C ≤ T_J ≤ 125°C	3.4		7.5	
I_L	Output leakage current[4] [6]	Output = 0 V, V_{IN} = 40 V				50	µA
		Output = –1 V			2	30	mA
I_Q	Operating quiescent current[6]	See [6]			5	10	mA
I_{STBY}	Current standby quiescent	$\overline{\text{ON}}$/OFF pin = 5 V (OFF)[7]	T_J = 25°C		80	200	µA
			–40°C ≤ T_J ≤ 125°C			250	µA
$\overline{\text{SHUTDOWN}}$/SOFT-START CONTROL (see Figure 9-13 for test circuit)							
V_{IH}	$\overline{\text{ON}}$/OFF pin logic input threshold voltage	Low (regulator ON)	T_J = 25°C		1.3		V
			–40°C ≤ T_J ≤ 125°C			0.6	
V_{IL}		High (regulator OFF)	T_J = 25°C		1.3		V
			–40°C ≤ T_J ≤ 125°C	2			
I_H	$\overline{\text{ON}}$/OFF pin input current	V_{LOGIC} = 2.5 V (regulator OFF)			5	15	µA
I_L		V_{LOGIC} = 0.5 V (regulator ON)			0.02	5	µA

(1) All room temperature limits are 100% production tested. All limits at temperature extremes are specified via correlation using standard Statistical Quality Control (SQC) methods. All limits are used to calculate Average Outgoing Quality Level (AOQL).
(2) Typical numbers are at 25°C and represent the most likely norm.
(3) The switching frequency is reduced when the second stage current limit is activated. The amount of reduction is determined by the severity of current overload.
(4) No diode, inductor, or capacitor connected to output pin.
(5) Feedback pin removed from output and connected to 0 V to force the output transistor switch ON.
(6) Feedback pin removed from output and connected to 12 V for the 3.3-V, 5-V, and the adjustable versions, and 15 V for the 12-V version, to force the output transistor switch OFF.
(7) V_{IN} = 40 V.

7.10 Typical Characteristics

See Figure 9-13 for test circuit

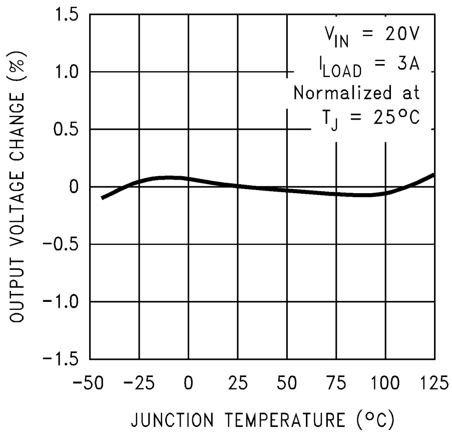


Figure 7-1. Normalized Output Voltage

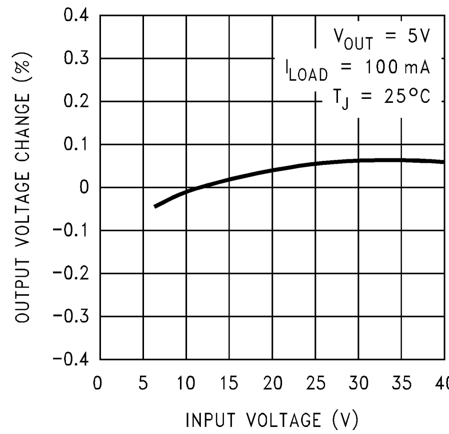


Figure 7-2. Line Regulation

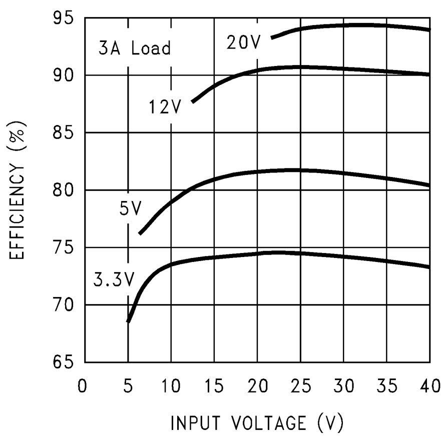


Figure 7-3. Efficiency

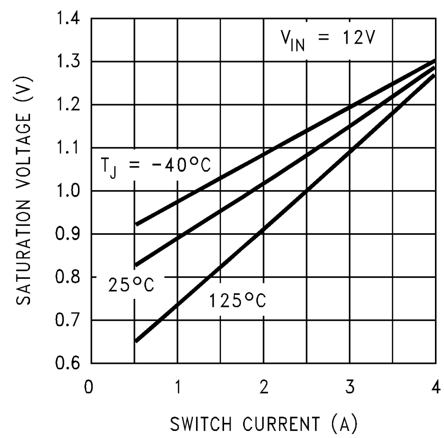


Figure 7-4. Switch Saturation Voltage

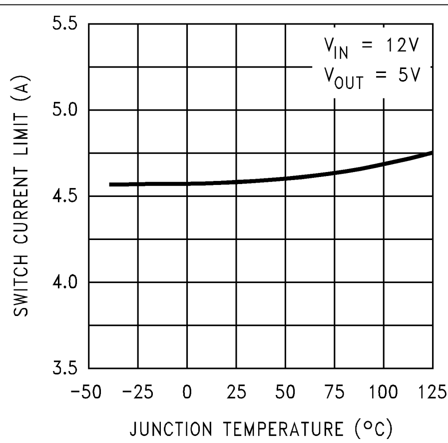


Figure 7-5. Switch Current Limit

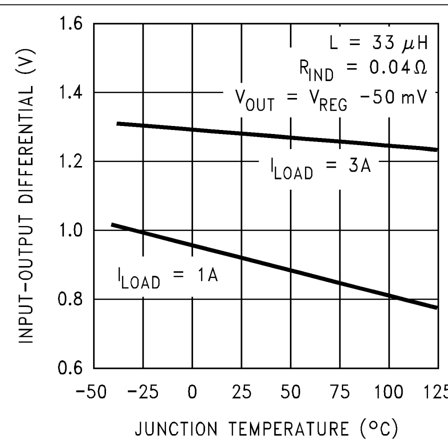


Figure 7-6. Dropout Voltage

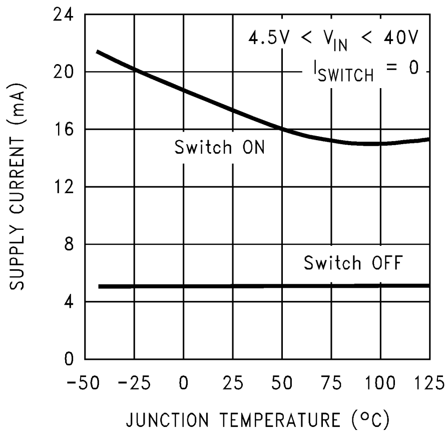


Figure 7-7. Operating Quiescent Current

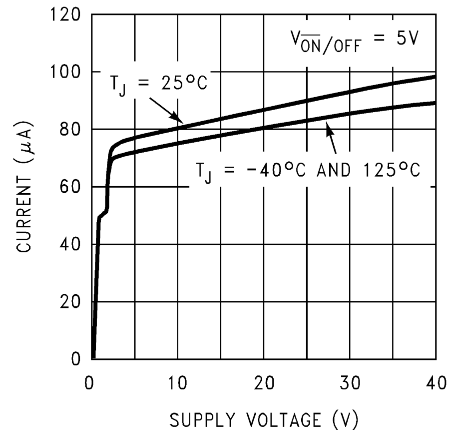


Figure 7-8. Shutdown Quiescent Current

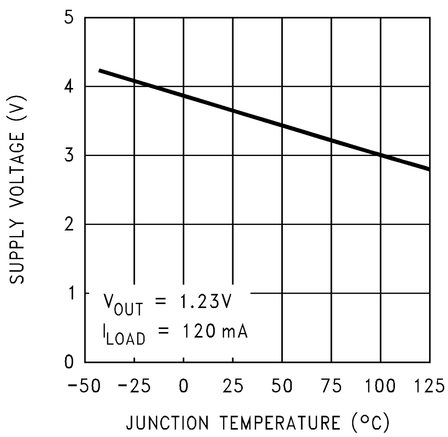


Figure 7-9. Minimum Operating Supply Voltage

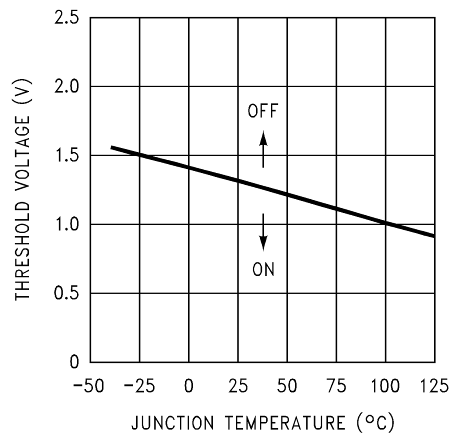


Figure 7-10. $\overline{ON}$/OFF Threshold Voltage

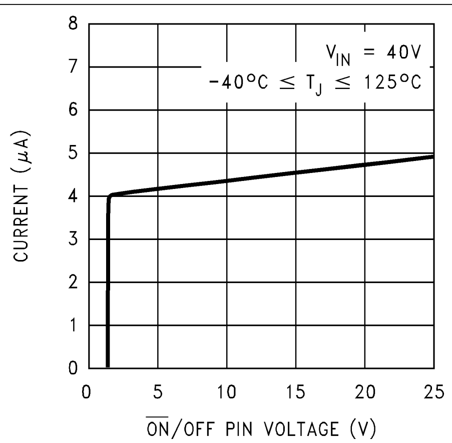


Figure 7-11. $\overline{ON}$/OFF Pin Current (Sinking)

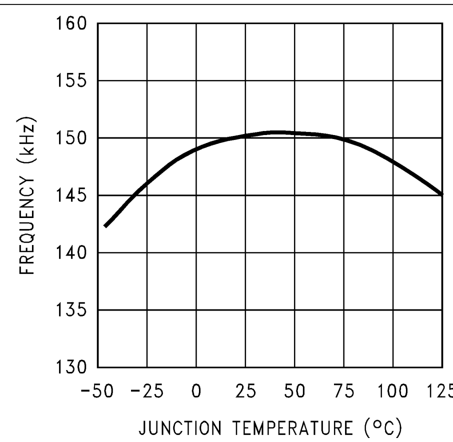


Figure 7-12. Switching Frequency

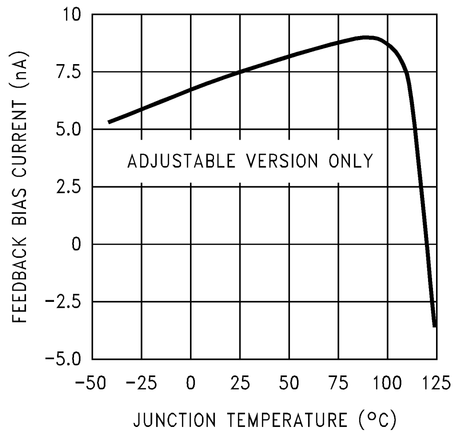


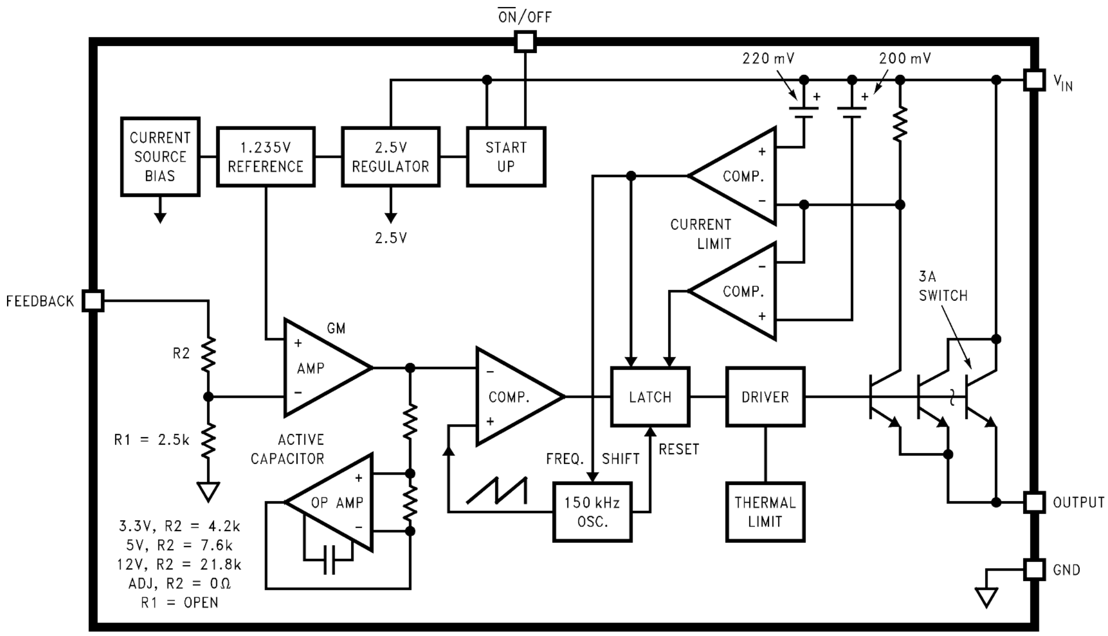
Figure 7-13. Feedback Pin Bias Current

8 Detailed Description

8.1 Overview

The LM2596 SIMPLE SWITCHER® power converter regulator is an easy-to-use, nonsynchronous, step-down DC-DC converter with a wide input voltage range up to 40 V. The regulator is capable of delivering up to 3-A DC load current with excellent line and load regulation. These devices are available in fixed output voltages of 3.3-V, 5-V, 12-V, and an adjustable output version. The family requires few external components, and the pin arrangement was designed for simple, optimum PCB layout.

8.2 Functional Block Diagram



8.3 Feature Description

8.3.1 Delayed Start-Up

The circuit in Figure 8-1 uses the $\overline{\text{ON}}$/OFF pin to provide a time delay between the time the input voltage is applied and the time the output voltage comes up (only the circuitry pertaining to the delayed start-up is shown). As the input voltage rises, the charging of capacitor C1 pulls the $\overline{\text{ON}}$/OFF pin high, keeping the regulator OFF. After the input voltage reaches its final value and the capacitor stops charging, resistor R_2 pulls the $\overline{\text{ON}}$/OFF pin low, thus allowing the circuit to start switching. Resistor R_1 is included to limit the maximum voltage applied to the $\overline{\text{ON}}$/OFF pin (maximum of 25 V), reduces power supply noise sensitivity, and also limits the capacitor C1 discharge current. When high input ripple voltage exists, avoid long delay time, because this ripple can be coupled into the $\overline{\text{ON}}$/OFF pin and cause problems.

This delayed start-up feature is useful in situations where the input power source is limited in the amount of current it can deliver. It allows the input voltage to rise to a higher voltage before the regulator starts operating. Buck regulators require less input current at higher input voltages.

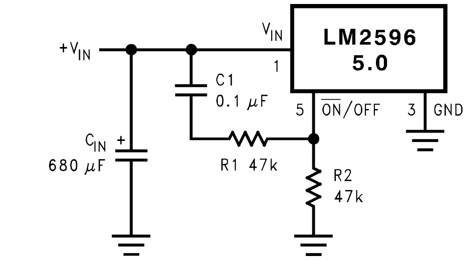


Figure 8-1. Delayed Start-Up

8.3.2 Undervoltage Lockout

Some applications require the regulator to remain off until the input voltage reaches a predetermined voltage. Figure 8-2 shows an undervoltage lockout feature applied to a buck regulator, while Figure 8-3 and Figure 8-4 apply the same feature to an inverting circuit. The circuit in Figure 8-3 features a constant threshold voltage for turnon and turnoff (Zener voltage plus approximately one volt). If hysteresis is required, the circuit in Figure 8-4 has a turnon voltage which is different than the turnoff voltage. The amount of hysteresis is approximately equal to the value of the output voltage. If Zener voltages greater than 25 V are used, an additional 47-kΩ resistor is required from the $\overline{\text{ON}}$/OFF pin to the ground pin to stay within the 25 V maximum limit of the $\overline{\text{ON}}$/OFF pin.

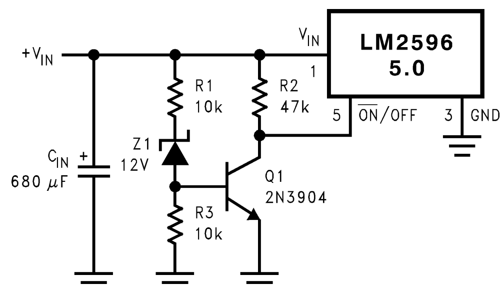
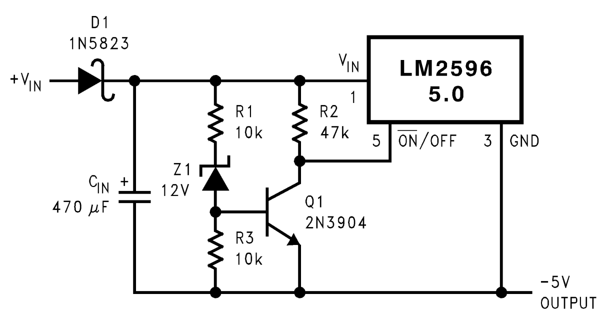


Figure 8-2. Undervoltage Lockout for Buck Regulator

8.3.3 Inverting Regulator

The circuit in Figure 8-5 converts a positive input voltage to a negative output voltage with a common ground. The circuit operates by bootstrapping the ground pin of the regulator to the negative output voltage, then grounding the feedback pin, the regulator senses the inverted output voltage and regulates it.



This circuit has an $\overline{\text{ON}}$/OFF threshold of approximately 13 V.

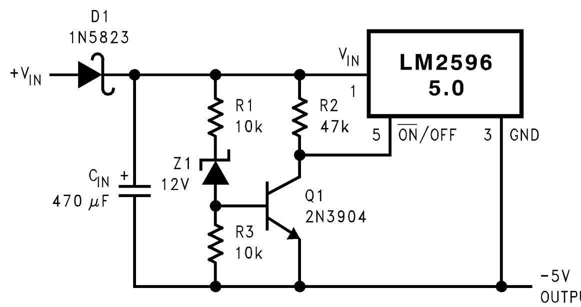
Figure 8-3. Undervoltage Lockout for Inverting Regulator

This example uses the LM2596-5.0 to generate a −5-V output, but other output voltages are possible by selecting other output voltage versions, including the adjustable version. Because this regulator topology can produce an output voltage that is either greater than or less than the input voltage, the maximum output current greatly depends on both the input and output voltage. Figure 8-6 provides a guide as to the amount of output load current possible for the different input and output voltage conditions.

The maximum voltage appearing across the regulator is the absolute sum of the input and output voltage, and this must be limited to a maximum of 40 V. For example, when converting +20 V to −12 V, the regulator can see 32 V between the input pin and ground pin. The LM2596 has a maximum input voltage spec of 40 V.

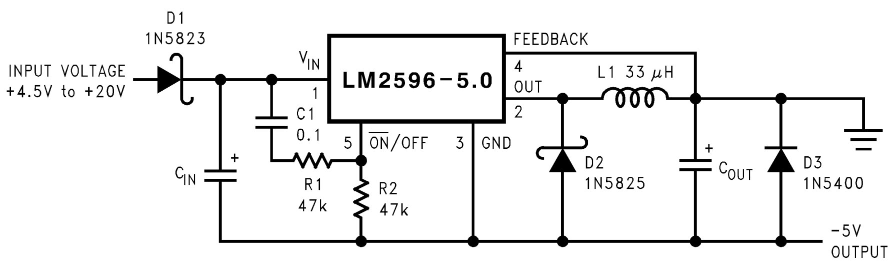
Additional diodes are required in this regulator configuration. Diode D1 is used to isolate input voltage ripple or noise from coupling through the C_{IN} capacitor to the output, under light or no load conditions. Also, this diode isolation changes the topology to closely resemble a buck configuration, thus providing good closed-loop stability. TI recommends using a Schottky diode for low input voltages, (because of its lower voltage drop) but for higher input voltages, a fast recovery diode can be used.

Without diode D3, when the input voltage is first applied, the charging current of C_{IN} can pull the output positive by several volts for a short period of time. Adding D3 prevents the output from going positive by more than a diode voltage.



This circuit has hysteresis Regulator starts switching at V_{IN} = 13 V Regulator stops switching at V_{IN} = 8 V

Figure 8-4. Undervoltage Lockout With Hysteresis for Inverting Regulator



C_{IN} — 68-µF, 25-V Tant. Sprague 595D 470 -µF, 50-V Elec. Panasonic HFQ C_{OUT} — 47-µF, 20-V Tant. Sprague 595D 220-µF, 25-V Elec. Panasonic HFQ

Figure 8-5. Inverting −5-V Regulator With Delayed Start-Up

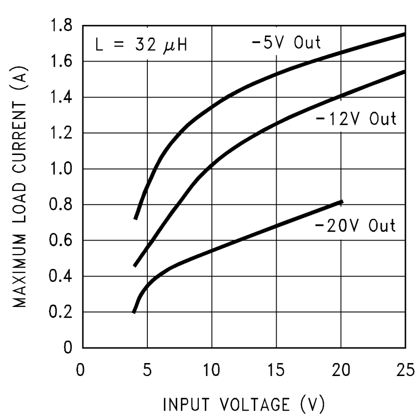


Figure 8-6. Inverting Regulator Typical Load Current

Because of differences in the operation of the inverting regulator, the standard design procedure is not used to select the inductor value. In the majority of designs, a 33-µH, 3.5-A inductor is the best choice. Capacitor selection can also be narrowed down to just a few values. Using the values shown in Figure 8-5 will provide good results in the majority of inverting designs.

This type of inverting regulator can require relatively large amounts of input current when starting up, even with light loads. Input currents as high as the LM2596 current limit (approximately 4.5 A) are required for at least 2 ms or more, until the output reaches its nominal output voltage. The actual time depends on the output voltage and the size of the output capacitor. Input power sources that are current limited or sources that can not deliver these currents without getting loaded down, can not work correctly. Because of the relatively high start-up currents required by the inverting topology, TI recommends the delayed start-up feature (C1, R_1, and R_2) shown in Figure 8-5. By delaying the regulator start-up, the input capacitor is allowed to charge up to a higher voltage before the switcher begins operating. A portion of the high input current required for start-up is now supplied by the input capacitor (C_{IN}). For severe start-up conditions, the input capacitor can be made much larger than normal.

8.3.4 Inverting Regulator Shutdown Methods

Using the $\overline{ON}$/OFF pin in a standard buck configuration is simple. To turn the regulator ON, pull the $\overline{ON}$/OFF pin below 1.3 V (at 25°C, referenced to ground). To turn the regulator OFF, pull the $\overline{ON}$/OFF pin above 1.3 V. With the inverting configuration, some level shifting is required, because the ground pin of the regulator is no longer at ground, but is now setting at the negative output voltage level. Two different shutdown methods for inverting regulators are shown in Figure 8-7 and Figure 8-8.

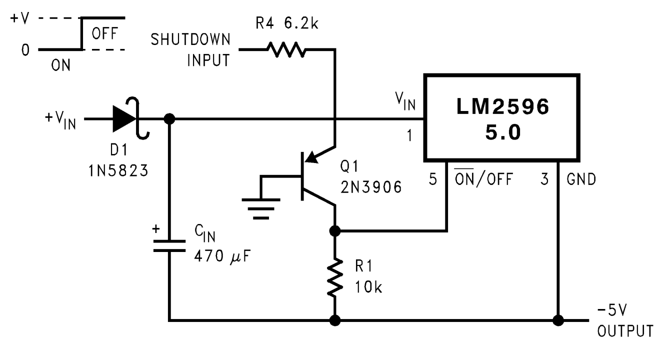


Figure 8-7. Inverting Regulator Ground Referenced Shutdown

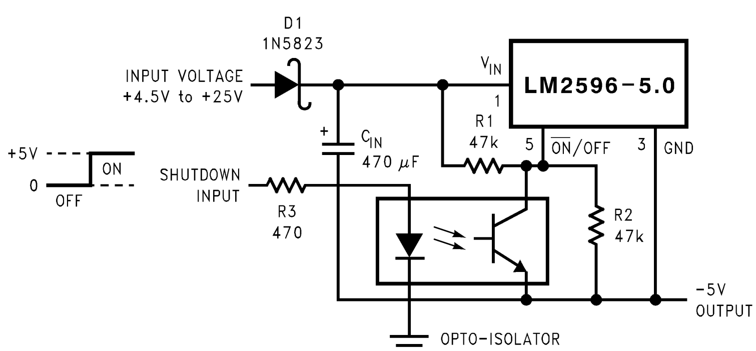


Figure 8-8. Inverting Regulator Ground Referenced Shutdown Using Opto Device

8.4 Device Functional Modes

8.4.1 Discontinuous Mode Operation

The selection guide chooses inductor values suitable for continuous mode operation, but for low current applications or high input voltages, a discontinuous mode design can be a better choice. A discontinuous mode design can use an inductor that can be physically smaller, and can require only one half to one third the inductance value required for a continuous mode design. The peak switch and inductor currents will be higher in a discontinuous design, but at these low load currents (1 A and below), the maximum switch current will still be less than the switch current limit.

About This Guide

This document introduces the specifications of ESP8266EX.

Release Notes

Date	Version	Release Notes
2015.12	V4.6	Updated Chapter 3.
2016.02	V4.7	Updated Section 3.6 and Section 4.1.
2016.04	V4.8	Updated Chapter 1.
2016.08	V4.9	Updated Chapter 1.
2016.11	V5.0	Added Appendix II "Learning Resources".
2016.11	V5.1	Changed the power consumption during Deep-sleep from 10 μA to 20 μA in Table 5-2.
2016.11	V5.2	Changed the crystal frequency range from "26 MHz to 52 MHz" to "24 MHz to 52 MHz" in Section 3.3.
2016.12	V5.3	Changed the minimum working voltage from 3.0 V to 2.5 V.
2017.04	V5.4	Changed chip input and output impedance from 50 Ω to 39 + j6 Ω.
2017.10	V5.5	Updated Chapter 3 regarding the range of clock amplitude to 0.8 V ~ 1.5 V.
2017.11	V5.6	Updated VDDPST from 1.8 V ~ 3.3 V to 1.8 V ~ 3.6 V.
2017.11	V5.7	• Corrected a typo in the description of SDIO_DATA_0 in Table 2-1; • Added the testing conditions for the data in Table 5-2.
2018.02	V5.8	• Updated Wi-Fi protocols in Section 1.1; • Updated description of the integrated Tensilica processor in 3.1.

Date	Version	Release Notes
2018.09	V5.9	• Update document cover; • Added a note for Table 1-1; • Updated Wi-Fi key features in Section 1.1; • Updated description of the Wi-Fi function in 3.5; • Updated pin layout diagram; • Fixed a typo in Table 2-1; • Removed Section AHB and AHB module; • Restructured Section Power Management; • Fixed a typo in Section UART; • Removed description of transmission angle in Section IR Remote Control; • Other optimization (wording).
2018.11	V6.0	• Added an SPI pin in Table 4-2; • Updated the diagram of packing information.
2019.08	V6.1	Removed description of the GPIO function in Section 4.1.
2019.08	V6.2	Updated notes on CHIP_EN in Section 5.1
2019.12	V6.3	Add feedback links.
2020.04	V6.4	• Removed the description of "Antenna diversity"; • Updated the feedback links.
2020.07	V6.5	• Updated the description of HSPI in Section 4.3; • Updated links in Appendix.
2020.10	V6.6	• Fixed a typo in Figure 2-1; • Updated the link of *ESP8266 Pin List.*
2022.07	v6.7	• Updated Figure 2-1; • Updated the link of *ESP8266 Hardware Resources.*
2022.10	v6.8	Updated typos in Chapter 6.
2023.02	v6.9	Added link to *Xtensa® Instruction Set Architecture (ISA) Summary* in Section 3.1.1.
2023.06	v7.0	• Added a note on the cover page; • Updated two documents in Appendix.

1. Overview

Espressif's ESP8266EX delivers highly integrated Wi-Fi SoC solution to meet users' continuous demands for efficient power usage, compact design and reliable performance in the Internet of Things industry.

With the complete and self-contained Wi-Fi networking capabilities, ESP8266EX can perform either as a standalone application or as the slave to a host MCU. When ESP8266EX hosts the application, it promptly boots up from the flash. The integrated high-speed cache helps to increase the system performance and optimize the system memory. Also, ESP8266EX can be applied to any microcontroller design as a Wi-Fi adaptor through SPI/SDIO or UART interfaces.

ESP8266EX integrates antenna switches, RF balun, power amplifier, low noise receive amplifier, filters and power management modules. The compact design minimizes the PCB size and requires minimal external circuitries.

Besides the Wi-Fi functionalities, ESP8266EX also integrates an enhanced version of Tensilica's L106 Diamond series 32-bit processor and on-chip SRAM. It can be interfaced with external sensors and other devices through the GPIOs. Software Development Kit (SDK) provides sample codes for various applications.

Espressif Systems' Smart Connectivity Platform (ESCP) enables sophisticated features including:

- Fast switch between sleep and wakeup mode for energy-efficient purpose;
- Adaptive radio biasing for low-power operation
- Advance signal processing
- Spur cancellation and RF co-existence mechanisms for common cellular, Bluetooth, DDR, LVDS, LCD interference mitigation

1.1. Wi-Fi Key Features

- 802.11 b/g/n support
- 802.11 n support (2.4 GHz), up to 72.2 Mbps
- Defragmentation
- 2 x virtual Wi-Fi interface
- Automatic beacon monitoring (hardware TSF)
- Support Infrastructure BSS Station mode/SoftAP mode/Promiscuous mode

1.2. Specifications

Table 1-1. Specifications

Categories	Items	Parameters
Wi-Fi	Certification	Wi-Fi Alliance
	Protocols	802.11 b/g/n (HT20)
	Frequency Range	2.4 GHz ~ 2.5 GHz (2400 MHz ~ 2483.5 MHz)
	TX Power	802.11 b: +20 dBm
		802.11 g: +17 dBm
		802.11 n: +14 dBm
	Rx Sensitivity	802.11 b: –91 dbm (11 Mbps)
		802.11 g: –75 dbm (54 Mbps)
		802.11 n: –72 dbm (MCS7)
	Antenna	PCB Trace, External, IPEX Connector, Ceramic Chip
Hardware	CPU	Tensilica L106 32-bit processor
	Peripheral Interface	UART/SDIO/SPI/I2C/I2S/IR Remote Control
		GPIO/ADC/PWM/LED Light & Button
	Operating Voltage	2.5 V ~ 3.6 V
	Operating Current	Average value: 80 mA
	Operating Temperature Range	–40 °C ~ 125 °C
	Package Size	QFN32-pin (5 mm x 5 mm)
	External Interface	-
Software	Wi-Fi Mode	Station/SoftAP/SoftAP+Station
	Security	WPA/WPA2
	Encryption	WEP/TKIP/AES
	Firmware Upgrade	UART Download / OTA (via network)
	Software Development	Supports Cloud Server Development / Firmware and SDK for fast on-chip programming
	Network Protocols	IPv4, TCP/UDP/HTTP
	User Configuration	AT Instruction Set, Cloud Server, Android/iOS App

📖 ***Note:***

The TX power can be configured based on the actual user scenarios.

1.3. Applications

- Home appliances
- Home automation
- Smart plugs and lights
- Industrial wireless control
- Baby monitors
- IP cameras
- Sensor networks
- Wearable electronics
- Wi-Fi location-aware devices
- Security ID tags
- Wi-Fi position system beacons

2. Pin Definitions

Figure 2-1 shows the pin layout for 32-pin QFN package.

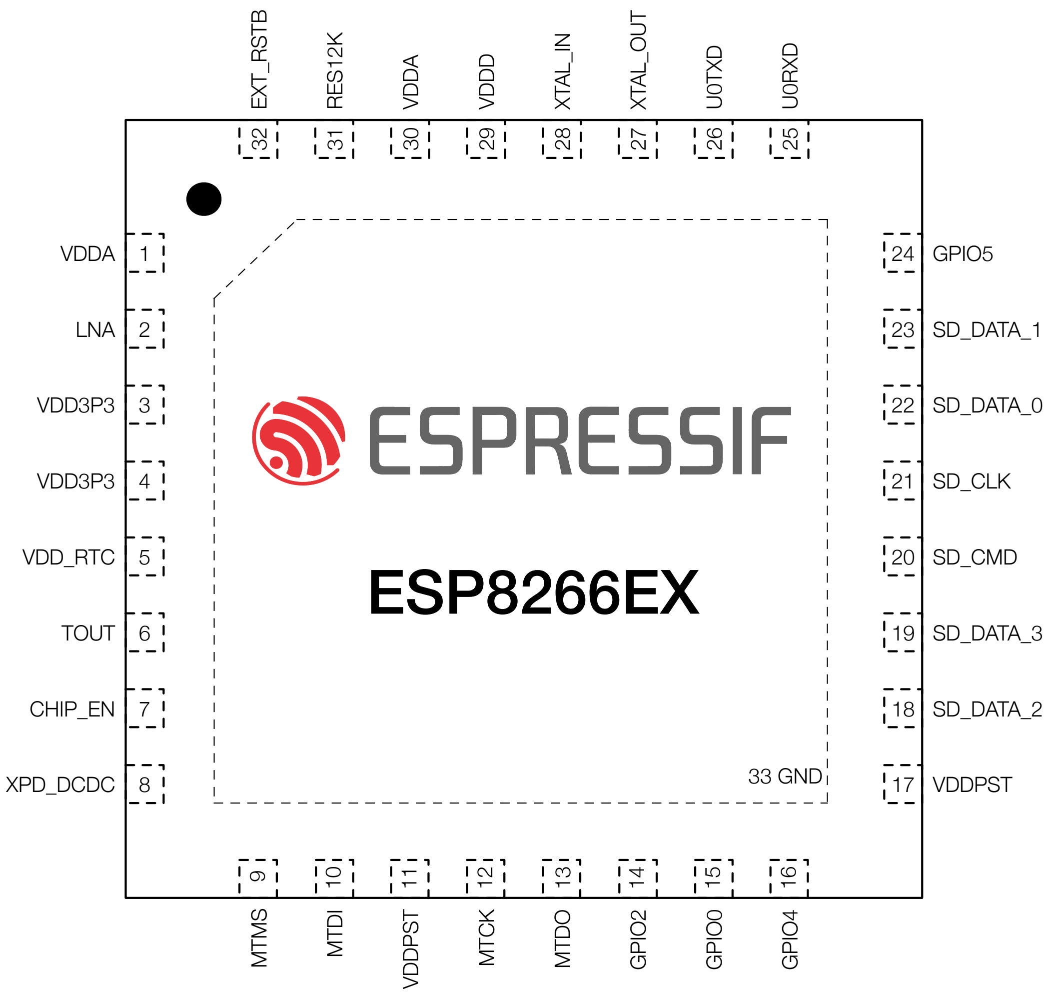


Figure 2-1. Pin Layout (Top View)

Table 2-1 lists the definitions and functions of each pin.

Table 2-1. ESP8266EX Pin Definitions

Pin	Name	Type	Function
1	VDDA	P	Analog Power 2.5 V ~ 3.6 V
2	LNA	I/O	RF antenna interface Chip output impedance = 39 + j6 Ω. It is suggested to retain the π-type matching network to match the antenna.
3	VDD3P3	P	Amplifier Power 2.5 V ~ 3.6 V

Pin	Name	Type	Function
4	VDD3P3	P	Amplifier Power 2.5 V ~ 3.6 V
5	VDD_RTC	P	NC (1.1 V)
6	TOUT	I	ADC pin. It can be used to test the power-supply voltage of VDD3P3 (Pin3 and Pin4) and the input power voltage of TOUT (Pin 6). However, these two functions cannot be used simultaneously.
7	CHIP_EN	I	Chip Enable High: On, chip works properly Low: Off, small current consumed
8	XPD_DCDC	I/O	Deep-sleep wakeup (need to be connected to EXT_RSTB); GPIO16
9	MTMS	I/O	GPIO 14; HSPI_CLK
10	MTDI	I/O	GPIO 12; HSPI_MISO
11	VDDPST	P	Digital/IO Power Supply (1.8 V ~ 3.6 V)
12	MTCK	I/O	GPIO 13; HSPI_MOSI; UART0_CTS
13	MTDO	I/O	GPIO 15; HSPI_CS; UART0_RTS
14	GPIO2	I/O	UART TX during flash programming; GPIO2
15	GPIO0	I/O	GPIO0; SPI_CS2
16	GPIO4	I/O	GPIO4
17	VDDPST	P	Digital/IO Power Supply (1.8 V ~ 3.6 V)
18	SDIO_DATA_2	I/O	Connect to SD_D2 (Series R: 20 Ω); SPIHD; HSPIHD; GPIO9
19	SDIO_DATA_3	I/O	Connect to SD_D3 (Series R: 200 Ω); SPIWP; HSPIWP; GPIO10
20	SDIO_CMD	I/O	Connect to SD_CMD (Series R: 200 Ω); SPI_CS0; GPIO11
21	SDIO_CLK	I/O	Connect to SD_CLK (Series R: 200 Ω); SPI_CLK; GPIO6
22	SDIO_DATA_0	I/O	Connect to SD_D0 (Series R: 200 Ω); SPI_MISO; GPIO7
23	SDIO_DATA_1	I/O	Connect to SD_D1 (Series R: 200 Ω); SPI_MOSI; GPIO8
24	GPIO5	I/O	GPIO5
25	U0RXD	I/O	UART Rx during flash programming; GPIO3
26	U0TXD	I/O	UART TX during flash programming; GPIO1; SPI_CS1
27	XTAL_OUT	I/O	Connect to crystal oscillator output, can be used to provide BT clock input
28	XTAL_IN	I/O	Connect to crystal oscillator input
29	VDDD	P	Analog Power 2.5 V ~ 3.6 V
30	VDDA	P	Analog Power 2.5 V ~ 3.6 V

Pin	Name	Type	Function
31	RES12K	I	Serial connection with a 12 kΩ resistor and connect to the ground
32	EXT_RSTB	I	External reset signal (Low voltage level: active)

📖 ***Note:***

1. *GPIO2, GPIO0, and MTDO are used to select booting mode and the SDIO mode;*
2. *U0TXD should not be pulled externally to a low logic level during the powering-up.*

3. Functional Description

The functional diagram of ESP8266EX is shown as in Figure 3-1.

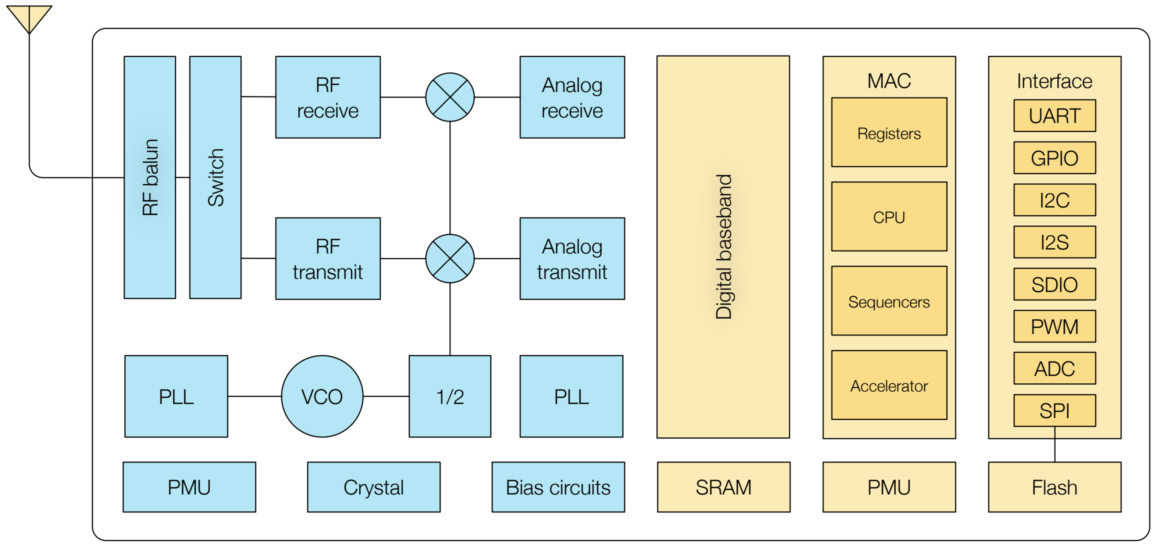


Figure 3-1. Functional Block Diagram

3.1. CPU, Memory, and Flash

3.1.1. CPU

The ESP8266EX integrates a Tensilica L106 32-bit RISC processor, which achieves extra-low power consumption and reaches a maximum clock speed of 160 MHz. The Real-Time Operating System (RTOS) and Wi-Fi stack allow 80% of the processing power to be available for user application programming and development. The CPU includes the interfaces as below:

- Programmable RAM/ROM interfaces (iBus), which can be connected with memory controller, and can also be used to visit flash.
- Data RAM interface (dBus), which can connected with memory controller.
- AHB interface which can be used to visit the register.

For information about the Xtensa® Instruction Set Architecture, please refer to *Xtensa® Instruction Set Architecture (ISA) Summary*.

3.1.2. Memory

ESP8266EX Wi-Fi SoC integrates memory controller and memory units including SRAM and ROM. MCU can access the memory units through iBus, dBus, and AHB interfaces. All memory units can be accessed upon request, while a memory arbiter will decide the running sequence according to the time when these requests are received by the processor.

According to our current version of SDK, SRAM space available to users is assigned as below.

- RAM size < 50 kB, that is, when ESP8266EX is working under the Station mode and connects to the router, the maximum programmable space accessible in Heap + Data section is around 50 kB.
- There is no programmable ROM in the SoC. Therefore, user program must be stored in an external SPI flash.

3.1.3. External Flash

ESP8266EX uses external SPI flash to store user programs, and supports up to 16 MB memory capacity theoretically.

The minimum flash memory of ESP8266EX is shown below:

- OTA disabled: 512 kB at least
- OTA enabled: 1 MB at least

⚠️ **Notice:**

SPI mode supported: Standard SPI, Dual SPI and Quad SPI. The correct SPI mode should be selected when flashing bin files to ESP8266. Otherwise, the downloaded firmware/program may not be working properly.

3.2. Clock

3.2.1. High Frequency Clock

The high frequency clock on ESP8266EX is used to drive both transmit and receive mixers. This clock is generated from internal crystal oscillator and external crystal. The crystal frequency ranges from 24 MHz to 52 MHz.

The internal calibration inside the crystal oscillator ensures that a wide range of crystals can be used, nevertheless the quality of the crystal is still a factor to consider to have reasonable phase noise and good Wi-Fi sensitivity. Refer to Table 3-1 to measure the frequency offset.

Table 3-1. High Frequency Clock Specifications

Parameter	Symbol	Min	Max	Unit
Frequency	FXO	24	52	MHz
Loading capacitance	CL	-	32	pF
Motional capacitance	CM	2	5	pF

Parameter	Symbol	Min	Max	Unit
Series resistance	RS	0	65	Ω
Frequency tolerance	ΔFXO	–15	15	ppm
Frequency vs temperature (–25 °C ~ 75 °C)	ΔFXO,Temp	–15	15	ppm

3.2.2. External Clock Requirements

An externally generated clock is available with the frequency ranging from 24 MHz to 52 MHz. The following characteristics are expected to achieve good performance of radio.

Table 3-2. External Clock Reference

Parameter	Symbol	Min	Max	Unit
Clock amplitude	VXO	0.8	1.5	Vpp
External clock accuracy	ΔFXO,EXT	–15	15	ppm
Phase noise @1-kHz offset, 40-MHz clock	-	-	–120	dBc/Hz
Phase noise @10-kHz offset, 40-MHz clock	-	-	–130	dBc/Hz
Phase noise @100-kHz offset, 40-MHz clock	-	-	–138	dBc/Hz

3.3. Radio

ESP8266EX radio consists of the following blocks.

- 2.4 GHz receiver
- 2.4 GHz transmitter
- High speed clock generators and crystal oscillator
- Bias and regulators
- Power management

3.3.1. Channel Frequencies

The RF transceiver supports the following channels according to IEEE802.11 b/g/n standards.

Table 3-3. Frequency Channel

Channel No.	Frequency (MHz)	Channel No.	Frequency (MHz)
1	2412	8	2447
2	2417	9	2452
3	2422	10	2457

Channel No.	Frequency (MHz)	Channel No.	Frequency (MHz)
4	2427	11	2462
5	2432	12	2467
6	2437	13	2472
7	2442	14	2484

3.3.2. 2.4 GHz Receiver

The 2.4 GHz receiver down-converts the RF signals to quadrature baseband signals and converts them to the digital domain with 2 high resolution high speed ADCs. To adapt to varying signal channel conditions, RF filters, automatic gain control (AGC), DC offset cancelation circuits and baseband filters are integrated within ESP8266EX.

3.3.3. 2.4 GHz Transmitter

The 2.4 GHz transmitter up-converts the quadrature baseband signals to 2.4 GHz, and drives the antenna with a high-power CMOS power amplifier. The function of digital calibration further improves the linearity of the power amplifier, enabling a state of art performance of delivering +19.5 dBm average TX power for 802.11b transmission and +18 dBm for 802.11n (MSC0) transmission.

Additional calibrations are integrated to offset any imperfections of the radio, such as:

- Carrier leakage
- I/Q phase matching
- Baseband nonlinearities

These built-in calibration functions reduce the product test time and make the test equipment unnecessary.

3.3.4. Clock Generator

The clock generator generates quadrature 2.4 GHz clock signals for the receiver and transmitter. All components of the clock generator are integrated on the chip, including all inductors, varactors, loop filters, linear voltage regulators and dividers.

The clock generator has built-in calibration and self test circuits. Quadrature clock phases and phase noise are optimized on-chip with patented calibration algorithms to ensure the best performance of the receiver and transmitter.

3.4. Wi-Fi

ESP8266EX implements TCP/IP and full 802.11 b/g/n WLAN MAC protocol. It supports Basic Service Set (BSS) STA and SoftAP operations under the Distributed Control Function

(DCF). Power management is handled with minimum host interaction to minimize active-duty period.

3.4.1. Wi-Fi Radio and Baseband

The ESP8266EX Wi-Fi Radio and Baseband support the following features:

- 802.11 b and 802.11 g
- 802.11 n MCS0-7 in 20 MHz bandwidth
- 802.11 n 0.4 μs guard-interval
- up to 72.2 Mbps of data rate
- Receiving STBC 2 x 1
- Up to 20.5 dBm of transmitting power
- Adjustable transmitting power

3.4.2. Wi-Fi MAC

The ESP8266EX Wi-Fi MAC applies low-level protocol functions automatically, as follows:

- 2 × virtual Wi-Fi interfaces
- Infrastructure BSS Station mode/SoftAP mode/Promiscuous mode
- Request To Send (RTS), Clear To Send (CTS) and Immediate Block ACK
- Defragmentation
- CCMP (CBC-MAC, counter mode), TKIP (MIC, RC4), WEP (RC4) and CRC
- Automatic beacon monitoring (hardware TSF)
- Dual and single antenna Bluetooth co-existence support with optional simultaneous receive (Wi-Fi/Bluetooth) capability

3.5. Power Management

ESP8266EX is designed with advanced power management technologies and intended for mobile devices, wearable electronics and the Internet of Things applications.

The low-power architecture operates in the following modes:

- Active mode: The chip radio is powered on. The chip can receive, transmit, or listen.
- Modem-sleep mode: The CPU is operational. The Wi-Fi and radio are disabled.
- Light-sleep mode: The CPU and all peripherals are paused. Any wake-up events (MAC, host, RTC timer, or external interrupts) will wake up the chip.
- Deep-sleep mode: Only the RTC is operational and all other part of the chip are powered off.

Table 3-4. Power Consumption by Power Modes

Power Mode	Description	Power Consumption
Active (RF working)	Wi-Fi TX packet	Please refer to Table 5-2.
	Wi-Fi RX packet	
Modem-sleep①	CPU is working	15 mA
Light-sleep②	-	0.9 mA
Deep-sleep③	Only RTC is working	20 uA
Shut down	-	0.5 uA

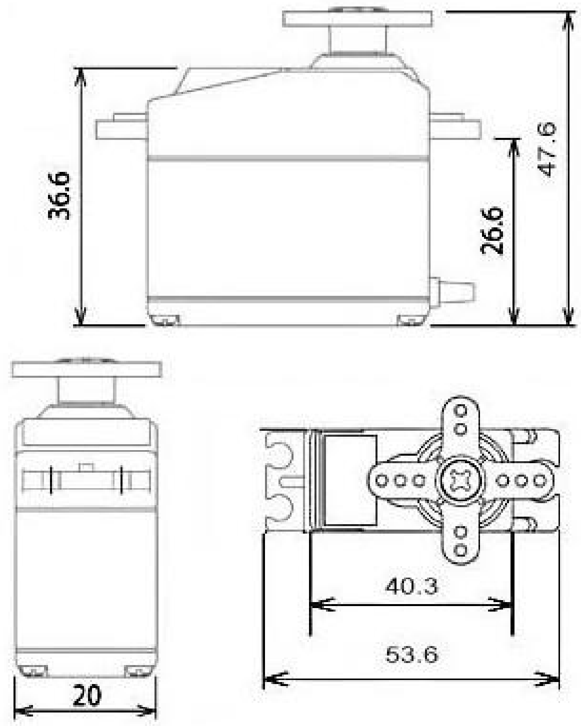
📖 ***Notes:***

① ***Modem-sleep*** *mode is used in the applications that require the CPU to be working, as in PWM or I2S applications. According to 802.11 standards (like U-APSD), it shuts down the Wi-Fi Modem circuit while maintaining a Wi-Fi connection with no data transmission to optimize power consumption. E.g., in DTIM3, maintaining a sleep of 300 ms with a wakeup of 3 ms cycle to receive AP's Beacon packages at interval requires about 15 mA current.*

② *During* ***Light-sleep*** *mode, the CPU may be suspended in applications like Wi-Fi switch. Without data transmission, the Wi-Fi Modem circuit can be turned off and CPU suspended to save power consumption according to the 802.11 standards (U-APSD). E.g. in DTIM3, maintaining a sleep of 300 ms with a wakeup of 3ms to receive AP's Beacon packages at interval requires about 0.9 mA current.*

③ *During* ***Deep-sleep*** *mode, Wi-Fi is turned off. For applications with long time lags between data transmission, e.g. a temperature sensor that detects the temperature every 100 s, sleeps for 300 s and wakes up to connect to the AP (taking about 0.3 ~ 1 s), the overall average current is less than 1 mA. The current of 20 μA is acquired at the voltage of 2.5 V.*

MG996R High Torque Metal Gear Dual Ball Bearing Servo



This High-Torque MG996R Digital Servo features metal gearing resulting in extra high 10kg stalling torque in a tiny package. The MG996R is essentially an upgraded version of the famous MG995 servo, and features upgraded shock-proofing and a redesigned PCB and IC control system that make it much more accurate than its predecessor. The gearing and motor have also been upgraded to improve dead bandwith and centering. The unit comes complete with 30cm wire and 3 pin 'S' type female header connector that fits most receivers, including Futaba, JR, GWS, Cirrus, Blue Bird, Blue Arrow, Corona, Berg, Spektrum and Hitec.

This high-torque standard servo can rotate approximately 120 degrees (60 in each direction). You can use any servo code, hardware or library to control these servos, so it's great for beginners who want to make stuff move without building a motor controller with feedback & gear box, especially since it will fit in small places. The MG996R Metal Gear Servo also comes with a selection of arms and hardware to get you set up nice and fast!

Specifications

- Weight: 55 g
- Dimension: 40.7 x 19.7 x 42.9 mm approx.
- Stall torque: 9.4 kgf·cm (4.8 V), 11 kgf·cm (6 V)
- Operating speed: 0.17 s/60º (4.8 V), 0.14 s/60º (6 V)

- Operating voltage: 4.8 V a 7.2 V
- Running Current 500 mA – 900 mA (6V)
- Stall Current 2.5 A (6V)
- Dead band width: 5 µs
- Stable and shock proof double ball bearing design
- Temperature range: 0 ºC – 55 ºC