RANCANG BANGUN ALAT PENGUKURAN RADIASI SINAR ULTRAVIOLET DAN RADIASI MATAHARI BERBASIS IoT

TUGAS AKHIR

Disusun dan Diajukan sabagai salah satu persyaratan Untuk Memperoleh Gelar Diploma III Teknik Listrik

Disusun Oleh :
Nama : Muhammad Fani Irsad
Nim : 19.52.032

PROGRAM STUDI TEKNIK LISTRIK D - III
FAKULTAS TEKNOLOGI INDUSTRI
INSTITUT TEKNOLOGI NASIONAL MALANG
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RANCANG BANGUN*ALAT PENGUKURAN RADIASI SINAR ULTRAVIOLET DAN RADIASI MATAHARI BERBASIS IoT*

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Malang, 10 Juli 2023

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RANCANG BANGUN*ALAT PENGUKURAN RADIASI SINAR ULTRAVIOLET DAN RADIASI MATAHARI BERBASIS IoT*

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ABSTRAK

Teknologi energi terbarukan di Indonesia saat ini semakin digencarkan salah satunya dengan mendirikannya Pembangkit Listrik Tenaga Surya. Namun untuk mendirikan PLTS perlu diperhatikan beberapa faktor salah satunya radiasi matahari yang menjadi faktor utama bagi PLTS untuk menghasilkan energi listrik. Dalam Tugas Akhir ini dirancang suatu alat ukur radiasi matahari untuk lebih memudahkan pengukuran intensitas radiasi matahari pada suatu area dengan memantaunya dari jarak jauh. Alat pengukuran yang dibuat memakai beberapa sensor yaitu, sensor UV, sensor intensitas cahaya, sensor inframerah dan sensor suhu. Alat pengukuran ini juga didukung dengan basis IoT dengan menggunakan ESP32 yang memungkinkan alat ini mampu mengirimkan data hasil pengukuran dari jarak jauh. Alat ini berfungsi baik dengan menggunakan power supply 12V yang diturunkan menjadi 5V oleh alat ini.

Kata Kunci : Sensor, IoT, Energi

IoT BASED MEASUREMENT TOOL FOR ULTRAVIOLET AND SOLAR RADIATION DESIGN

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ABSTRACT

Renewable energy technology in Indonesia is currently being intensified, one of which is by establishing a solar power plant. However, to set up a PLTS, several factors need to be considered, one of which is solar radiation which is the main factor for PLTS to produce electrical energy. In this Final Project a solar radiation measuring device is designed to make it easier to measure the intensity of solar radiation in an area by monitoring it from a distance. The measurement tool is made using several sensors, namely, UV sensors, light intensity sensors, infrared sensors and temperature sensors. This measurement tool is also supported on an IoT basis using ESP32 which allows this tool to be able to send measurement results remotely. This tool functions well by using a 12V power supply which is reduced to 5V by this tool.

Keywords: Sensors, IoT, Energy

KATA PENGANTAR

Puji syukur kehadirat Allah SWT atas segala limpahan rahmat-Nya sehingga tugas akhir ini yang berjudul “RANCANG BANGUN*ALAT PENGUKURAN RADIASI SINAR ULTRAVIOLET DAN RADIASI MATAHARI BERBASIS IoT*” Dapat terselesaikan.

Laporan Tugas Akhir ini dibuat untuk memenuhi salah satu syarat dalam memperoleh gelar ahli madya teknik listrik diploma tiga. Ucapan terima kasih yang sebesar-besarnya penulis sampaikan kepada Yang terhormat :

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7. Semua pihak yang telah membantu dalam penulisan dan penyusunan tugas akhir ini.

Penulis menyadari bahwa laporan tugas akhir ini masih jauh dari kata sempurna, untuk itu kritik dan saran dari pembaca sangat penulis harapkan untuk perbaikan laporan tugas akhir ini.

Malang, 10 Juli 2023

Penulis

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BAB I
PENDAHULUAN

1.1 LatarBelakang

Radiasi energi matahari, intensitas cahaya matahari, intensitas sinar UV, dan kualitas udara yang buruk merupakan beberapa faktor yang dapat mempengaruhi panel surya atau PLTS dalam menghasilkan energi listrik. Faktor-faktor tersebut dapat menjadi masalah bagi panel surya karena dapat menyebabkan ketidakefektifan bagi panel surya karena besarnya pengaruh radiasi matahari bagi panel surya untuk menghasilkan energi listrik.

Untuk mengatasi masalah tersebut, perlu dikembangkan sebuah alat yang dapat mengukur radiasi energi matahari, intensitas cahaya matahari, intensitas sinar UV, dan kualitas udara secara akurat dan efisien. Dalam hal ini, purwarupa alat pengukur radiasi energi matahari, intensitas cahaya matahari, intensitas sinar UV, dan sensor debu dianggap sebagai solusi yang tepat. Oleh karena itu, rancang bangun ini bertujuan untuk mendesain dan membuat purwarupa alat pengukur radiasi energi matahari, intensitas cahaya matahari, intensitas sinar UV, dan sensor debu dengan menggunakan teknologi terkini sehingga dapat digunakan untuk membantu mengatasi masalah tersebut.

1.2 Rumusan Masalah

Berdasarkan latar belakang masalah di atas, rumusan masalah yang dapat diajukan adalah sebagai berikut

a. Bagaimana merancang dan membuat purwarupa alat pengukur radiasi energi matahari, intensitas cahaya matahari dan intensitas sinar UV yang akurat dan efisien?

b. Bagaimana melakukan pengujian alat pengukur radiasi energi matahari, intensitas cahaya matahari dan intensitas sinar UV?

c. Bagaimana menganalisis hasil pengukuran radiasi energi matahari, intensitas cahaya mataharidan intensitas sinar UV yang dilakukan dengan alat yang telah dibuat?

d. Bagaimana mengevaluasi efektivitas dan kegunaan alat pengukur radiasi energi matahari, intensitas cahaya matahari dan intensitas sinar UV dalam membantu mengatasi masalah energi dan lingkungan yang disebabkan oleh faktor-faktor tersebut?

1.3 Tujuan

Tujuan penelitian tentang pembuatan purwarupa alat pengukur radiasi energi matahari, intensitas cahaya matahari, intensitas sinar UV, dan sensor debu adalah sebagai berikut:

a. Merancang dan membuat purwarupa alat pengukur radiasi energi matahari, intensitas cahaya matahari dan intensitas sinar UV yang akurat dan efisien.

b. Melakukan pengujian alat pengukur radiasi energi matahari, intensitas cahaya matahari dan intensitas sinar UV untuk menjamin keakuratan hasil pengukuran.

c. Menganalisis hasil pengukuran radiasi energi matahari, intensitas cahaya matahari dan intensitas sinar UV yang dilakukan dengan alat yang telah dibuat.

1.4 Batasan Masalah

Adapun batasan masalah dalam penelitian ini serta dapat lebih terarah, maka pembahasan ini akan dibatasi pada:

a) Perancangan alat pengukuran ini digunakan untuk menentukan kelayakan sebuah bakal area panel surya.
b) Perancangan alat pengukuran ini digunakan untuk mengukur dampak dari radiasi matahari.

1.5 Manfaat

Manfaat penelitian tentang pembuatan purwarupa alat pengukur radiasi energi matahari, intensitas cahaya matahari dan intensitas sinar UV adalah sebagai berikut:

a. Memberikan kontribusi pada pengembangan teknologi alat pengukur radiasi energi matahari, intensitas cahaya matahari dan intensitas sinar UV yang lebih akurat dan efisien.

b. Meningkatkan pemahaman dan pengetahuan tentang pengukuran radiasi energi matahari, intensitas cahaya matahari, intensitas sinar UV, dan kualitas udara, serta memperluas aplikasi teknologi alat pengukur tersebut.

c. Membantu dalam upaya penentuan lokasi pembangunan sebuah PLTS yang bergantung pada faktor radiasi energi matahari, intensitas cahaya matahari dan intensitas sinar UV dengan menyediakan alat pengukur yang mudah diakses dan digunakan.

d. Menjadi acuan untuk melakukan pengukuran radiasi energi matahari, intensitas cahaya matahari dan intensitas sinar UV di berbagai bidang seperti energi, lingkungan, industri, dan pertanian.

e. Mendorong pengembangan alat pengukur yang lebih ramah lingkungan dan berkelanjutan di masa depan.

1.6 SISTEM PENULISAN

Sistematika penyusunan tugas akhir ini terdiri dari :

BAB I : PENDAHULUAN

Merupakan sub bab, pendahuluan yang menjelaskan tentang latar belakang, rumusan masalah, tujuan, batasan masalah, manfaat dan sistematika penulisan.

BAB II : LANDASAN TEORI

Berisi landasan teori yang diperoleh dari literatur untuk mendukung pengujian dan pembuatan alat ini.

BAB III : PERANCANGAN DAN PEMBUATAN ALAT

Merupakan detail perhitungan dari dasar teori yang telah dijelaskan untuk proses perancangan.

BAB IV : PENGUJIAN ALAT

Merupakan hasil pembahasan tentang percobaan alat dan data-data yang diperoleh dari hasil pengujian yang dilakukan.

BAB V : PENUTUP

Merupakan hasil percobaan dari beberapa factor yang telah di uji coba dan diharapkan mampu memberikan masukan untuk melakukan evaluasi perancangan kedepannya.

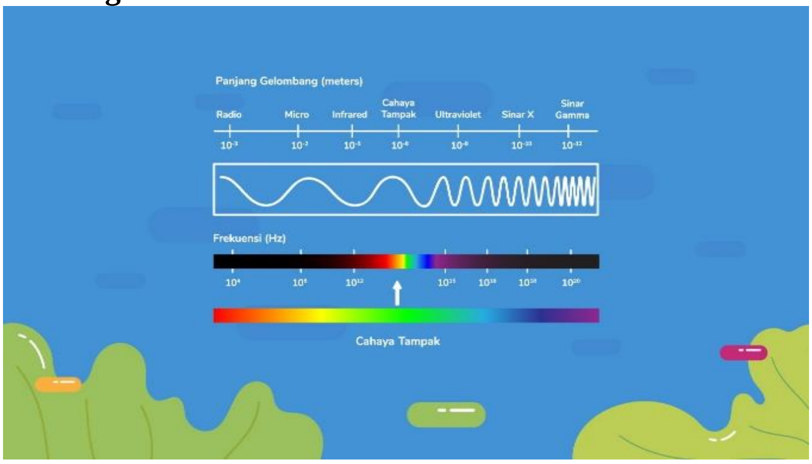
DAFTAR PUSTAKA

LAMPIRAN-LAMPIRAN

DAFTAR RIWAYAT HIDUP

BAB II
LANDASAN TEORI

2.1 Radiasi Energi Matahari



Gambar 2.1 Macam-macam Panjang Gelombang Matahari

Sumber :(https://pahamify.com/blog/pahami-materi/materi-ipa/fisika-spektrum-gelombang-elektromagnetik/)

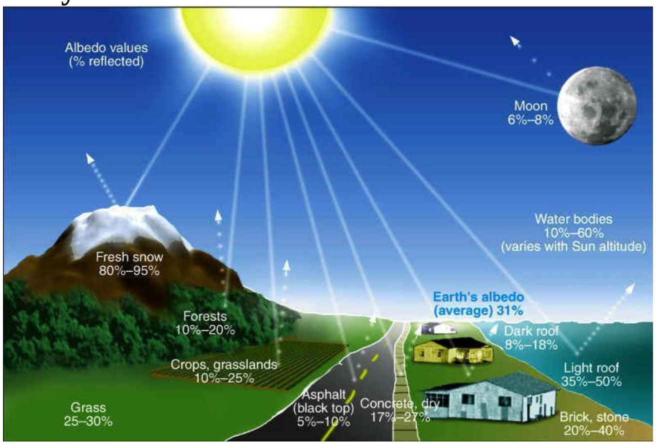
Radiasi energi matahari adalah radiasi elektromagnetik yang dipancarkan oleh Matahari dan terdiri dari berbagai macam panjang gelombang, mulai dari sinar gamma hingga gelombang radio. Radiasi energi matahari sangat penting bagi kehidupan di Bumi, karena energi matahari memasok sebagian besar energi yang dibutuhkan oleh ekosistem Bumi. Radiasi matahari dapat dibagi menjadi tiga jenis, yaitu radiasi ultraviolet (UV), radiasi tampak, dan radiasi inframerah.

Radiasi UV memiliki panjang gelombang yang lebih pendek dari radiasi tampak dan memiliki energi yang lebih besar. Radiasi UV dibagi menjadi tiga kategori, yaitu UV-A, UV-B, dan UV-C. Radiasi UV-A memiliki panjang gelombang yang paling panjang di antara ketiganya, sedangkan radiasi UV-C memiliki panjang gelombang yang paling pendek. Radiasi UV-B mempunyai energi yang paling besar di antara ketiga radiasi tersebut dan dapat berdampak kerusakan pada kulit dan penyakit tertentu jika terlalu banyak terpapar

Radiasi tampak adalah radiasi elektromagnetik yang terlihat oleh mata manusia. Radiasi tampak memiliki panjang gelombang yang lebih panjang dari radiasi UV dan memiliki energi yang lebih rendah. Radiasi tampak terdiri dari spektrum warna yang berbeda, mulai dari warna merah dengan panjang gelombang terpanjang hingga warna ungu dengan panjang gelombang terpendek.

Radiasi inframerah memiliki panjang gelombang yang lebih panjang dari radiasi tampak dan memiliki energi yang lebih rendah. Radiasi inframerah terdiri dari tiga jenis, yaitu IR-A, IR-B, dan IR-C. Radiasi IR-C memiliki panjang gelombang yang paling panjang, sedangkan radiasi IR-A memiliki panjang gelombang yang paling pendek. Radiasi IR-B mempunyai energi yang paling besar di antara ketiga radiasi tersebut dan dapat berdampak kerusakan pada jaringan tubuh jika terlalu banyak terpapar.

2.2 Intensitas Cahaya Matahari



Gambar 2.2 Ilustrasi Intensitas cahaya matahari

Sumber : (https://docplayer.info/49182469-Radiasi-matahari-dan-temperatur.html)

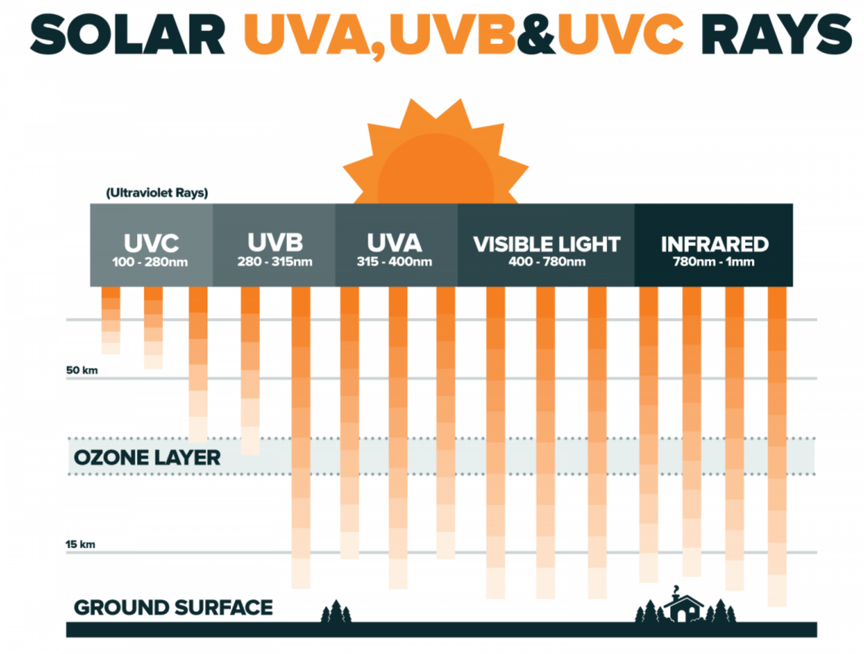
Energi yang dipancarkan oleh Matahari dalam bentuk cahaya per satuan waktu dan satuan luas. Intensitas cahaya matahari dapat ditaksir dalam satuan watt per meter persegi (W/m2) dan merupakan parameter penting dalam berbagai aplikasi seperti pertanian, teknologi energi, dan meteorologi.

Intensitas cahaya matahari dipengaruhi oleh beberapa faktor, di antaranya adalah jarak Bumi ke Matahari, waktu hari, cuaca, dan kondisi atmosfer. Jarak Bumi ke Matahari bervariasi dalam setiap saat dan berpengaruh terhadap intensitas cahaya matahari yang diterima di Bumi. Selain itu, intensitas cahaya matahari juga dipengaruhi oleh waktu hari, karena intensitas cahaya matahari yang diterima di Bumi lebih besar saat Matahari berada di atas kepala dibanding saat Matahari berada di ufuk timur atau barat.

Faktor cuaca juga mempengaruhi intensitas cahaya matahari yang diterima di Bumi. Saat cuaca cerah, intensitas cahaya matahari yang diterima di Bumi lebih besar daripada saat cuaca berawan atau hujan. Selain itu, kondisi atmosfer juga mempengaruhi intensitas cahaya matahari yang diterima di Bumi. Misalnya, atmosfer yang bersih memungkinkan lebih banyak radiasi matahari untuk mencapai permukaan Bumi, sementara atmosfer yang berdebu atau berpolusi akan menyerap dan memantulkan sebagian besar radiasi matahari.

Untuk mengukur intensitas cahaya matahari, digunakan alat yang disebut dengan pyranometer. Pyranometer adalah alat pengukur intensitas radiasi matahari yang memiliki sensitivitas terhadap radiasi tampak dan inframerah. Pyranometer biasanya digunakan dalam aplikasi meteorologi, teknologi energi, dan pertanian untuk mengukur intensitas cahaya matahari yang diterima di suatu lokasi pada saat tertentu.

2.3 Intensitas Sinar UV



Gambar 2.3 Intensitas sinar UV pada *bumi*

Sumber :(https://www.climate4life.info/2020/04/mengenal-sinar-ultraviolet-uv-index-manfaat-dan-bahaya-sinar-UV.html)

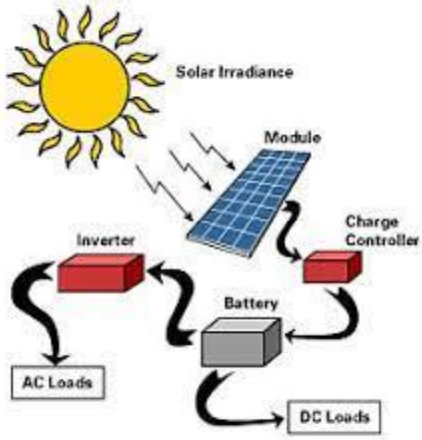
Intensitas sinar ultraviolet (UV) adalah ukuran jumlah radiasi UV yang diterima oleh suatu benda dalam bentuk cahaya per satuan waktu dan satuan luas. Radiasi UV memiliki panjang gelombang antara 100 hingga 400 nanometer (nm) dan terbagi menjadi tiga kategori, yaitu UV-A (315-400 nm), UV-B (280-315 nm), dan UV-C (100-280 nm).

Intensitas sinar UV dapat berdampak positif atau negatif pada manusia dan lingkungan. Pada manusia, sinar UV dapat membantu dalam produksi vitamin D dan mengobati beberapa penyakit kulit. Namun, paparan sinar UV yang berlebihan dapat menyebabkan kanker kulit, penuaan dini, dan kerusakan pada mata.

Intensitas sinar UV juga dapat mempengaruhi lingkungan, terutama pada tanaman dan hewan. Sinar UV dapat memicu pertumbuhan dan produksi senyawa yang berguna pada tanaman, seperti pigmen fotosintetik, tetapi pada tingkat yang terlalu tinggi, sinar UV dapat menyebabkan kerusakan pada jaringan tanaman dan menghambat pertumbuhan. Pada hewan, sinar UV dapat mempengaruhi kesehatan kulit dan reproduksi.

Untuk mengukur intensitas sinar UV, dapat digunakan alat yang disebut dengan radiometer UV. Radiometer UV adalah alat pengukur intensitas radiasi UV yang memiliki sensitivitas terhadap radiasi UV-A, UV-B, dan UV-C. Radiometer UV biasanya digunakan dalam aplikasi seperti meteorologi

2.4 Konversi Radiasi Matahari Pada Sel Surya



Gambar 2.4 Ilustrasi konversi energi pada sel surya

Sumber:(http://repository.umy.ac.id/bitstream/handle/123456789/28738/BAB%20II.pdf?sequence =6&isAllowed=y)

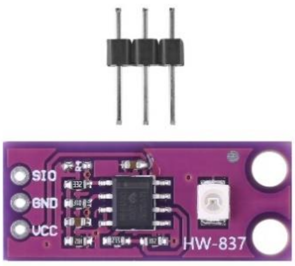
Sel surya memiliki bermacam komponen fotovoltaik atau komponen yang bisa mengkonversi cahaya menjadi listrik. Biasanya, sel surya memiliki bagian semikonduktor, logam, dan lapisan silikon yang merupakan strip anti reflektif, dan konduktor logam. Jumlah sel surya yang digunakan untuk membentuk panel surya berimbang dengan energi yang ditimbulkan. bertambah banyak sel surya yang dipakai, bertambah banyak juga energi matahari yang diubah menjadi energi listrik.

Cara kerja sel surya diawali dari partikel yang diujar “Foton” yaitu partikel sinar matahari berbentuk kecil. Disaat foton ini mengenai atom semi-konduktor sel surya, foton ini dapat menghasilkan energi yang besar yang dapat memisahkan elektron dari struktur atomnya. Elektron yang terpisah dan bermuatan negatif akan bebas beredar di daerah pita konduksi bahan semikonduktor, karenanya atom yang elektronnya hilang akan mengosongkan strukturnya dan disebut “hole” bermuatan positif.[5]

Elektron bebas bersifat negatif serta daerah semikonduktor berlaku sebagai penyumbang elektron yang disebut semikonduktor tipe N, sementara itu area “hole” sebagai penerima elektron disebut semi konduktor tipe Pdi. Perpotongan daerah negatif dan positif akan menimbulkan energi yang mendorong elektron dan “hole” untuk beredar ke arah yang berlawanan. “Hole” menjauh dari daerah positif dan Elektron bergerak menjauh dari daerah negatif. Ketika diberi beban berupa lampu atau alat listrik lainnya, maka akan menghasilkan arus listrik.[5]

Sederhananya, ketika sel surya menerima cahaya, maka terjadi pergerakan elektron pada sisi negatif dan positif. Gerakan ini menghasilkan arus listrik karenanya dapat digunakan sebagai energi untuk perangkat elektronik.

2.5 Sensor UV



Gambar 2.5 Sensor HW-837 GUVA-S12SD

Sumber: (*https://tur.grandado.com/products/hw-837-guva-s12sd-uv-sensor-modulu-240nm-370nm-ultraviyole-yogunlugu-sensoru*)

HW-837 GUVA-S12SD adalah detektor UV yang hanya mendeteksi cahaya dari 240nm hingga 370nm yang merupakan spektrum UV-B dan sebagian besar

UV-A. Sensor ini dapat digunakan untuk mengukur Indeks UV yang menyediakan skala untuk menentukan seberapa kuat sinar UV matahari dan tindakan perlindungan apa yang harus diambil.

2.5.1 Cara kerja GUVA-S12SD

Modul ini mencakup op amp ganda LM358 yang mengubah arus keluaran sensor menjadi tegangan dan kemudian memperkuat keluaran tersebut sehingga dapat dibaca oleh masukan analog pada MCU untuk mengambil pembacaan UV.

Op amp tahap pertama menghasilkan tegangan sebanding dengan arus foto sensor 4,3 * dalam µA. Jika arus foto adalah 0,1µA (0,09mW/cm^2), maka outputnya adalah 0,43V.[7]

Ini memberi input op amp tahap kedua dengan penguatan tambahan 6,1x. Dalam contoh ini hasil akhirnya adalah 0,43V x 6,1 = 2,62V.[7]

Sesuai konfigurasi, modul terutama berguna untuk mengukur tingkat sinar UV sedang hingga tinggi atau jika sensor ditempatkan di belakang filter densitas netral untuk mengurangi persentase UV yang mengenai sensor.[7]

Jika diinginkan untuk mengukur tingkat UV yang sangat tinggi, amplifikasi tahap kedua dapat dilewati. Ini dapat dicapai dengan menyingkat resistor 5.1K "512" dan melepaskan resistor 1K di sebelah kanannya dengan menandai "01B" atau "102". Ini mengubah penguatan op amp keluaran menjadi x1 secara efektif mengeluarkannya dari sirkuit. Dengan modifikasi tersebut, indeks UV kemudian dihitung dengan mengalikan output dengan 10.[7]

Tabel 2.1 Spesifikasi HW-837 GUVA-S12SD

Sumber:(https://www.digikey.com/en/products/detail/genicom-co-ltd/GUVA-S12SD/9960951)

NO	Spesifikasi	Keterangan
1	Rentang Spektral	240nm ~ 370nm
2	Responsivitas @ nm	0.14 A/W @ 350nm
3	Voltage	5V
4	Suhu Operasional	-30°C ~ 85°C

5	Output analog signal	varies from 0-1 V

2.6 Sensor Intensitas Cahaya

Gambar 2.6 Sensor TEMT6000

Sumber: (https://how2electronics.com/temt6000-ambient-light-sensor-arduino-measure-light-intensity/)

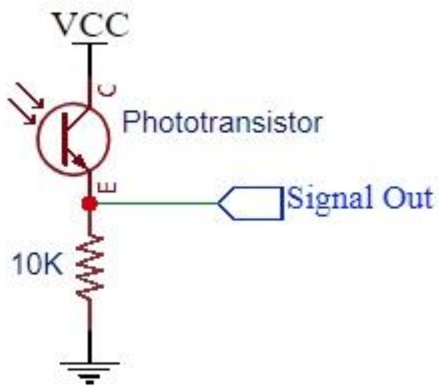
TEMT6000 dirancang sebagai detektor cahaya sekitar untuk secara otomatis mengontrol peredupan lampu latar ponsel, laptop, dasbor mobil, dan barang serupa. Ini dapat digunakan dalam banyak aplikasi yang diinginkan untuk mengukur kecerahan relatif dari cahaya yang jatuh pada sensor.[10]

Sensor dirancang terutama untuk mendeteksi spektrum cahaya yang terlihat oleh mata manusia dengan sensitivitas puncak pada 570nm yang berada dalam spektrum hijau. Rentang penuh mencakup 440nm hingga 800nm.[10]

2.6.1 Prinsip Kerja TEMT6000

Sensor itu sendiri adalah fototransistor NPN. Peningkatan intensitas cahaya pada basis transistor meningkatkan arus yang mengalir melalui kolektor/emitor transistor.[11]

Modul ini mencakup resistor 10K. Sensor TEMT6000 dan resistor membentuk jaringan pembagi tegangan seperti yang ditunjukkanpada Gambar 2.9. Dengan meningkatnya intensitas cahaya, aliran arus juga meningkat. Hal ini menyebabkan penurunan tegangan pada resistor 10K meningkat sehingga tegangan pada output sinyal meningkat menuju Vcc.[11]



Gambar 2.7 Ilustrasi Prinsip Kerja TEMT6000
Sumber: (https://protosupplies.com/product/temt6000-ambient-light-sensor-module/)

Tegangan output cukup linier dengan intensitas iluminasi (lux) yang jatuh pada perangkat. Kisaran deteksi yang andal mencakup rendah 10 lux hingga tinggi 1000 lux.

Keluaran analog dari modul biasanya dimasukkan ke masukan analog pada mikrokontroler yang dapat diukur dan ditindaklanjuti. Ini bekerja cukup baik untuk melakukan pengukuran relatif dan menentukan apakah semakin terang atau semakin gelap.[11]

Tabel 2.2 Spesifikasi TEMT6000
Sumber :(https://www.mouser.com/ProductDetail/Vishay-Semiconductors/TEMT6000?qs=HsFHTXumnCR2I3GlkUjIMw%3D%3D)

NO	Spesifikasi	Keterangan	
1	Power supply	3.3v ~ 5v	
2	Operating temperature	-40 to 85°C	
3	Peak wavelength	570 nm	
4	Collector Light Current	20 lux 100 lux Max bright conditions	10uA (typical) 50uA (typical) 3.8V (typ with Vdd = 5V)

2.7 Sensor Inframerah

Gambar 2.8 Sensor GY-2561 TSL2561
*Sumber: (*https://www.flyrobo.in/)

GY-2561 TSL2561 Ambient Light Sensor Module mengintegrasikan sensor adalah sensor cahaya canggih yang memiliki respons datar di sebagian besar spektrum yang terlihat. Tidak seperti sensor yang lebih sederhana, TSL2561 mengukur cahaya inframerah dan tampak untuk mendekati respons mata manusia dengan lebih baik. Dan karena TSL2561 adalah sensor pengintegrasian (menyerap cahaya untuk jangka waktu yang telah ditentukan), TSL2561 mampu mengukur jumlah cahaya kecil dan besar dengan mengubah waktu integrasi.[14]

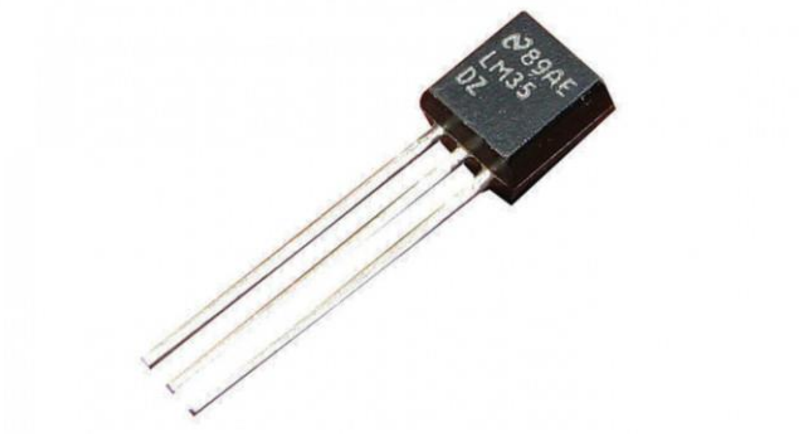
TSL2561 mampu melakukan komunikasi I2C langsung dan mampu melakukan rentang cahaya spesifik dari 0,1 – 40k+ Lux dengan mudah. Selain itu, TSL2561 berisi dua konverter analog-ke-digital (ADC) terintegrasi yang mengintegrasikan arus dari dua fotodioda, secara bersamaan. Setiap pelarian membutuhkan tegangan suplai 3V dan arus suplai rendah maks 0,6Ma.[14]

Tabel 2.3 Spesifikasi GY-2561 TSL2561
Sumber:(https://www.okystar.com/product-item/gy-2561-infrared-light-sensor-module-learning-resources-oky3250/)

NO	Spesifikasi	Keterangan
1	Power supply	3.3v ~ 5v
2	Digital output	High-resolution 16-Bit at 400 kHz I2C Fast-Mode

3	Dynamic range	0.1 – 40,000 LUX
4	operating temperature range	-40°C to 85°C
5	Antarmuka	I2C

2.8 Sensor LM35



Gambar 2.9 Sensor LM35
Sumber: (https://www.robotics.org.za/)

Sensor LM35 bertindak dengan mengkonversi besaran suhu menjadi besaran tegangan. Tegangan optimal yang muncul dari LM35 memiliki rasio 100° C ekuivalen dengan 1 volt. Sensor ini memiliki pemanasan sendiri kurang dari 0,1° C, dan dapat dijalankan menggunakan catu daya tunggal dan bisa dihubungkan ke antarmuka sirkuit kontrol dengan sangat mudah. [17]

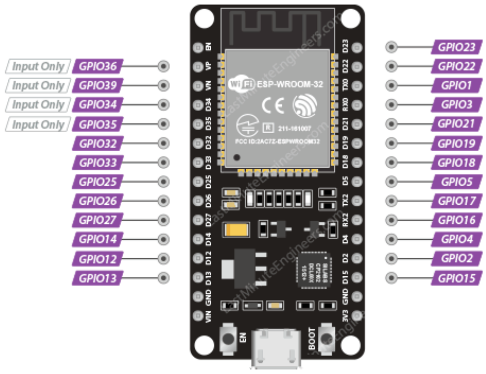
IC LM 35 adalah sensor suhu yang akurat dan terintegrasi dalam bentuk Sirkuit Terpadu (IC), memiliki output tegangan keluaran yang linier terhadap perubahan suhu. Sensor ini memiliki fungsi sebagai pengubah dari besaran fisik suhu ke besaran tegangan yang memiliki koefisien 10 mV/°C yang berarti kenaikan suhu 1° C maka terjadi perubahan naik tegangan sebesar 10 mV.17]

Tabel 2.4 Spesifikasi LM35
Sumber: (https://www.mahirelektro.com/)

NO	Spesifikasi	Keterangan
1	Linearitas	+10 mV/ ° C
2	Akurasi	0,5 ° C pada suhu ruang

3	Range	+2 º C – 150 º C
4	Input	4 V – 30 V

2.9 ESP32



Gambar 2.10 ESP32

Sumber: (https://lastminuteengineers.com/)

ESP32 adalah chip kombo Bluetooth 2,4 GHz dan Wi-Fi tunggal yang dibuat dengan TSMC berdaya rendah 40 nm. Teknologi ini dibuat untuk mendapat daya terbaik dan kinerja RF, menentukan, keandalan, keserbagunaan dan ketahanan dalam berbagai aplikasi dan skenario daya.[18]

ESP32 dibuat untuk aplikasi seluler, Internet of Things (IoT) dan perangkat elektronik yang dapat dikenakan. Ini memiliki banyak fitur chip berdaya rendah canggih, termasuk gerbang jam resolusi halus, mode daya, dan penskalaan daya dinamis.[18]

Tabel 2.5 Spesifikasi ESP32

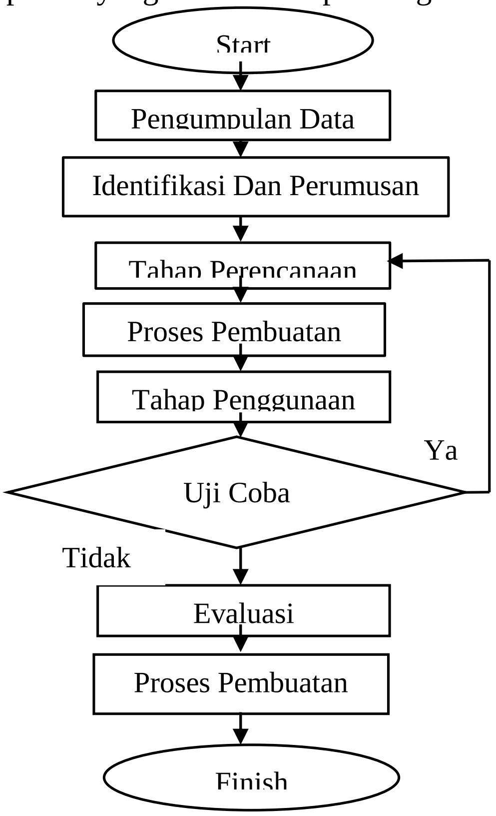
Sumber: (https://www.espressif.com/)

NO	**Spesifikasi**	**Keterangan**
1	Frequency clock	240MHz
2	Microprocessor	Xtensa LX6 Dual Core
3	Operating voltage	3.3V
4	Communications	SPI(4), I2C(2), I2S(2), CAN, UART(3)
5	Bluetooth	V4.2 – Supports BLE and Classic Bluetooth
6	Wi-Fi	802.11b/g/n

BAB III
PERENCANAAN DAN PEMBUATAN ALAT

3.1 Tahap Perancangan Alat

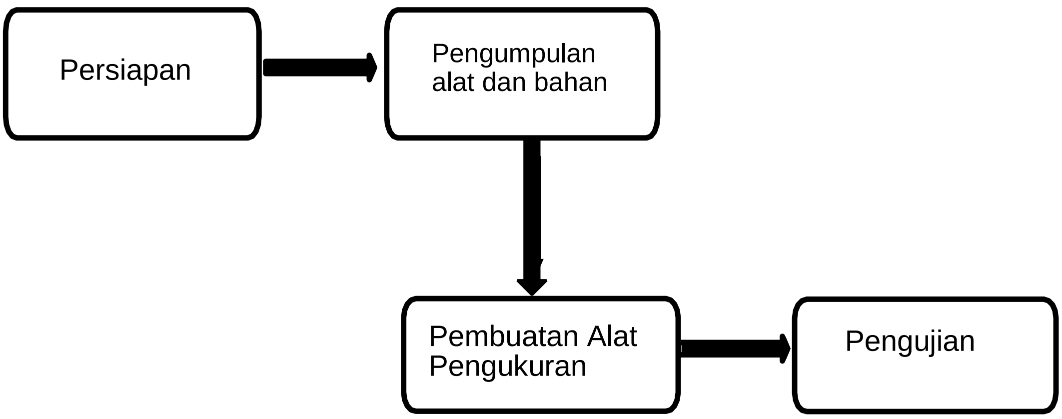
Pada perancangan alat ini saya akan membuat bagan tahapan agar mempermudah proses yang akan dibuat pada tugas akhir ini.



Gambar 3.1 Bagan tahap perancangan alat

3.2 Metode Perencanaan

Perencanaan rancangan alat pengukuran radiasi sinar ultraviolet dan radiasi matahari dilakukan beberapa tahapan :



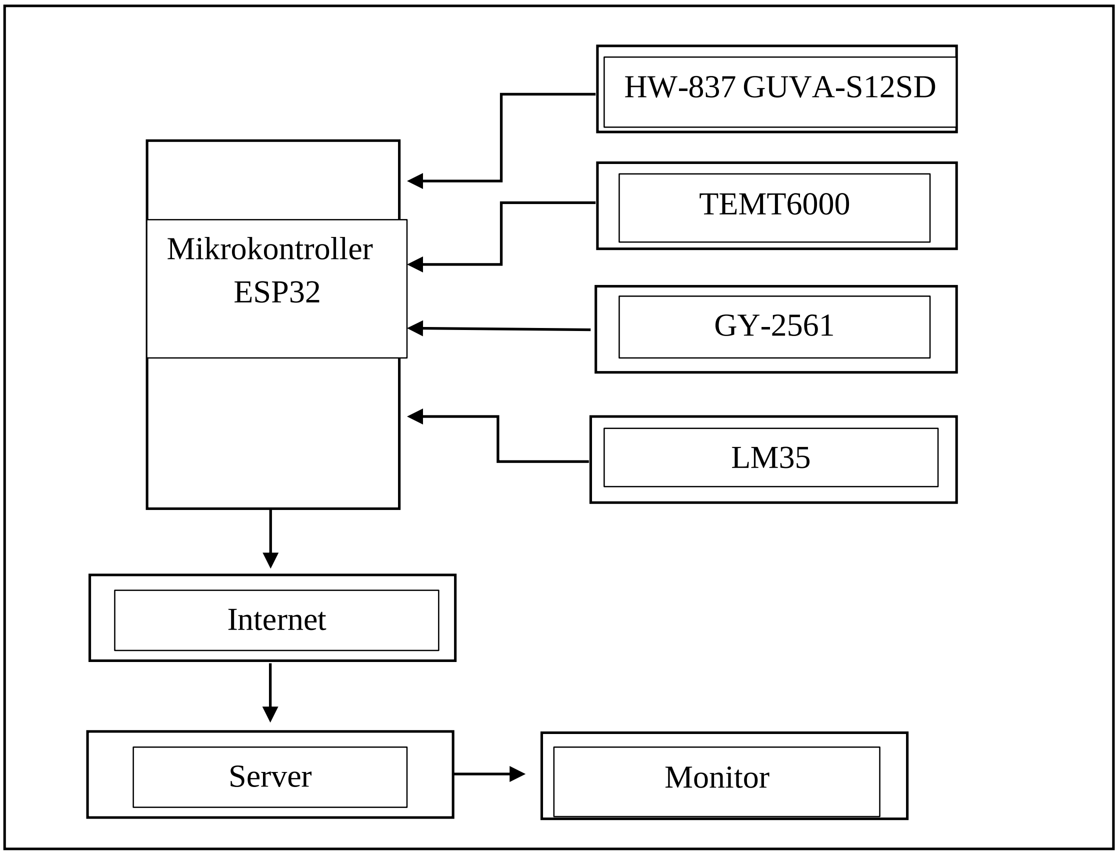
Gambar 3.2 Diagram Perencanaan Perancangan Alat

3.3 Tahap Pembuatan Alat

Dalam tahap pembuatan inverter ini perlu dipersiapkan bahan dan komponen alat sebagai berikut :

1. Sensor Ultraviolet
2. Sensor Intensitas Cahaya
3. Sensor Inframerah
4. Sensor Suhu
5. ESP32
6. PCB

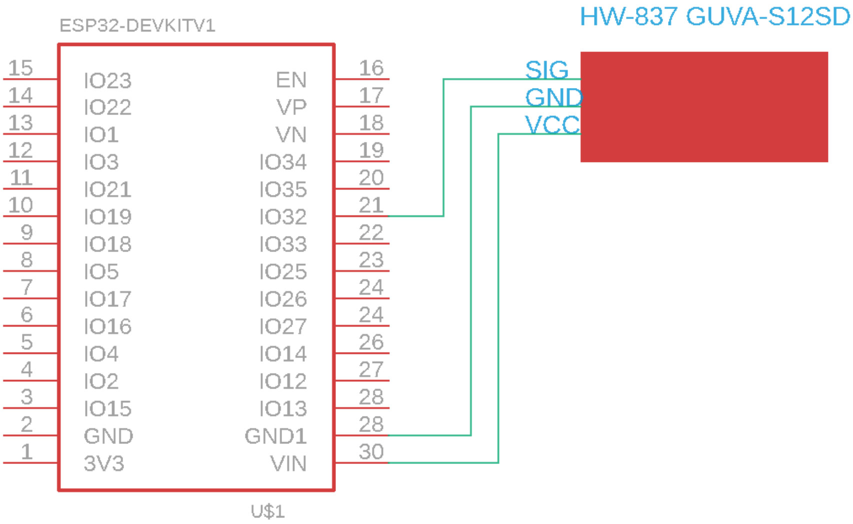
3.4 Diagram Blok



Gambar 3.3 Blok Diagram Perancangan Sistem

3.5 Rangkaian Sensor UV

Sensor HW-837 GUVA-S12SD digunakan untuk mengukur intensitas radiasi sinar UV di area sekitar sensor. Gambar skematik dari rangkaian sensor HW-837 GUVA-S12SD dapat dilihat pada Gambar 3.4.

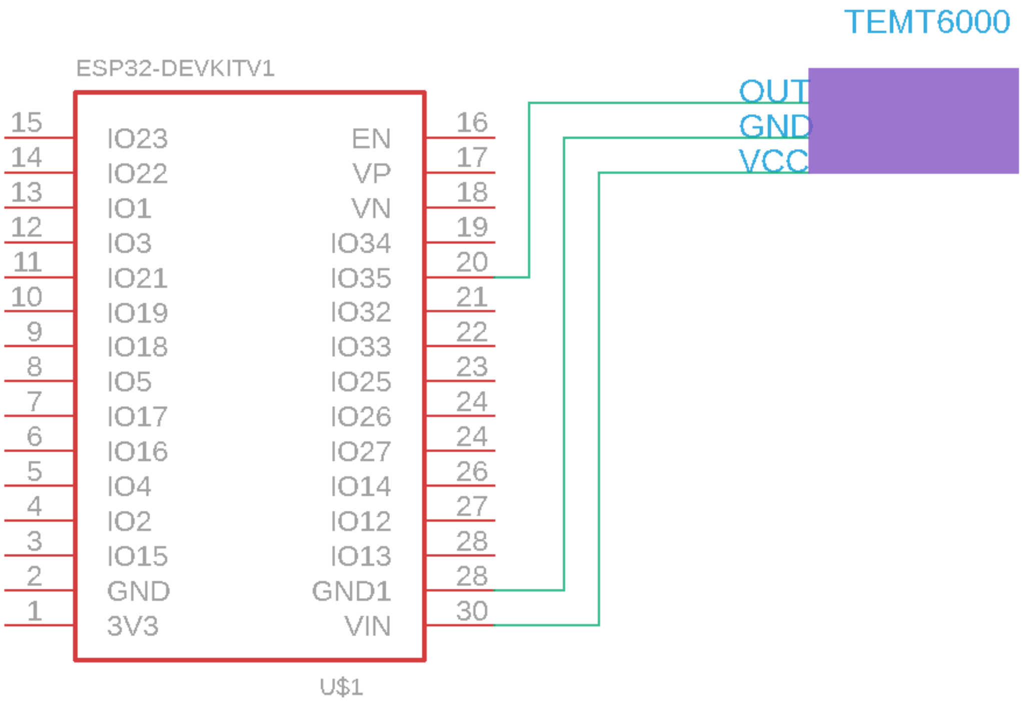


Gambar 3.4 Skematik Rangkaian Sensor HW-837 GUVA-S12SD

Sensor UV HW-87 GUVA-S12SD diatas memiliki output yang berupa sinyal analog yang kemudian dihubungkan pada mikrokontroler ESP32 melalui pin analog GPIO32.

3.6 Rangkaian Sensor Intensitas Cahaya

Sensor TEMT6000 digunakan untuk mengukur intensitas cahaya matahariyang terdapat pada area sekitar sensor dipasang. Gambar skematik dari rangkaian sensor TEMT6000 dapat dilihat pada Gambar 3.5.

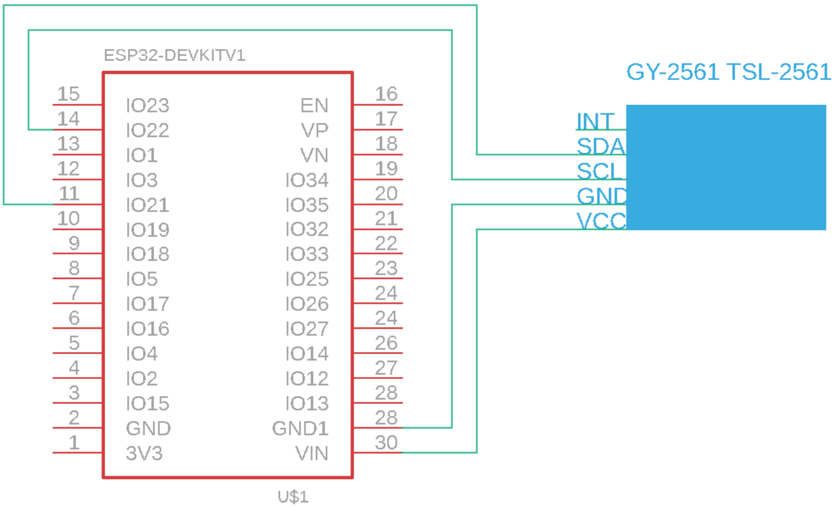


Gambar 3.5 Skematik Rangkaian Sensor TEMT6000

Sensor TEMT6000 diatas memliki output berupa sinyal analog yang dihubungkan langsung dengan mikrokontroler ESP32 melalui pin analog GPIO35.

3.7 Rangkaian sensor Inframerah

Sensor GY-2561 TSL-2561 digunakan untuk mendeteksi adanya sinar inframerah di area sekitar sensor dipasang. Gambar skematik dari rangkaian sensor GY-2561 TSL-2561 dapat dilihat pada gambar. 3.6.

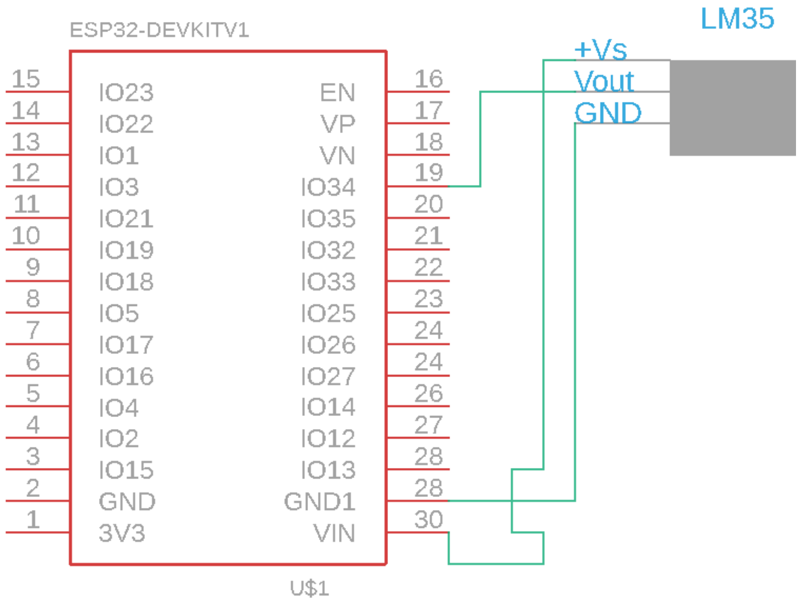


Gambar 3.6 Skematik Rangkaian Sensor GY-2561 TSL-2561

Sensor GY-2561 TSL-2561 di atas memiliki komunikasi antarmuka I2C yang kemudian dihubungkan dengan pin digital pada mikrokontroler ESP32.

3.8 Rangkaian Sensor Suhu

Sensor LM35 dipakai untuk mengukur suhu yang terdapat di area sekitar pemasangan sensor. Gambar skematik dari rangkaian sensor LM35 dapat dilihat pada Gambar 3.7

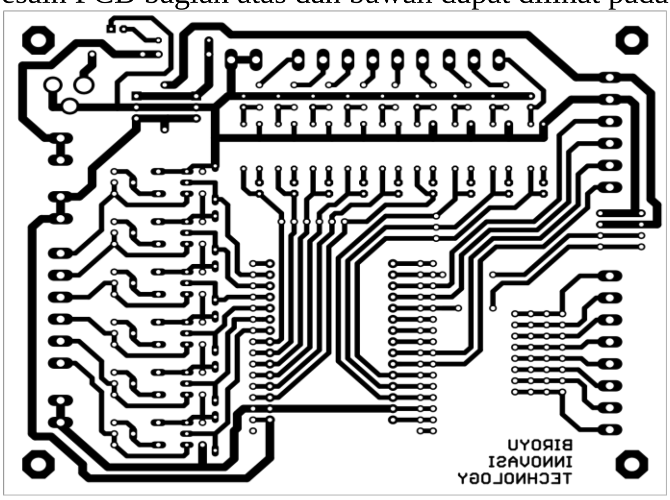


Gambar 3.7 Skematik Rangkaian Sensor LM35

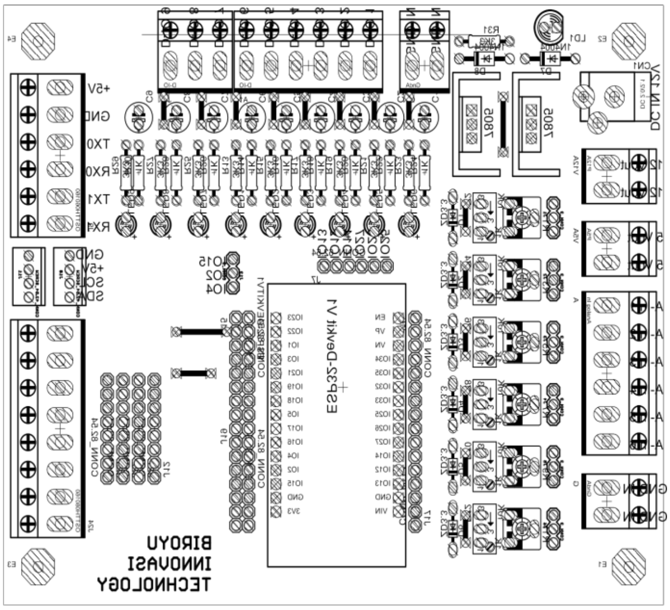
Pada gambar skematik rangkaian di atas, sensor LM35 memiliki output berupa sinyal analog yang kemudian dihubungkan pada mikrokontroler ESP32 melalui pin analog.

3.9 Desain PCB

Desain rangkaian PCB secara keseluruhan merupakan integrasi dari beberapa sensor yang kemudian dihubungkan dan diproses oleh mikrokontroler ESP32. Keluaran dari proses pengolahan tersebut kemudian ditampilkan melalui PC/Laptop. Desain PCB bagian atas dan bawah dapat dilihat pada Gambar 3.8.



Gambar 3.8 Desain PCB (Botom)



Gambar 3.9 Desain PCB (Top)

BAB IV
PENGUJIAN ALAT

4.1 Tahapan Pelaksanaan Pengujian

Pada bab ini akan dilaksanakan pengujian terhadap alat yang telah dibuat, dalam hal ini pengujian yang dilakukan adalah proses pengambilan data pada setiap sensor yang terpasang. Dalam tahap pengujian ini, sensor harus terpasang dengan benar dimana:

a) Memastikan proses pemrograman terhadap sensor sudah benar. Yang dimana perintah program terhadap sensor akan dibaca dengan benar oleh mikrokontroler.
b) Memastikan kabel sudah terhubung dengan benar dengan pin yang tersedia pada mikrokontroler.

4.2 Pengujian Alat

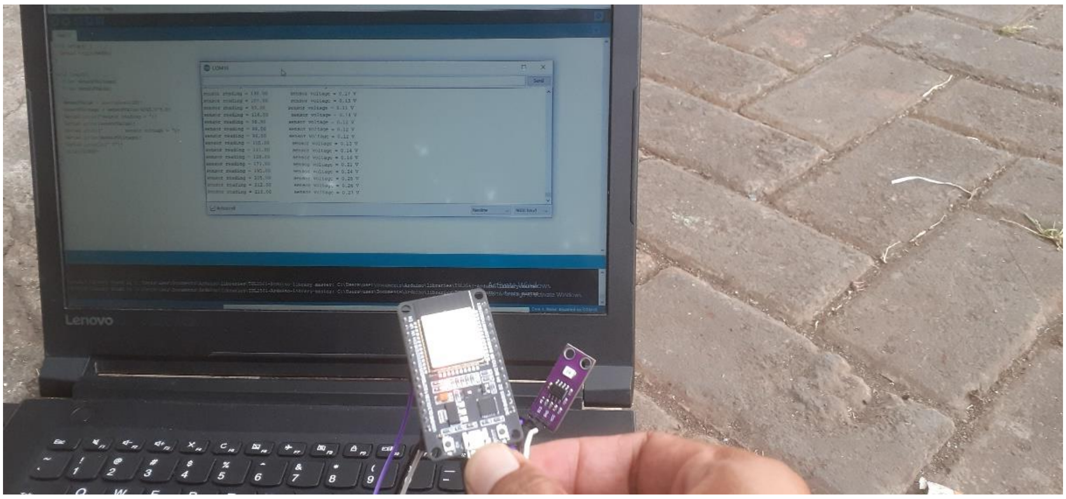
Pada bab ini akan dilakukan pengujian terhadap alat yang telah dibuat. Pengujian ini dilakukan untuk memperoleh data pengukuran pada alat karenanya dapat ditulis secara benar dalam laporan TA. Serta dilakukannya pengujian terhadap alat untuk mengetahui keberhasilan dalam pembuatan alat.

Gambar 4.1 Pengukuran Sinar Inframerah

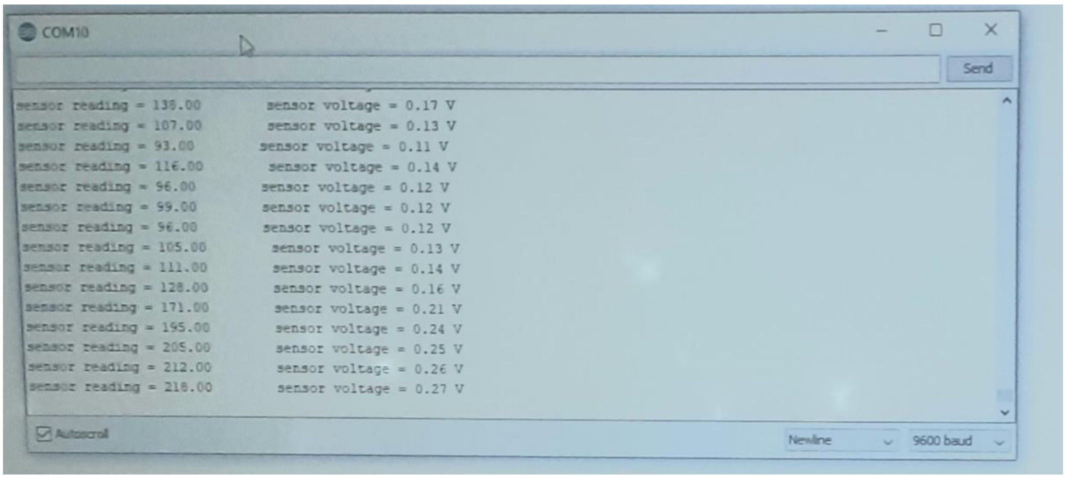
Gambar 4.2 Tampilan Output Pengukuran Sinar Inframerah Pada Laptop

Gambar 4.3 Pengukuran Intensitas Cahaya

Gambar 4.4 Tampilan Output Pengukuran Intensitas Cahaya Pada Laptop

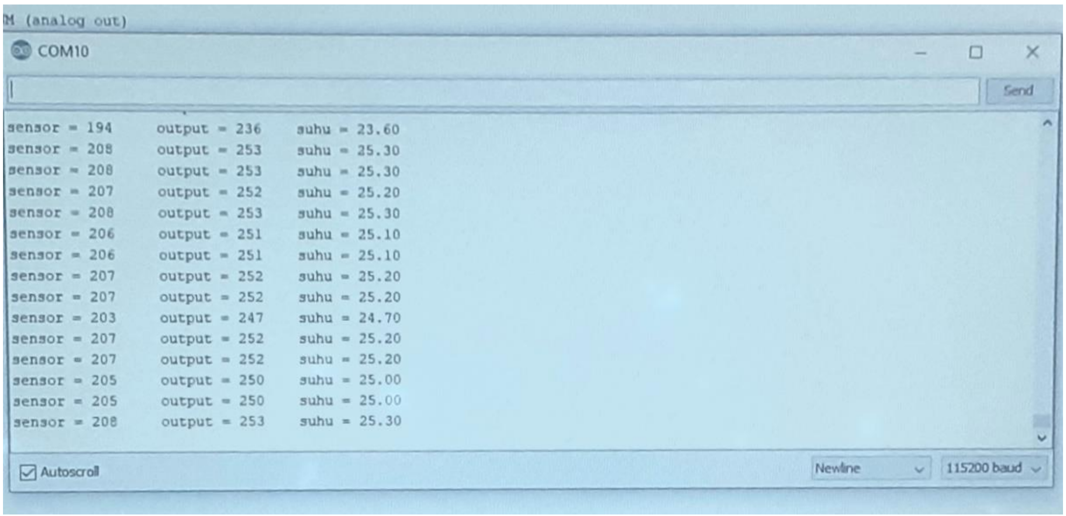


Gambar 4.5 Pengukuran Intensitas Sinar UV



Gambar 4.6 Tampilan Output Pengukuran Intensitas Sinar UV Pada Laptop

Gambar 4.7 Pengukuran Suhu



Gambar 4.8 Tampilan Output Pengukuran Suhu Pada Laptop

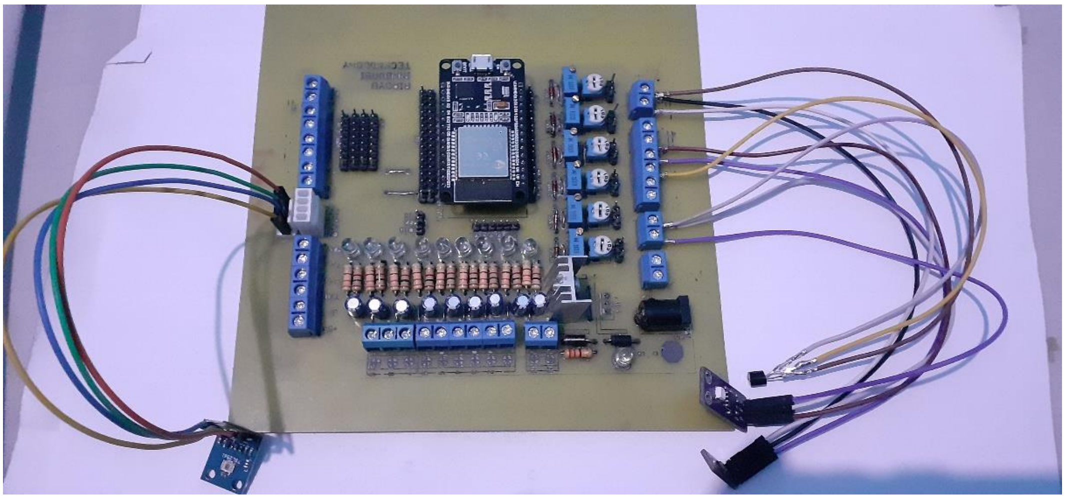
4.3 Pengujian dan Pengambilan Data Alat

Data yang diambil memalui hasil pengujian dibagi menjadi 3 jenis uji yaitu pengujian di area gelap, pengujian di area teduh, pengujian di bawah sinar matahari langsung dengan keterangan sebagai berikut :

- Area gelap merupakan tempat tanpa sinar matahari dimana alat ini ditutup oleh suatu benda sehingga tidak mendapat sinar matahari.
- Area teduh merupakan tempat di bawah atap atau pepohonan yang masih mendapatkan sebagian sinar matahari.
- Area di bawah sinar matahari langsung merupakan tempat yang terkena sinar matahari langsung tanpa halangan apapun.

4.3.1 Hasil Rancang Bangun Alat Ukur

Berikut merupakan hasil rancang bangun alat pengukuran. Rancang bangun ini dirangkai untuk mengukur radiasi sinar ultraviolet dan radiasi matahari yang selanjutnya akan ditampilkan melalui monitor PC/Laptop.



Gambar 4.9 Hasil Rancang Bangun Alat Ukur

4.3.2 Data Hasil Pengujian

Tabel 4.1 Hasil Pengujian di Area Gelap

NO	Waktu	GUVA-S12SD (nm)	TEMT6000 (light intensity)	GY-2561 (lux)	LM35 (°C)
1	14.30	0,00	0,07%	3	27,70
2	14.35	0,00	0,15%	2	26,70
3	14.40	0,00	0,02%	4	24,50
4	14.45	0,00	0,12%	2	26,00
5	14.50	0,00	0,02%	1	24,60
6	14.55	0,00	0,02%	2	26,90

Tabel di atas merupakan tabel hasil pengujian alat pengukuran radiasi sinar ultraviolet dan sinar matahari dengan pengujian di area gelap. Dari hasil pengukuran mendapatkan rata-rata sebagai berikut :

- Sensor UV (GUVA-S12SD) : 0,00 nm
- Sensor Intensitas Cahaya (TEMT6000) : 0,06%
- Sensor Infrared (GY-2561) : 2,3 lux
- Sensor Suhu (LM35) : 26,06°C

Tabel 4.2 Hasil Pengujian di Area Teduh

NO	Waktu	GUVA-S12SD (nm)	TEMT6000 (light intensity)	GY-2561 (lux)	LM35 (°C)
1	15.00	342,00	41,77%	1649	27,90
2	15.05	292,00	42,63%	1621	28,30
3	15.10	159,00	43,19%	1793	25,10
4	15.15	179,00	43,77%	1805	26,90
5	15.20	77,00	46,68%	1669	27,80
6	15.25	115,00	42,99%	1623	27,40

Tabel di atas merupakan tabel hasil pengujian alat pengukuran radiasi sinar ultraviolet dan sinar matahari dengan pengujian di area teduh. Dari hasil pengukuran mendapatkan rata-rata sebagai berikut :

- Sensor UV (GUVA-S12SD) : 194,00 nm
- Sensor Intensitas Cahaya (TEMT6000) : 43,50%
- Sensor Infrared (GY-2561) : 1693 lux
- Sensor Suhu (LM35) : 27,23°C

Tabel 4.3 Hasil Pengujian di Bawah Sinar Matahari Langsung

NO	Waktu	GUVA-S12SD (nm)	TEMT6000 (light intensity)	GY-2561 (lux)	LM35 (°C)
1	15.30	729,00	99,98%	3163	31,50
2	15.35	560,00	99,98%	3249	30,80
3	15.40	467,00	99,98%	3308	29,30
4	15.45	432,00	99,98%	3124	31,20
5	15.50	424,00	99,98%	3233	29,00
6	15.55	410,00	99,98%	3094	28,40

Tabel di atas merupakan tabel hasil pengujian alat pengukuran radiasi sinar ultraviolet dan sinar matahari dengan pengujian di bawah sinar matahari langsung. Dari hasil pengukuran mendapatkan rata-rata sebagai berikut :

- Sensor UV (GUVA-S12SD) : 503,00 nm
- Sensor Intensitas Cahaya (TEMT6000) : 99,98%
- Sensor Infrared (GY-2561) : 3195 lux
- Sensor Suhu (LM35) : 30,03°C

BAB V
PENUTUP

5.1 Kesimpulan

Bersandarkan rancang bangun yang telah dijalankan dapat disimpulkan bahwa:

a) Mendapat hasil bagus dalam merancang alat pengukuran radiasi sinar ultraviolet dan radiasi sinar matahari.
b) Telah berhasil melakukan pengujian terhadap alat pengukuran radiasi sinar ultraviolet dan radiasi matahari dengan hasil rata-rata Sensor UV : 503,00 nm, Sensor Intensitas Cahaya : 99,98%, Sensor Infrared : 3195 lux, Sensor Suhu : 30,03°C pada area di bawah sinar matahari langsung dengan kondisi cerah di sore hari.
c) Berdasarkan hasil pengukuran radiasi sinar ultraviolet dan sinar matahari pada area gelap, pada area teduh dan di bawah matahari langsung alat ini dapat berfungsi, dapat dianalisis dan diambil rata-rata.

5.2 Saran

Saran untuk pembuatan alat selanjutnya, anatara lain yaitu:

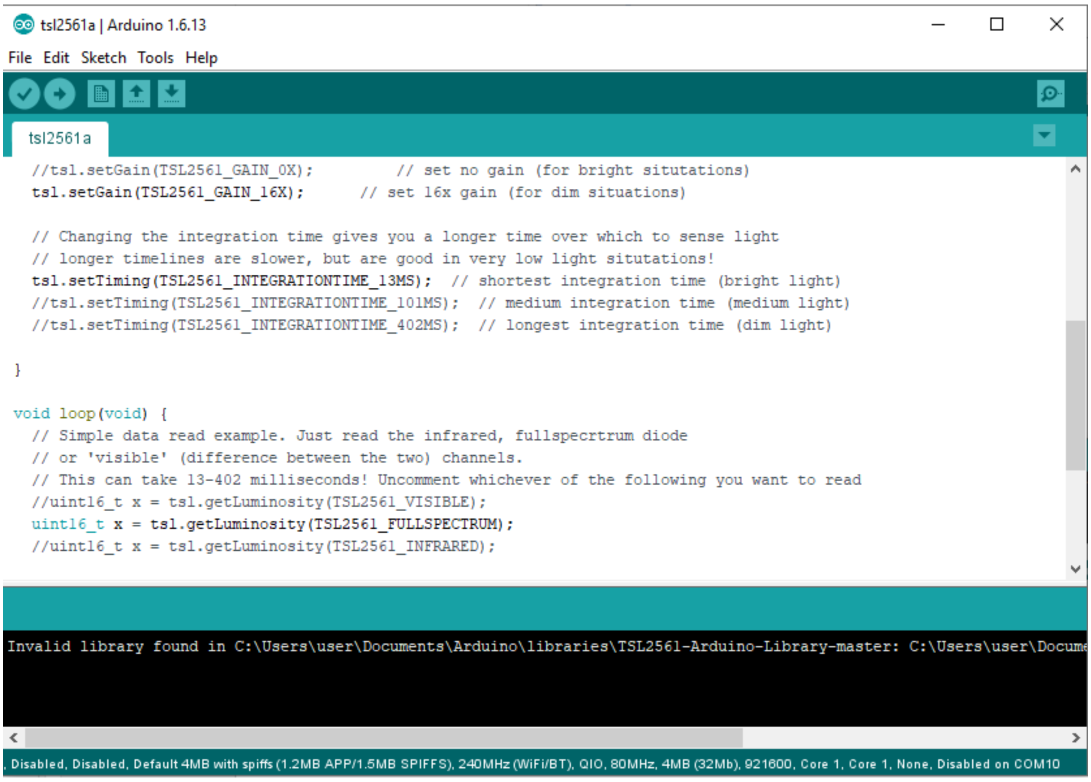
a) Pada awal pengerjaan sampai akhir diperlukan pembelajaran program arduino terlebih dahulu, karena apabila salah dalam memprogram maka akan menyebabkan error.
b) Mencari LM35 yang lebih baik lagi agar dapat melakukan pengukuran dengan tepat.
c) Menggunakan bread board atau PCB baru agar penataan sensor lebih rapi.
d) Menggunakan solder yang memiliki kualitas baik agar hasil penyolderan lebih bagus lagi.

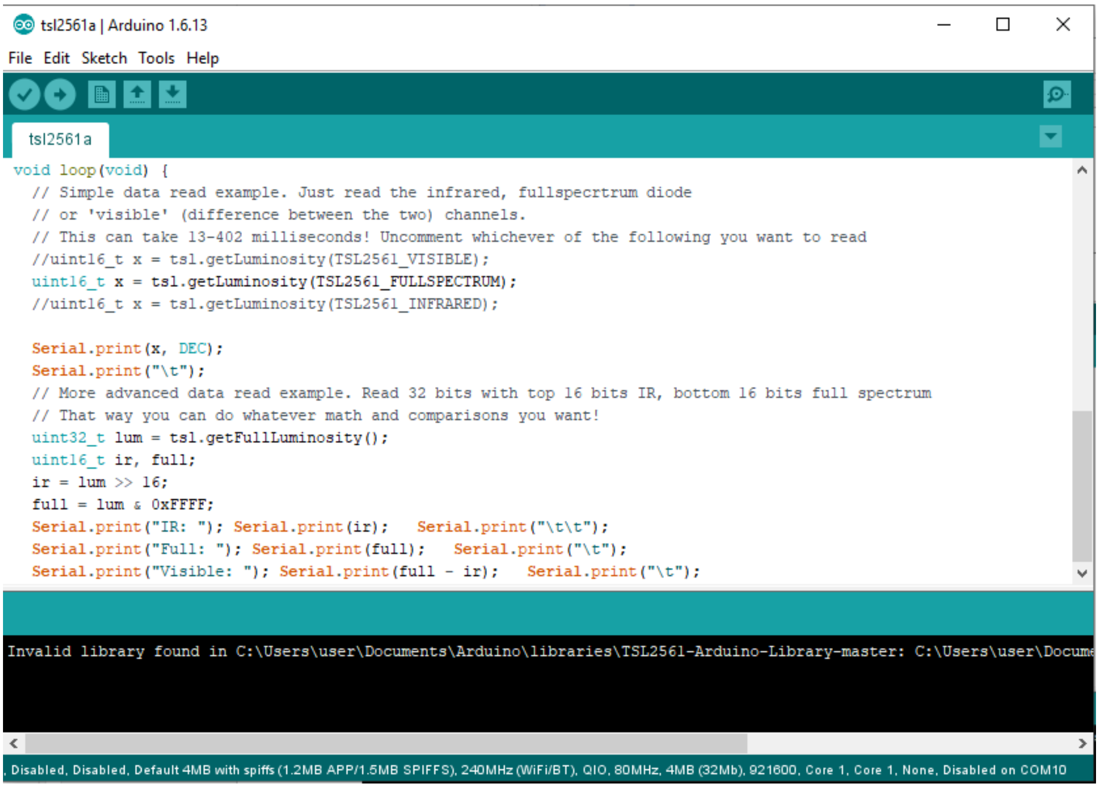
LAMPIRAN-LAMPIRAN

A. LAMPIRAN NASKAH PROGRAM

Gambar di atas merupakan naskah program untuk menjalankan sensor UV atau HW-837.

Gambar di atas merupakan naskah program untuk menjalankan sensor intensitas cahaya atau temt6000





Gambar di atas merupakan naskah program untuk menjalankan sensor inframerah atau TSL2561

Gambar di atas merupakan naskah program untuk menjalankan sensor suhu atau LM35

B. LAMPIRAN DATA SHEET LM35

National Semiconductor

November 2000

LM35
Precision Centigrade Temperature Sensors

General Description

The LM35 series are precision integrated-circuit temperature sensors, whose output voltage is linearly proportional to the Celsius (Centigrade) temperature. The LM35 thus has an advantage over linear temperature sensors calibrated in ˚ Kelvin, as the user is not required to subtract a large constant voltage from its output to obtain convenient Centigrade scaling. The LM35 does not require any external calibration or trimming to provide typical accuracies of ±¼˚C at room temperature and ±¾˚C over a full −55 to +150˚C temperature range. Low cost is assured by trimming and calibration at the wafer level. The LM35's low output impedance, linear output, and precise inherent calibration make interfacing to readout or control circuitry especially easy. It can be used with single power supplies, or with plus and minus supplies. As it draws only 60 µA from its supply, it has very low self-heating, less than 0.1˚C in still air. The LM35 is rated to operate over a −55˚ to +150˚C temperature range, while the LM35C is rated for a −40˚ to +110˚C range (−10˚ with improved accuracy). The LM35 series is available packaged in hermetic TO-46 transistor packages, while the LM35C, LM35CA, and LM35D are also available in the plastic TO-92 transistor package. The LM35D is also available in an 8-lead surface mount small outline package and a plastic TO-220 package.

Features

- Calibrated directly in ˚ Celsius (Centigrade)
- Linear + 10.0 mV/˚C scale factor
- 0.5˚C accuracy guaranteeable (at +25˚C)
- Rated for full −55˚ to +150˚C range
- Suitable for remote applications
- Low cost due to wafer-level trimming
- Operates from 4 to 30 volts
- Less than 60 µA current drain
- Low self-heating, 0.08˚C in still air
- Nonlinearity only ±¼˚C typical
- Low impedance output, 0.1 Ω for 1 mA load

Typical Applications

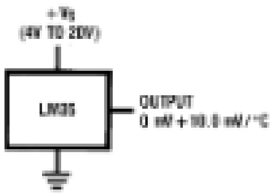
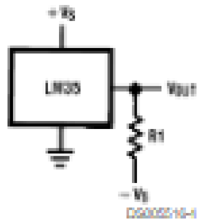


FIGURE 1. Basic Centigrade Temperature Sensor (+2˚C to +150˚C)



Choose $R_1 = -V_S/50\ \mu A$

V_{OUT} = +1,500 mV at +150˚C
= +250 mV at +25˚C
= −550 mV at −55˚C

FIGURE 2. Full-Range Centigrade Temperature Sensor

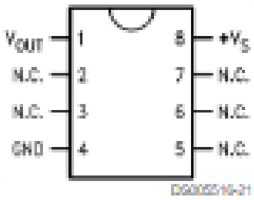
Connection Diagrams

TO-46
Metal Can Package*

*Case is connected to negative pin (GND)

Order Number LM35H, LM35AH, LM35CH, LM35CAH or LM35DH
See NS Package Number H03H

SO-8
Small Outline Molded Package



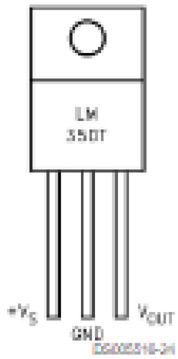
N.C. = No Connection

Top View
Order Number LM35DM
See NS Package Number M08A

TO-92
Plastic Package

Order Number LM35CZ, LM35CAZ or LM35DZ
See NS Package Number Z03A

TO-220
Plastic Package*



*Tab is connected to the negative pin (GND).
Note: The LM35DT pinout is different than the discontinued LM35D

Order Number LM35DT
See NS Package Number TA03F

Absolute Maximum Ratings (Note 10)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/ Distributors for availability and specifications.

Supply Voltage	+35V to −0.2V
Output Voltage	+6V to −1.0V
Output Current	10 mA
Storage Temp.;	
TO-46 Package,	−60°C to +180°C
TO-92 Package,	−60°C to +150°C
SO-8 Package,	−65°C to +150°C
TO-220 Package,	−65°C to +150°C
Lead Temp.:	
TO-46 Package, (Soldering, 10 seconds)	300°C
TO-92 and TO-220 Package, (Soldering, 10 seconds)	260°C
SO Package (Note 12)	
Vapor Phase (60 seconds)	215°C
Infrared (15 seconds)	220°C
ESD Susceptibility (Note 11)	2500V

Specified Operating Temperature Range: T_{MIN} to T_{MAX} (Note 2)

LM35, LM35A	−55°C to +150°C
LM35C, LM35CA	−40°C to +110°C
LM35D	0°C to +100°C

Electrical Characteristics

(Notes 1, 6)

Parameter	Conditions	LM35A			LM35CA			Units (Max.)
		Typical	Tested Limit (Note 4)	Design Limit (Note 5)	Typical	Tested Limit (Note 4)	Design Limit (Note 5)	
Accuracy (Note 7)	T_A=+25°C	±0.2	±0.5		±0.2	±0.5		°C
	T_A=−10°C	±0.3			±0.3		±1.0	°C
	T_A=T_{MAX}	±0.4	±1.0		±0.4	±1.0		°C
	T_A=T_{MIN}	±0.4	±1.0		±0.4		±1.5	°C
Nonlinearity (Note 8)	$T_{MIN}≤T_A≤T_{MAX}$	**±0.18**		**±0.35**	**±0.15**		**±0.3**	°C
Sensor Gain (Average Slope)	$T_{MIN}≤T_A≤T_{MAX}$	**+10.0**	**+9.9, +10.1**		**+10.0**		**+9.9, +10.1**	mV/°C
Load Regulation (Note 3) $0≤I_L≤1$ mA	T_A=+25°C	±0.4	±1.0		±0.4	±1.0		mV/mA
	$T_{MIN}≤T_A≤T_{MAX}$	**±0.5**		**±3.0**	**±0.5**		**±3.0**	mV/mA
Line Regulation (Note 3)	T_A=+25°C	±0.01	±0.05		±0.01	±0.05		mV/V
	$4V≤V_S≤30V$	**±0.02**		**±0.1**	**±0.02**		**±0.1**	mV/V
Quiescent Current (Note 9)	V_S=+5V, +25°C	56	67		56	67		µA
	V_S=+5V	**105**		**131**	**91**		**114**	µA
	V_S=+30V, +25°C	56.2	68		56.2	68		µA
	V_S=+30V	**105.5**		**133**	**91.5**		**116**	µA
Change of Quiescent Current (Note 3)	$4V≤V_S≤30V$, +25°C	0.2	1.0		0.2	1.0		µA
	$4V≤V_S≤30V$	**0.5**		**2.0**	**0.5**		**2.0**	µA
Temperature Coefficient of Quiescent Current		**+0.39**		**+0.5**	**+0.39**		**+0.5**	µA/°C
Minimum Temperature for Rated Accuracy	In circuit of *Figure 1*, I_L=0	+1.5		+2.0	+1.5		+2.0	°C
Long Term Stability	T_J=T_{MAX}, for 1000 hours	±0.08			±0.08			°C

Electrical Characteristics

(Notes 1, 6)

Parameter	Conditions	LM35 Typical	LM35 Tested Limit (Note 4)	LM35 Design Limit (Note 5)	LM35C, LM35D Typical	LM35C, LM35D Tested Limit (Note 4)	LM35C, LM35D Design Limit (Note 5)	Units (Max.)
Accuracy, LM35, LM35C (Note 7)	T_A=+25°C	±0.4	±1.0		±0.4	±1.0		°C
	T_A=−10°C	±0.5			±0.5		±1.5	°C
	T_A=T_{MAX}	±0.8	±1.5		±0.8		±1.5	°C
	T_A=T_{MIN}	±0.8		±1.5	±0.8		±2.0	°C
Accuracy, LM35D (Note 7)	T_A=+25°C				±0.6	±1.5		°C
	T_A=T_{MAX}				±0.9		±2.0	°C
	T_A=T_{MIN}				±0.9		±2.0	°C
Nonlinearity (Note 8)	T_{MIN}≤T_A≤T_{MAX}	**±0.3**		**±0.5**	**±0.2**		**±0.5**	°C
Sensor Gain (Average Slope)	T_{MIN}≤T_A≤T_{MAX}	**+10.0**	**+9.8, +10.2**		**+10.0**		**+9.8, +10.2**	mV/°C
Load Regulation (Note 3) 0≤I_L≤1 mA	T_A=+25°C	±0.4	±2.0		±0.4	±2.0		mV/mA
	T_{MIN}≤T_A≤T_{MAX}	**±0.5**		**±5.0**	**±0.5**		**±5.0**	mV/mA
Line Regulation (Note 3)	T_A=+25°C	±0.01	±0.1		±0.01	±0.1		mV/V
	4V≤V_S≤30V	**±0.02**		**±0.2**	**±0.02**		**±0.2**	mV/V
Quiescent Current (Note 9)	V_S=+5V, +25°C	56	80		56	80		µA
	V_S=+5V	**105**		**158**	**91**		**138**	µA
	V_S=+30V, +25°C	56.2	82		56.2	82		µA
	V_S=+30V	**105.5**		**161**	**91.5**		**141**	µA
Change of Quiescent Current (Note 3)	4V≤V_S≤30V, +25°C	0.2	2.0		0.2	2.0		µA
	4V≤V_S≤30V	**0.5**		**3.0**	**0.5**		**3.0**	µA
Temperature Coefficient of Quiescent Current		**+0.39**		**+0.7**	**+0.39**		**+0.7**	µA/°C
Minimum Temperature for Rated Accuracy	In circuit of *Figure 1*, I_L=0	+1.5		+2.0	+1.5		+2.0	°C
Long Term Stability	T_J=T_{MAX}, for 1000 hours	±0.08			±0.08			°C

Note 1: Unless otherwise noted, these specifications apply: −55°C≤T_J≤+150°C for the LM35 and LM35A; −40°≤T_J≤+110°C for the LM35C and LM35CA; and 0°≤T_J≤+100°C for the LM35D. V_S=+5Vdc and I_{LOAD}=50 µA, in the circuit of *Figure 2*. These specifications also apply from +2°C to T_{MAX} in the circuit of *Figure 1*. Specifications in **boldface** apply over the full rated temperature range.

Note 2: Thermal resistance of the TO-46 package is 400°C/W, junction to ambient, and 24°C/W junction to case. Thermal resistance of the TO-92 package is 180°C/W junction to ambient. Thermal resistance of the small outline molded package is 220°C/W junction to ambient. Thermal resistance of the TO-220 package is 90°C/W junction to ambient. For additional thermal resistance information see table in the Applications section.

Note 3: Regulation is measured at constant junction temperature, using pulse testing with a low duty cycle. Changes in output due to heating effects can be computed by multiplying the internal dissipation by the thermal resistance.

Note 4: Tested Limits are guaranteed and 100% tested in production.

Note 5: Design Limits are guaranteed (but not 100% production tested) over the indicated temperature and supply voltage ranges. These limits are not used to calculate outgoing quality levels.

Note 6: Specifications in **boldface** apply over the full rated temperature range.

Note 7: Accuracy is defined as the error between the output voltage and 10mv/°C times the device's case temperature, at specified conditions of voltage, current, and temperature (expressed in °C).

Note 8: Nonlinearity is defined as the deviation of the output-voltage-versus-temperature curve from the best-fit straight line, over the device's rated temperature range.

Note 9: Quiescent current is defined in the circuit of *Figure 1*.

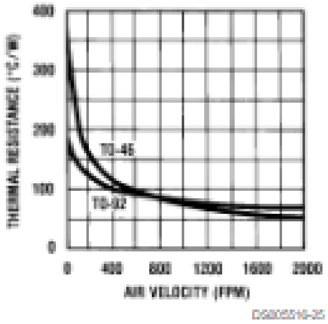
Note 10: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. DC and AC electrical specifications do not apply when operating the device beyond its rated operating conditions. See Note 1.

Note 11: Human body model, 100 pF discharged through a 1.5 kΩ resistor.

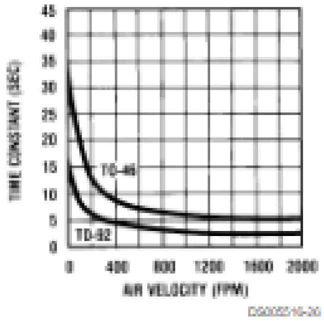
Note 12: See AN-450 "Surface Mounting Methods and Their Effect on Product Reliability" or the section titled "Surface Mount" found in a current National Semiconductor Linear Data Book for other methods of soldering surface mount devices.

Typical Performance Characteristics

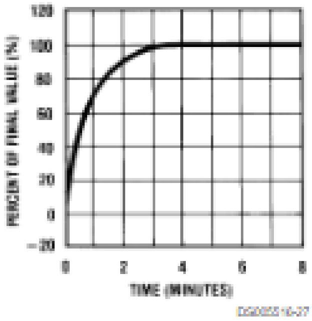
Thermal Resistance Junction to Air



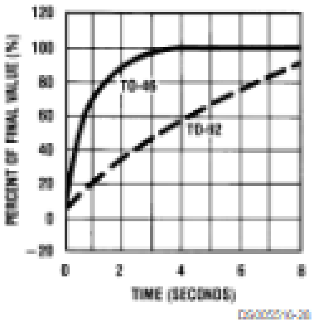
Thermal Time Constant



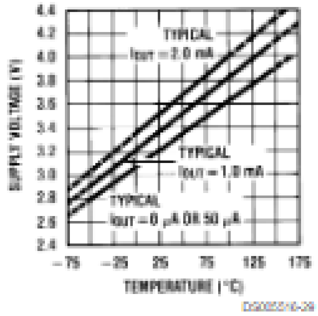
Thermal Response in Still Air



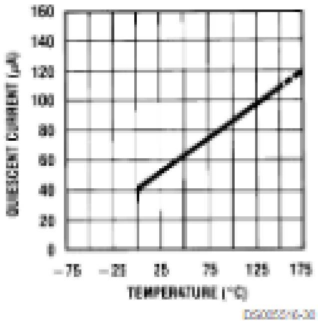
Thermal Response in Stirred Oil Bath



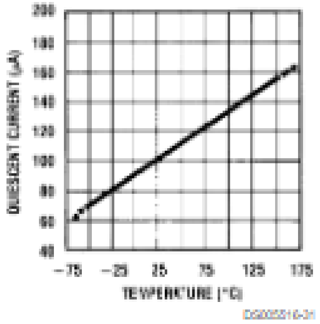
Minimum Supply Voltage vs. Temperature



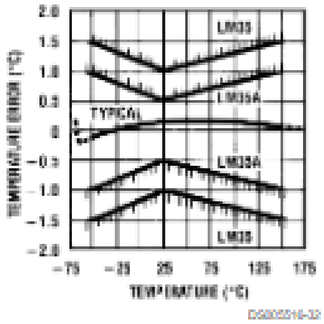
Quiescent Current vs. Temperature (In Circuit of *Figure 1*.)



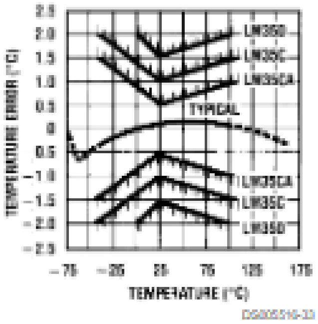
Quiescent Current vs. Temperature (In Circuit of *Figure 2*.)



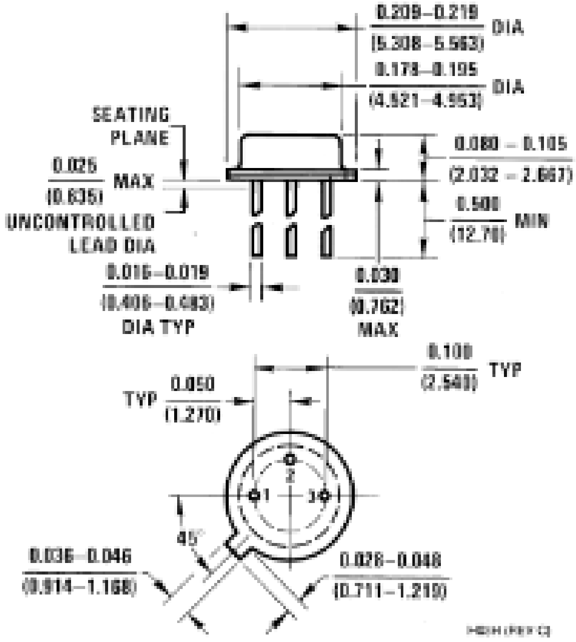
Accuracy vs. Temperature (Guaranteed)



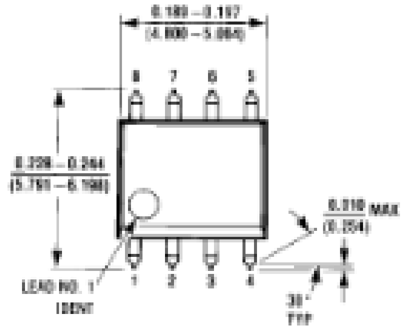
Accuracy vs. Temperature (Guaranteed)

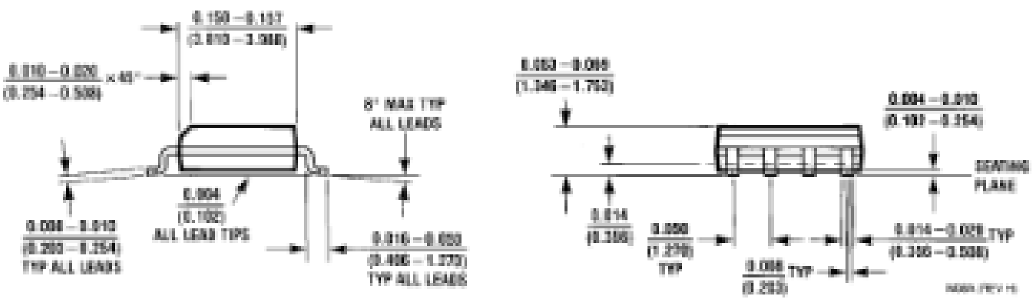


Physical Dimensions inches (millimeters) unless otherwise noted



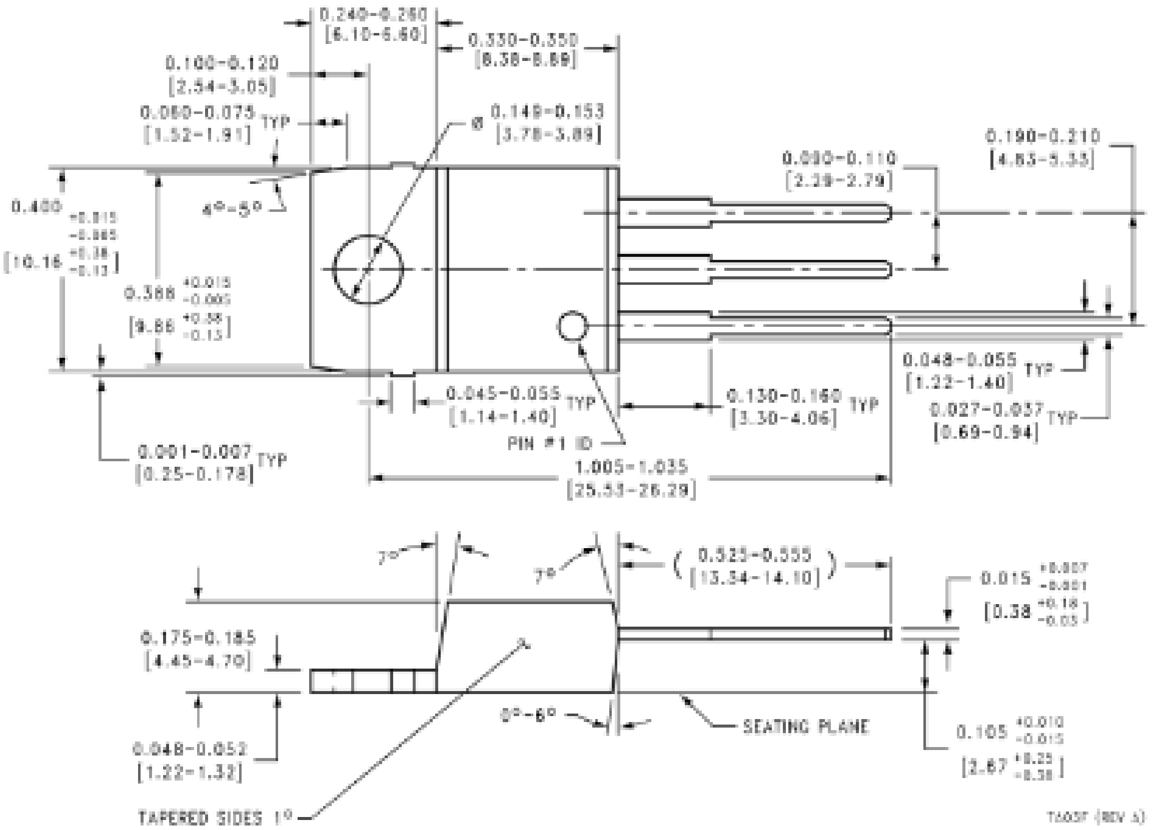
TO-46 Metal Can Package (H)
Order Number LM35H, LM35AH, LM35CH, LM35CAH, or LM35DH
NS Package Number H03H





SO-8 Molded Small Outline Package (M)
Order Number LM35DM
NS Package Number M08A

Physical Dimensions inches (millimeters) unless otherwise noted (Continued)



Power Package TO-220 (T)
Order Number LM35DT
NS Package Number TA03F

C. LAMPIRAN DATA SHEET HW-837 GUVA-S12SD

ROITHNER LASERTECHNIK GmbH
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GUVA-S12SD

TECHNICAL DATA

UV-B Sensor

Features

- Gallium Nitride Based Material
- Schottky-type Photodiode
- Photovoltaic Mode Operation
- Good Visible Blindness
- High Responsivity & Low Dark Current

Applications

- UV Index Monitoring
- UV-A Lamp Monitoring

Absolute Maximum Ratings

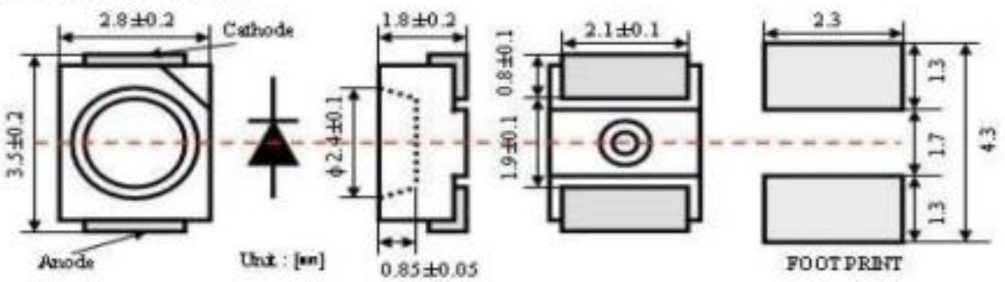
Item	Symbol	Value	Unit
Forward Current	I_F	1	mA
Reverse Voltage	V_R	5	V
Operating Temperature	T_{op}	-30 … +85	°C
Storage Temperature	T_{st}	-40 … +90	°C
Soldering Temperature *	T_{sol}	260	°C

* must be completed within 10 seconds

Characteristics (25°C)

Item	Symbol	Test Conditions	Min.	Typ.	Max.	Unit
Dark Current	I_D	V_R = 0.1 V	-	-	1	nA
Photo Current	I_{PD}	UVA Lamp, 1 mW/cm²	-	113	-	nA
		1 UVI	-	26	-	nA
Temperature Coefficient	I_{TC}	UVA Lamp	-	0.08	-	% / °C
Responsivity	R	λ = 300 nm, V_R = 0 V	-	0.14	-	A/W
Spectral Detection Range	λ	10% of R	240	-	370	nm

Package Dimension



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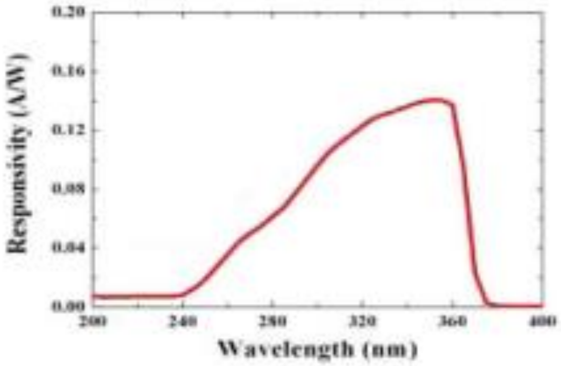
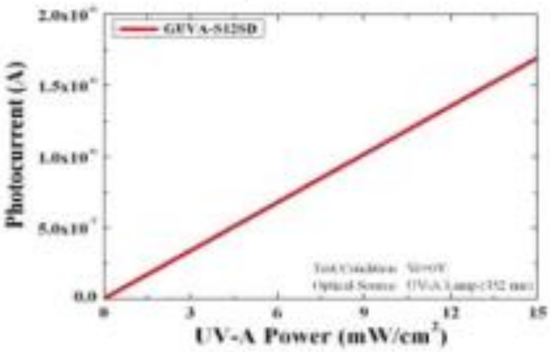
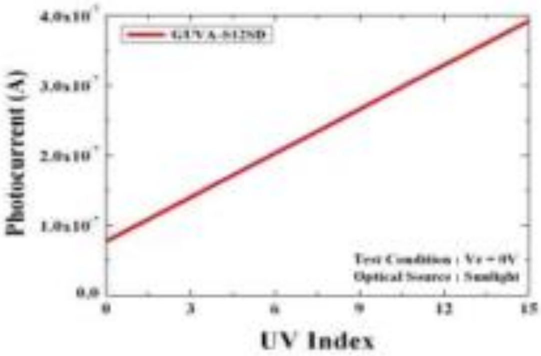
TEL. +43 1 586 52 43 -0, FAX. -44, OFFICE@ROITHNER-LASER.COM

Responsivity Curve



Photocurrent along UV Power

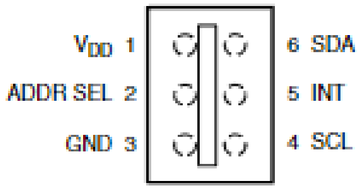




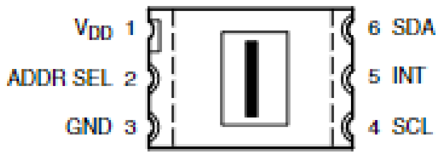
D. LAMPIRAN DATA SHEET GY-2561 TSL-2561

- **Approximates Human Eye Response**
- **Programmable Interrupt Function with User-Defined Upper and Lower Threshold Settings**
- **16-Bit Digital Output with SMBus (TSL2560) at 100 kHz or I^2C (TSL2561) Fast-Mode at 400 kHz**
- **Programmable Analog Gain and Integration Time Supporting 1,000,000-to-1 Dynamic Range**
- **Automatically Rejects 50/60-Hz Lighting Ripple**
- **Low Active Power (0.75 mW Typical) with Power Down Mode**
- **RoHS Compliant**

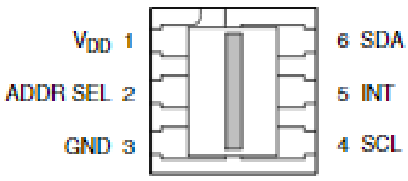
PACKAGE CS
6-LEAD CHIPSCALE
(TOP VIEW)



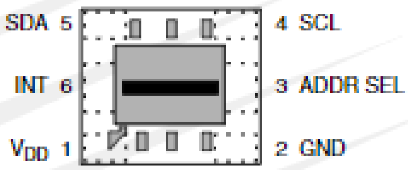
PACKAGE T
6-LEAD TMB
(TOP VIEW)



PACKAGE FN
DUAL FLAT NO-LEAD
(TOP VIEW)



PACKAGE CL
6-LEAD ChipLED
(TOP VIEW)



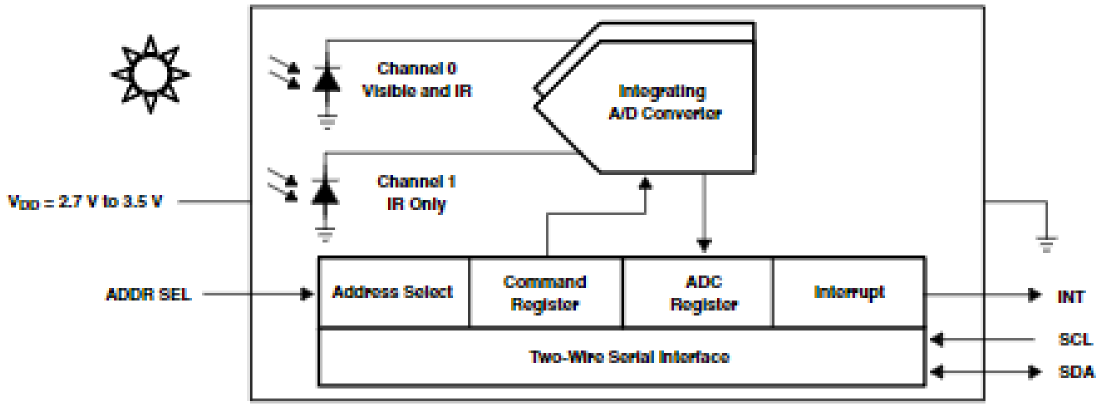
Package Drawings are Not to Scale

Description

The TSL2560 and TSL2561 are light-to-digital converters that transform light intensity to a digital signal output capable of direct I^2C (TSL2561) or SMBus (TSL2560) interface. Each device combines one broadband photodiode (visible plus infrared) and one infrared-responding photodiode on a single CMOS integrated circuit capable of providing a near-photopic response over an effective 20-bit dynamic range (16-bit resolution). Two integrating ADCs convert the photodiode currents to a digital output that represents the irradiance measured on each channel. This digital output can be input to a microprocessor where illuminance (ambient light level) in lux is derived using an empirical formula to approximate the human eye response. The TSL2560 device permits an SMB-Alert style interrupt, and the TSL2561 device supports a traditional level style interrupt that remains asserted until the firmware clears it.

While useful for general purpose light sensing applications, the TSL2560/61 devices are designed particularly for display panels (LCD, OLED, etc.) with the purpose of extending battery life and providing optimum viewing in diverse lighting conditions. Display panel backlighting, which can account for up to 30 to 40 percent of total platform power, can be automatically managed. Both devices are also ideal for controlling keyboard illumination based upon ambient lighting conditions. Illuminance information can further be used to manage exposure control in digital cameras. The TSL2560/61 devices are ideal in notebook/tablet PCs, LCD monitors, flat-panel televisions, cell phones, and digital cameras. In addition, other applications include street light control, security lighting, sunlight harvesting, machine vision, and automotive instrumentation clusters.

Functional Block Diagram



Detailed Description

The TSL2560 and TSL2561 are second-generation ambient light sensor devices. Each contains two integrating analog-to-digital converters (ADC) that integrate currents from two photodiodes. Integration of both channels occurs simultaneously. Upon completion of the conversion cycle, the conversion result is transferred to the Channel 0 and Channel 1 data registers, respectively. The transfers are double-buffered to ensure that the integrity of the data is maintained. After the transfer, the device automatically begins the next integration cycle.

Communication to the device is accomplished through a standard, two-wire SMBus or I^2C serial bus. Consequently, the TSL256x device can be easily connected to a microcontroller or embedded controller. No external circuitry is required for signal conditioning, thereby saving PCB real estate as well. Since the output of the TSL256x device is digital, the output is effectively immune to noise when compared to an analog signal.

The TSL256x devices also support an interrupt feature that simplifies and improves system efficiency by eliminating the need to poll a sensor for a light intensity value. The primary purpose of the interrupt function is to detect a meaningful change in light intensity. The concept of a *meaningful change* can be defined by the user both in terms of light intensity and time, or persistence, of that change in intensity. The TSL256x devices have the ability to define a threshold above and below the current light level. An interrupt is generated when the value of a conversion exceeds either of these limits.

Available Options

DEVICE	INTERFACE	PACKAGE – LEADS	PACKAGE DESIGNATOR	ORDERING NUMBER
TSL2560	SMBus	Chipscale	CS	TSL2560CS
TSL2560	SMBus	TMB-6	T	TSL2560T
TSL2560	SMBus	Dual Flat No-Lead – 6	FN	TSL2560FN
TSL2560	SMBus	ChipLED-6	CL	TSL2560CL
TSL2561	I^2C	Chipscale	CS	TSL2561CS
TSL2561	I^2C	TMB-6	T	TSL2561T
TSL2561	I^2C	Dual Flat No-Lead – 6	FN	TSL2561FN
TSL2561	I^2C	ChipLED-6	CL	TSL2561CL

Terminal Functions

TERMINAL NAME	CS, T, FN PKG NO.	CL PKG NO.	TYPE	DESCRIPTION
ADDR SEL	2	3	I	SMBus device select — three-state
GND	3	2		Power supply ground. All voltages are referenced to GND.
INT	5	6	O	Level or SMB Alert interrupt — open drain.
SCL	4	4	I	SMBus serial clock input terminal — clock signal for SMBus serial data.
SDA	6	5	I/O	SMBus serial data I/O terminal — serial data I/O for SMBus.
V_{DD}	1	1		Supply voltage.

Absolute Maximum Ratings over operating free-air temperature range (unless otherwise noted)†

Supply voltage, V_{DD} (see Note 1) . . . . 3.8 V
Digital output voltage range, V_O . . . . –0.5 V to 3.8 V
Digital output current, I_O . . . . –1 mA to 20 mA
Storage temperature range, T_{stg} . . . . –40°C to 85°C
ESD tolerance, human body model . . . . 2000 V

† Stresses beyond those listed under "absolute maximum ratings" may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated under "recommended operating conditions" is not implied. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.

NOTE 1: All voltages are with respect to GND.

Recommended Operating Conditions

	MIN	NOM	MAX	UNIT
Supply voltage, V_{DD}	2.7	3	3.6	V
Operating free-air temperature, T_A	–30		70	°C
SCL, SDA input low voltage, V_{IL}	–0.5		0.8	V
SCL, SDA input high voltage, V_{IH}	2.1		3.6	V

Electrical Characteristics over recommended operating free-air temperature range (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
I_{DD}	Supply current	Active		0.24	0.6	mA
		Power down		3.2	15	µA
V_{OL}	INT, SDA output low voltage	3 mA sink current	0		0.4	V
		6 mA sink current	0		0.6	V
I_{LEAK}	Leakage current		–5		5	µA

Operating Characteristics, High Gain (16×), V_{DD} = 3 V, T_A = 25°C, (unless otherwise noted) (see Notes 2, 3, 4, 5)

	PARAMETER	TEST CONDITIONS	CHANNEL	TSL2560T, FN, & CL TSL2561T, FN & CL			TSL2560CS, TSL2561CS			UNIT
				MIN	TYP	MAX	MIN	TYP	MAX	
f_{osc}	Oscillator frequency			690	735	780	690	735	780	kHz
	Dark ADC count value	E_e = 0, T_{int} = 402 ms	Ch0	0		4	0		4	counts
			Ch1	0		4	0		4	
	Full scale ADC count value (Note 6)	T_{int} > 178 ms	Ch0			65535			65535	counts
			Ch1			65535			65535	
		T_{int} = 101 ms	Ch0			37177			37177	
			Ch1			37177			37177	
		T_{int} = 13.7 ms	Ch0			5047			5047	
			Ch1			5047			5047	
	ADC count value	λ_p = 640 nm, T_{int} = 101 ms E_e = 36.3 μW/cm^2	Ch0	750	1000	1250				counts
			Ch1		200					
		λ_p = 940 nm, T_{int} = 101 ms E_e = 119 μW/cm^2	Ch0	700	1000	1300				
			Ch1		820					
		λ_p = 640 nm, T_{int} = 101 ms E_e = 41 μW/cm^2	Ch0				750	1000	1250	counts
			Ch1					190		
		λ_p = 940 nm, T_{int} = 101 ms E_e = 135 μW/cm^2	Ch0				700	1000	1300	
			Ch1					850		
	ADC count value ratio: Ch1/Ch0	λ_p = 640 nm, T_{int} = 101 ms		0.15	0.20	0.25	0.14	0.19	0.24	
		λ_p = 940 nm, T_{int} = 101 ms		0.69	0.82	0.95	0.70	0.85	1	
R_e	Irradiance responsivity	λ_p = 640 nm, T_{int} = 101 ms	Ch0		27.5			24.4		counts/ (μW/ cm^2)
			Ch1		5.5			4.6		
		λ_p = 940 nm, T_{int} = 101 ms	Ch0		8.4			7.4		
			Ch1		6.9			6.3		
R_v	Illuminance responsivity	Fluorescent light source: T_{int} = 402 ms	Ch0		36			35		counts/ lux
			Ch1		4			3.8		
		Incandescent light source: T_{int} = 402 ms	Ch0		144			129		
			Ch1		72			67		
	ADC count value ratio: Ch1/Ch0	Fluorescent light source: T_{int} = 402 ms			0.11			0.11		
		Incandescent light source: T_{int} = 402 ms			0.5			0.52		
R_v	Illuminance responsivity, low gain mode (Note 7)	Fluorescent light source: T_{int} = 402 ms	Ch0		2.3			2.2		counts/ lux
			Ch1		0.25			0.24		
		Incandescent light source: T_{int} = 402 ms	Ch0		9			8.1		
			Ch1		4.5			4.2		
	(Sensor Lux) / (actual Lux), high gain mode (Note 8)	Fluorescent light source: T_{int} = 402 ms		0.65	1	1.35	0.65	1	1.35	
		Incandescent light source: T_{int} = 402 ms		0.60	1	1.40	0.60	1	1.40	

NOTES: 2. Optical measurements are made using small-angle incident radiation from light-emitting diode optical sources. Visible 640 nm LEDs and infrared 940 nm LEDs are used for final product testing for compatibility with high-volume production.

3. The 640 nm irradiance E_e is supplied by an AlInGaP light-emitting diode with the following characteristics: peak wavelength $\lambda p = 640$ nm and spectral halfwidth $\Delta\lambda½ = 17$ nm.

4. The 940 nm irradiance E_e is supplied by a GaAs light-emitting diode with the following characteristics: peak wavelength $\lambda p = 940$ nm and spectral halfwidth $\Delta\lambda½ = 40$ nm.

5. Integration time T_{int}, is dependent on internal oscillator frequency (f_{osc}) and on the integration field value in the timing register as described in the *Register Set* section. For nominal f_{osc} = 735 kHz, nominal T_{int} = (number of clock cycles)/f_{osc}.
Field value 00: $T_{int} = (11 \times 918)/f_{osc} = 13.7$ ms
Field value 01: $T_{int} = (81 \times 918)/f_{osc} = 101$ ms
Field value 10: $T_{int} = (322 \times 918)/f_{osc} = 402$ ms
Scaling between integration times vary proportionally as follows: 11/322 = 0.034 (field value 00), 81/322 = 0.252 (field value 01), and 322/322 = 1 (field value 10).

6. Full scale ADC count value is limited by the fact that there is a maximum of one count per two oscillator frequency periods and also by a 2-count offset.
Full scale ADC count value = ((number of clock cycles)/2 − 2)
Field value 00: Full scale ADC count value = ((11 × 918)/2 − 2) = 5047
Field value 01: Full scale ADC count value = ((81 × 918)/2 − 2) = 37177
Field value 10: Full scale ADC count value = 65535, which is limited by 16 bit register. This full scale ADC count value is reached for 131074 clock cycles, which occurs for T_{int} = 178 ms for nominal f_{osc} = 735 kHz.

7. Low gain mode has 16× lower gain than high gain mode: (1/16 = 0.0625).

8. The sensor Lux is calculated using the empirical formula shown on p. 22 of this data sheet based on measured Ch0 and Ch1 ADC count values for the light source specified. Actual Lux is obtained with a commercial luxmeter. The range of the (sensor Lux) / (actual Lux) ratio is estimated based on the variation of the 640 nm and 940 nm optical parameters. Devices are not 100% tested with fluorescent or incandescent light sources.

AC Electrical Characteristics, V_{DD} = 3 V, T_A = 25°C (unless otherwise noted)

PARAMETER†		TEST CONDITIONS	MIN	TYP	MAX	UNIT
$t_{(CONV)}$	Conversion time		12	100	400	ms
$f_{(SCL)}$	Clock frequency (I²C only)		0		400	kHz
	Clock frequency (SMBus only)		10		100	kHz
$t_{(BUF)}$	Bus free time between start and stop condition		1.3			μs
$t_{(HDSTA)}$	Hold time after (repeated) start condition. After this period, the first clock is generated.		0.6			μs
$t_{(SUSTA)}$	Repeated start condition setup time		0.6			μs
$t_{(SUSTO)}$	Stop condition setup time		0.6			μs
$t_{(HDDAT)}$	Data hold time		0		0.9	μs
$t_{(SUDAT)}$	Data setup time		100			ns
$t_{(LOW)}$	SCL clock low period		1.3			μs
$t_{(HIGH)}$	SCL clock high period		0.6			μs
$t_{(TIMEOUT)}$	Detect clock/data low timeout (SMBus only)		25		35	ms
t_F	Clock/data fall time				300	ns
t_R	Clock/data rise time				300	ns
C_i	Input pin capacitance				10	pF

† Specified by design and characterization; not production tested.

TYPICAL CHARACTERISTICS

SPECTRAL RESPONSIVITY

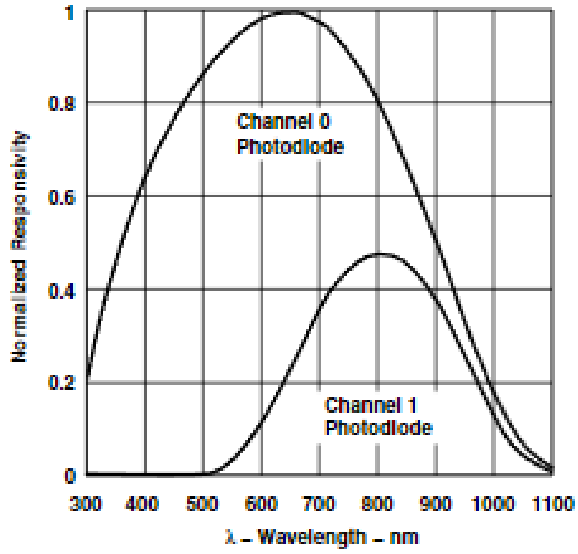


Figure 4

NORMALIZED RESPONSIVITY
vs.
ANGULAR DISPLACEMENT — CS PACKAGE

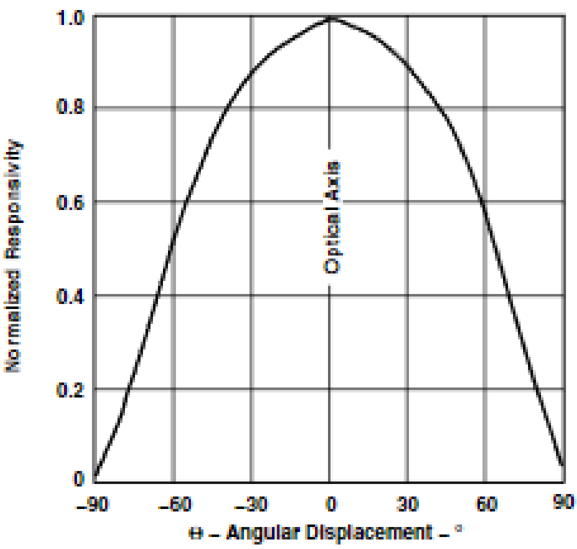


Figure 5

NORMALIZED RESPONSIVITY
vs.
ANGULAR DISPLACEMENT — T PACKAGE

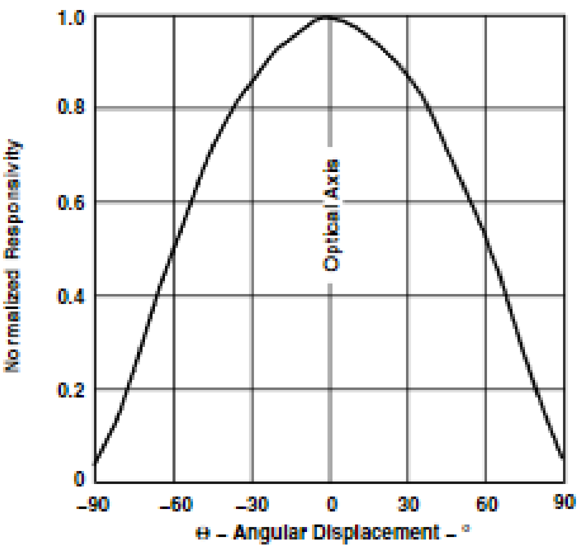


Figure 6

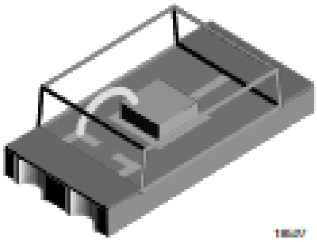
E. LAMPIRAN DATA SHEET TEMT6000

VISHAY

TEMT6000

Vishay Semiconductors

Ambient Light Sensor



Description

TEMT6000 is a silicon NPN epitaxial planar phototransistor in a miniature transparent mold for surface mounting onto a printed circuit board. The device is sensitive to the visible spectrum.

Features

- Adapted to human eye responsivity
- Wide angle of half sensitivity $\phi = \pm 60°$
- SMD style package on PCB technology
- Suitable for IR reflow soldering
- Lead free component
- Component in accordance to RoHS 2002/95/EC and WEEE 2002/96/EC

Applications

Ambient light sensor for display backlight dimming in:

Mobile phones

Notebook computers

PDA's

Cameras

Dashboards

Absolute Maximum Ratings

T_{amb} = 25 °C, unless otherwise specified

Parameter	Test condition	Symbol	Value	Unit
Collector Emitter Voltage		V_{CEO}	6	V
Emitter Collector Voltage		V_{ECO}	1.5	V
Collector current		I_C	20	mA
Total Power Dissipation	$T_{amb} \leq 55$ °C	P_{tot}	100	mW
Junction Temperature		T_j	100	°C
Operating Temperature Range		T_{amb}	- 40 to + 85	°C
Storage Temperature Range		T_{stg}	- 40 to + 85	°C
Soldering Temperature	$t \leq 3$ s	T_{sd}	260	°C
Thermal Resistance Junction/ Ambient		R_{thJA}	450	K/W

TEMT6000

Vishay Semiconductors

Basic Characteristics

T_{amb} = 25 °C, unless otherwise specified

Parameter	Test condition	Symbol	Min	Typ.	Max	Unit
Collector Emitter Breakdown Voltage	I_C = 0.1 mA	V_{CEO}	6			V
Collector dark current	V_{CE} = 5 V, E = 0	I_{CEO}		3	50	nA
Collector-emitter capacitance	V_{CE} = 0 V, f = 1 MHz, E = 0	C_{CEO}		16		pF
Collector Light Current	E_V = 20 lx, standard light A	I_{ca}	3.5	10	16	μA
	E_V = 100 lx, standard light A	I_{ca}		50		μA
Angle of Half Sensitivity		ϕ		±60		deg
Wavelength of Peak Sensitivity		λ_p		570		nm
Range of Spectral Bandwidth		$\lambda_{0.1}$		360 to 970		nm
Collector Emitter Saturation Voltage	E_V = 20 lx, 0.45 μA	V_{CEsat}		0.1		V

Typical Characteristics (T_{amb} = 25 °C unless otherwise specified)

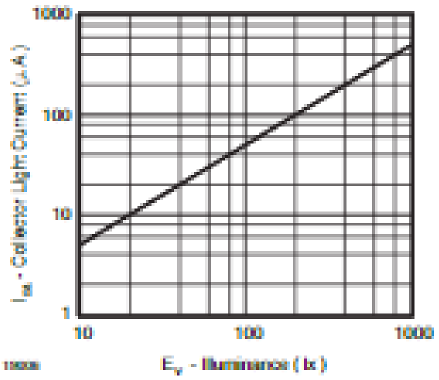


Figure 1. Collector Light Current vs. Illuminance

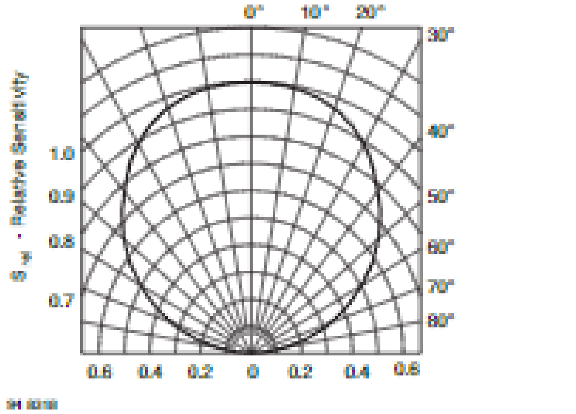


Figure 3. Relative Radiant Sensitivity vs. Angular Displacement

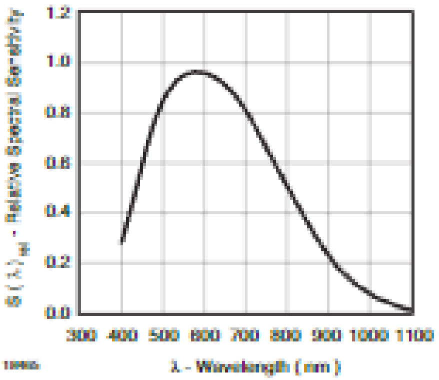


Figure 2. Relative Spectral Responsivity vs. Wavelength

Reflow Solder Profiles

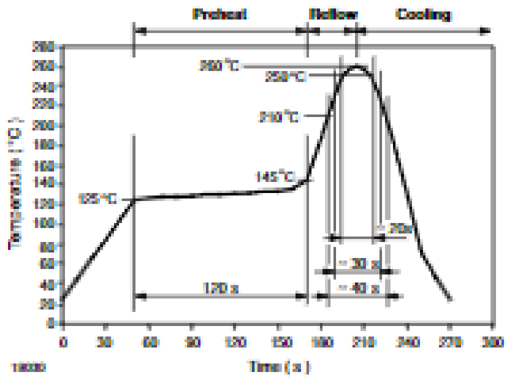


Figure 4. Lead-Free (Sn) Reflow Solder Profile

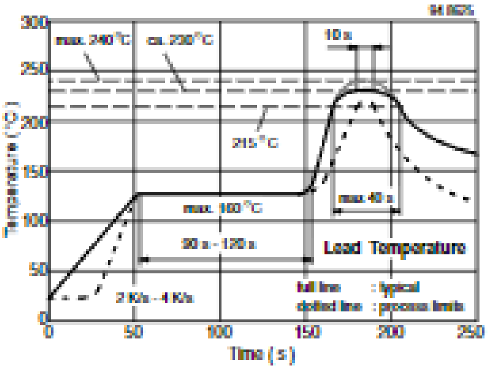


Figure 5. Lead Tin (SnPb) Reflow Solder Profile

Drypack

Devices are packed in moisture barrier bags (MBB) to prevent the products from moisture absorption during transportation and storage. Each bag contains a desiccant.

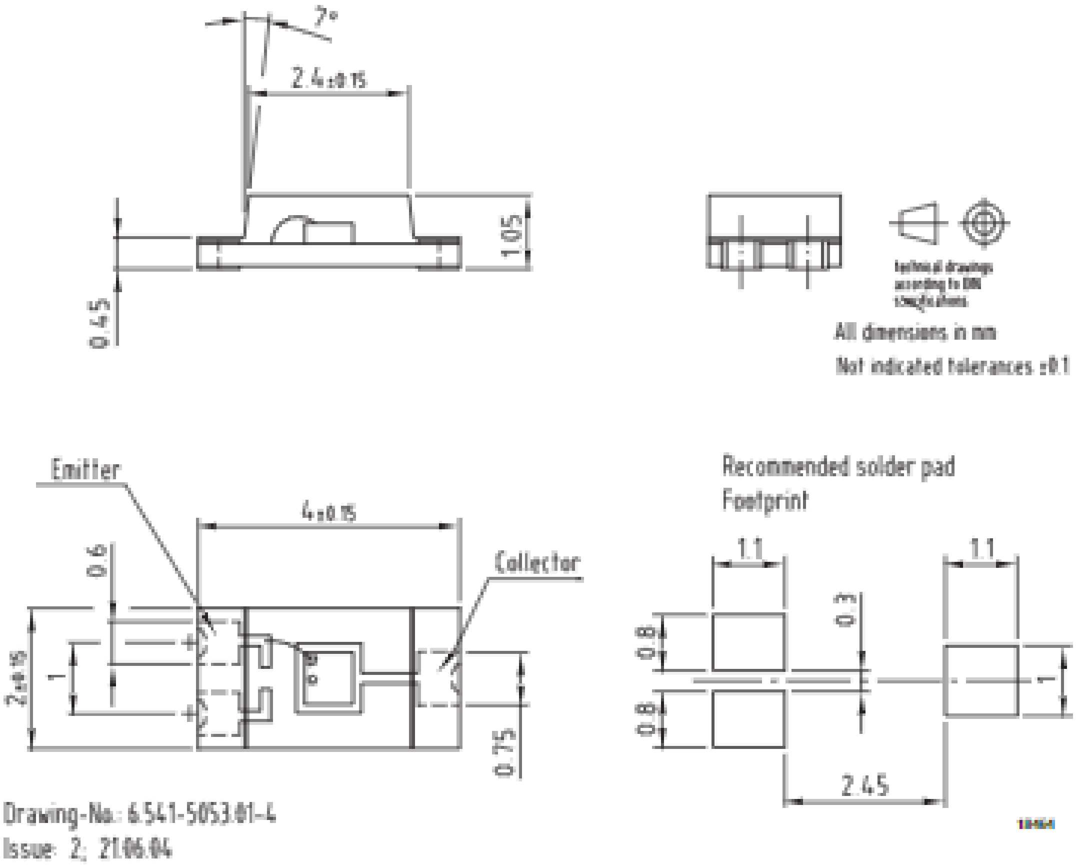
Floor Life

Floor life (time between soldering and removing from MBB) must not exceed the time indicated in J-STD-020. TEMT6000 is released for:
Moisture Sensitivity Level 4, according to JEDEC, J-STD-020
Floor Life: 72 h
Conditions: T_{amb} < 30 °C, RH < 60 %

Drying

In case of moisture absorption devices should be baked before soldering. Conditions see J-STD-020 or Label. Devices taped on reel dry using recommended conditions 192 h @ 40 °C (+ 5 °C), RH < 5 %

Package Dimensions in mm



F. LAMPIRAN ESP32

1. Overview

ESP32 is a single 2.4 GHz Wi-Fi-and-Bluetooth combo chip designed with the TSMC ultra-low-power 40 nm technology. It is designed to achieve the best power and RF performance, showing robustness, versatility and reliability in a wide variety of applications and power scenarios.

The ESP32 series of chips includes ESP32-D0WD-V3, ESP32-D0WDQ6-V3, ESP32-D0WD, ESP32-D0WDQ6, ESP32-D2WD, ESP32-S0WD, and ESP32-U4WDH, among which, ESP32-D0WD-V3, ESP32-D0WDQ6-V3, and ESP32-U4WDH are based on ECO V3 wafer.

For details on part numbers and ordering information, please refer to Section 7.

For details on ECO V3 instructions, please refer to *ESP32 ECO V3 User Guide*.

1.1 Featured Solutions

1.1.1 Ultra-Low-Power Solution

ESP32 is designed for mobile, wearable electronics, and Internet-of-Things (IoT) applications. It features all the state-of-the-art characteristics of low-power chips, including fine-grained clock gating, multiple power modes, and dynamic power scaling. For instance, in a low-power IoT sensor hub application scenario, ESP32 is woken up periodically and only when a specified condition is detected. Low-duty cycle is used to minimize the amount of energy that the chip expends. The output of the power amplifier is also adjustable, thus contributing to an optimal trade-off between communication range, data rate and power consumption.

> **Note:**
> For more information, refer to Section 3.7 *RTC and Low-Power Management*.

1.1.2 Complete Integration Solution

ESP32 is a highly-integrated solution for Wi-Fi-and-Bluetooth IoT applications, with around 20 external components. ESP32 integrates an antenna switch, RF balun, power amplifier, low-noise receive amplifier, filters, and power management modules. As such, the entire solution occupies minimal Printed Circuit Board (PCB) area.

ESP32 uses CMOS for single-chip fully-integrated radio and baseband, while also integrating advanced calibration circuitries that allow the solution to remove external circuit imperfections or adjust to changes in external conditions. As such, the mass production of ESP32 solutions does not require expensive and specialized Wi-Fi testing equipment.

1.2 Wi-Fi Key Features

- 802.11 b/g/n
- 802.11 n (2.4 GHz), up to 150 Mbps
- WMM
- TX/RX A-MPDU, RX A-MSDU

- Immediate Block ACK
- Defragmentation
- Automatic Beacon monitoring (hardware TSF)
- 4 × virtual Wi-Fi interfaces
- Simultaneous support for Infrastructure Station, SoftAP, and Promiscuous modes
  Note that when ESP32 is in Station mode, performing a scan, the SoftAP channel will be changed.
- Antenna diversity

> **Note:**
> For more information, please refer to Section 3.5 *Wi-Fi*.

1.3 BT Key Features

- Compliant with Bluetooth v4.2 BR/EDR and BLE specifications
- Class-1, class-2 and class-3 transmitter without external power amplifier
- Enhanced Power Control
- +12 dBm transmitting power
- NZIF receiver with –94 dBm BLE sensitivity
- Adaptive Frequency Hopping (AFH)
- Standard HCI based on SDIO/SPI/UART
- High-speed UART HCI, up to 4 Mbps
- Bluetooth 4.2 BR/EDR BLE dual mode controller
- Synchronous Connection-Oriented/Extended (SCO/eSCO)
- CVSD and SBC for audio codec
- Bluetooth Piconet and Scatternet
- Multi-connections in Classic BT and BLE
- Simultaneous advertising and scanning

1.4 MCU and Advanced Features

1.4.1 CPU and Memory

- Xtensa® single-/dual-core 32-bit LX6 microprocessor(s), up to 600 MIPS (200 MIPS for ESP32-S0WD/ESP32-U4WDH, 400 MIPS for ESP32-D2WD)
- 448 KB ROM
- 520 KB SRAM
- 16 KB SRAM in RTC
- QSPI supports multiple flash/SRAM chips

1.4.2 Clocks and Timers

- Internal 8 MHz oscillator with calibration
- Internal RC oscillator with calibration
- External 2 MHz ~ 60 MHz crystal oscillator (40 MHz only for Wi-Fi/BT functionality)
- External 32 kHz crystal oscillator for RTC with calibration
- Two timer groups, including 2 × 64-bit timers and 1 × main watchdog in each group
- One RTC timer
- RTC watchdog

1.4.3 Advanced Peripheral Interfaces

- 34 × programmable GPIOs
- 12-bit SAR ADC up to 18 channels
- 2 × 8-bit DAC
- 10 × touch sensors
- 4 × SPI
- 2 × I^2S
- 2 × I^2C
- 3 × UART
- 1 host (SD/eMMC/SDIO)
- 1 slave (SDIO/SPI)
- Ethernet MAC interface with dedicated DMA and IEEE 1588 support
- CAN 2.0
- IR (TX/RX)
- Motor PWM
- LED PWM up to 16 channels
- Hall sensor

1.4.4 Security

- Secure boot
- Flash encryption
- 1024-bit OTP, up to 768-bit for customers
- Cryptographic hardware acceleration:
  - AES
  - Hash (SHA-2)
  - RSA

- ECC
- Random Number Generator (RNG)

1.5 Applications (A Non-exhaustive List)

- Generic Low-power IoT Sensor Hub
- Generic Low-power IoT Data Loggers
- Cameras for Video Streaming
- Over-the-top (OTT) Devices
- Speech Recognition
- Image Recognition
- Mesh Network
- Home Automation
  - Light control
  - Smart plugs
  - Smart door locks
- Smart Building
  - Smart lighting
  - Energy monitoring
- Industrial Automation
  - Industrial wireless control
  - Industrial robotics
- Smart Agriculture
  - Smart greenhouses
  - Smart irrigation
  - Agriculture robotics
- Audio Applications
  - Internet music players
  - Live streaming devices
  - Internet radio players
  - Audio headsets
- Health Care Applications
  - Health monitoring
  - Baby monitors
- Wi-Fi-enabled Toys
  - Remote control toys
  - Proximity sensing toys
  - Educational toys
- Wearable Electronics
  - Smart watches
  - Smart bracelets
- Retail & Catering Applications
  - POS machines
  - Service robots

1.6 Block Diagram

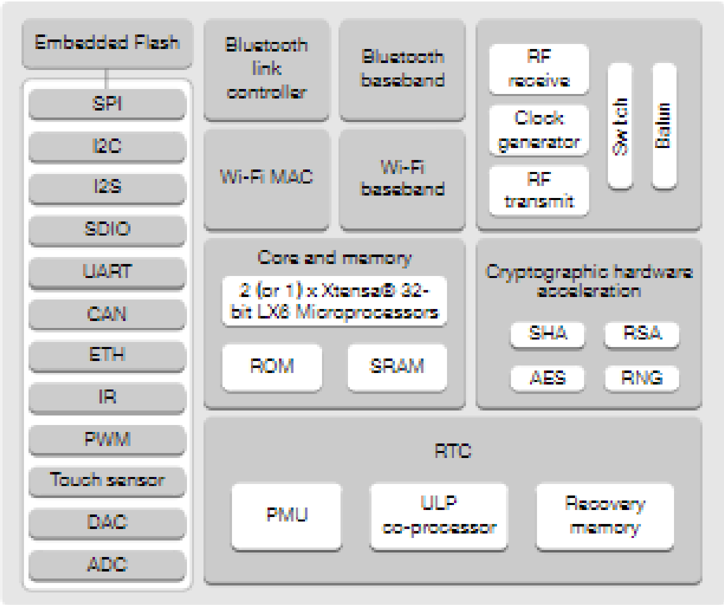


Figure 1: Functional Block Diagram

2. Pin Definitions

2.1 Pin Layout

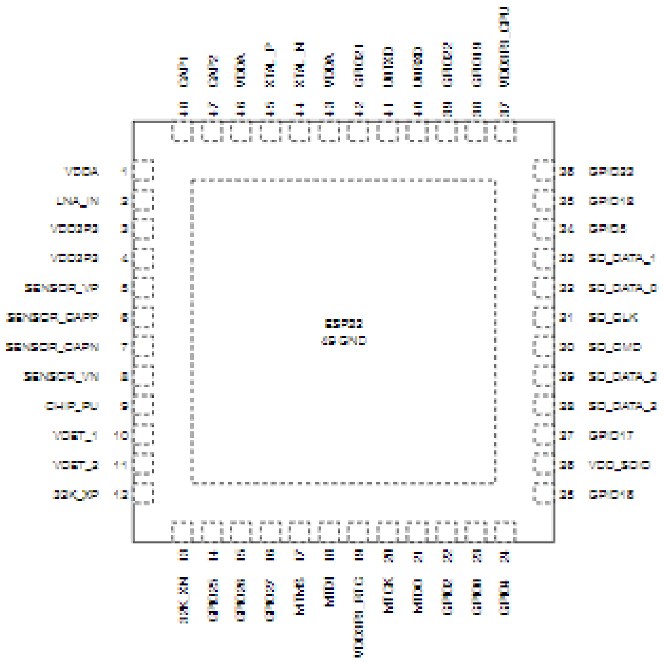


Figure 2: ESP32 Pin Layout (QFN 6*6, Top View)

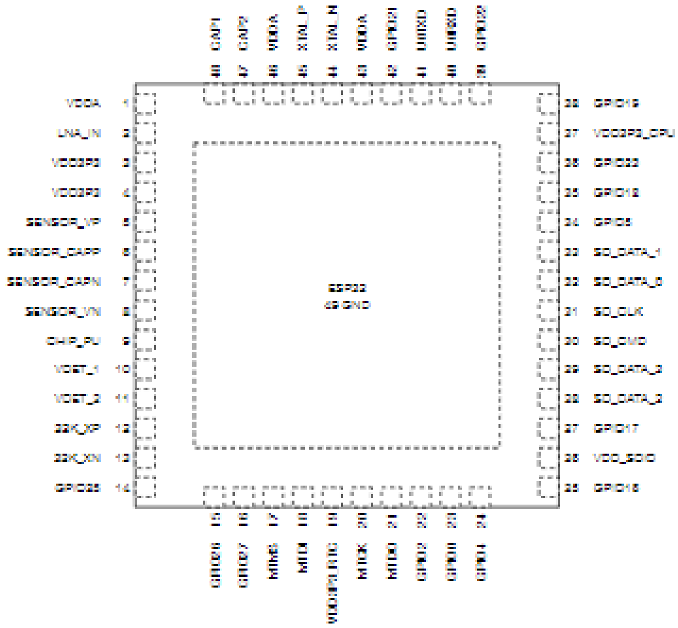


Figure 3: ESP32 Pin Layout (QFN 5*5, Top View)

2.2 Pin Description

Table 1: Pin Description

Name	No.	Type	Function
			Analog
VDDA	1	P	Analog power supply (2.3 V ~ 3.6 V)
LNA_IN	2	I/O	RF input and output
VDD3P3	3	P	Analog power supply (2.3 V ~ 3.6 V)
VDD3P3	4	P	Analog power supply (2.3 V ~ 3.6 V)
			VDD3P3_RTC
SENSOR_VP	5	I	GPIO36, ADC1_CH0, RTC_GPIO0
SENSOR_CAPP	6	I	GPIO37, ADC1_CH1, RTC_GPIO1
SENSOR_CAPN	7	I	GPIO38, ADC1_CH2, RTC_GPIO2
SENSOR_VN	8	I	GPIO39, ADC1_CH3, RTC_GPIO3
CHIP_PU	9	I	High: On; enables the chip Low: Off; the chip powers off Note: Do not leave the CHIP_PU pin floating.
VDET_1	10	I	GPIO34, ADC1_CH6, RTC_GPIO4
VDET_2	11	I	GPIO35, ADC1_CH7, RTC_GPIO5
32K_XP	12	I/O	GPIO32, ADC1_CH4, RTC_GPIO9, TOUCH9, 32K_XP (32.768 kHz crystal oscillator input)
32K_XN	13	I/O	GPIO33, ADC1_CH5, RTC_GPIO8, TOUCH8, 32K_XN (32.768 kHz crystal oscillator output)
GPIO25	14	I/O	GPIO25, ADC2_CH8, RTC_GPIO6, DAC_1, EMAC_RXD0
GPIO26	15	I/O	GPIO26, ADC2_CH9, RTC_GPIO7, DAC_2, EMAC_RXD1
GPIO27	16	I/O	GPIO27, ADC2_CH7, RTC_GPIO17, TOUCH7, EMAC_RX_DV
MTMS	17	I/O	GPIO14, ADC2_CH6, RTC_GPIO16, TOUCH6, EMAC_TXD2, HSPICLK, HS2_CLK, SD_CLK, MT
MTDI	18	I/O	GPIO12, ADC2_CH5, RTC_GPIO15, TOUCH5, EMAC_TXD3, HSPIQ, HS2_DATA2, SD_DATA2, MT
VDD3P3_RTC	19	P	Input power supply for RTC IO (2.3 V ~ 3.6 V)
MTCK	20	I/O	GPIO13, ADC2_CH4, RTC_GPIO14, TOUCH4, EMAC_RX_ER, HSPID, HS2_DATA3, SD_DATA3, MT
MTDO	21	I/O	GPIO15, ADC2_CH3, RTC_GPIO13, TOUCH3, EMAC_RXD3, HSPICS0, HS2_CMD, SD_CMD, MT

Name	No.	Type	Function
GPIO2	22	I/O	GPIO2, ADC2_CH2, RTC_GPIO12, TOUCH2, HSPIWP, HS2_DATA0, SD_DATA0
GPIO0	23	I/O	GPIO0, ADC2_CH1, RTC_GPIO11, TOUCH1, EMAC_TX_CLK, CLK_OUT1,
GPIO4	24	I/O	GPIO4, ADC2_CH0, RTC_GPIO10, TOUCH0, EMAC_TX_ER, HSPIHD, HS2_DATA1, SD_DATA1
			VDD_SDIO
GPIO16	25	I/O	GPIO16, HS1_DATA4, U2RXD, EMAC_CLK_OUT
VDD_SDIO	26	P	Output power supply: 1.8 V or the same voltage as VDD3P3_RTC
GPIO17	27	I/O	GPIO17, HS1_DATA5, U2TXD, EMAC_CLK_OUT_180
SD_DATA_2	28	I/O	GPIO9, HS1_DATA2, U1RXD, SD_DATA2, SPIHD
SD_DATA_3	29	I/O	GPIO10, HS1_DATA3, U1TXD, SD_DATA3, SPIWP
SD_CMD	30	I/O	GPIO11, HS1_CMD, U1RTS, SD_CMD, SPICS0
SD_CLK	31	I/O	GPIO6, HS1_CLK, U1CTS, SD_CLK, SPICLK
SD_DATA_0	32	I/O	GPIO7, HS1_DATA0, U2RTS, SD_DATA0, SPIQ
SD_DATA_1	33	I/O	GPIO8, HS1_DATA1, U2CTS, SD_DATA1, SPID
			VDD3P3_CPU
GPIO5	34	I/O	GPIO5, HS1_DATA6, VSPICS0, EMAC_RX_CLK
GPIO18	35	I/O	GPIO18, HS1_DATA7, VSPICLK
GPIO23	36	I/O	GPIO23, HS1_STROBE, VSPID
VDD3P3_CPU	37	P	Input power supply for CPU IO (1.8 V ~ 3.6 V)
GPIO19	38	I/O	GPIO19, U0CTS, VSPIQ, EMAC_TXD0
GPIO22	39	I/O	GPIO22, U0RTS, VSPIWP, EMAC_TXD1
U0RXD	40	I/O	GPIO3, U0RXD, CLK_OUT2
U0TXD	41	I/O	GPIO1, U0TXD, CLK_OUT3, EMAC_RXD2
GPIO21	42	I/O	GPIO21, VSPIHD, EMAC_TX_EN
			Analog
VDDA	43	P	Analog power supply (2.3 V ~ 3.6 V)
XTAL_N	44	O	External crystal output
XTAL_P	45	I	External crystal input
VDDA	46	P	Analog power supply (2.3 V ~ 3.6 V)
CAP2	47	I	Connects to a 3 nF capacitor and 20 kΩ resistor in parallel to CAP1
CAP1	48	I	Connects to a 10 nF series capacitor to ground
GND	49	P	Ground

Note:

- The pin-pin mapping between ESP32-D2WD/ESP32-U4WDH and the embedded flash is as follows: GPIO16 = CS#, GPIO17 = IO1/DO, SD_CMD = IO3/HOLD#, S CLK, SD_DATA_0 = IO2/WP#, SD_DATA_1 = IO0/DI. The pins used for embedded flash are not recommended for other uses.
- In most cases, the data port connection between ESP32 series of chips other than ESP32-D2WD/ESP32-U4WDH and external flash is as follows: SD_DATA0/SPIQ = SD_DATA1/SPID = IO0/DI, SD_DATA2/SPIHD = IO3/HOLD#, SD_DATA3/SPIWP = IO2/WP#.
- For a quick reference guide to using the IO_MUX, Ethernet MAC, and GIPO Matrix pins of ESP32, please refer to Appendix *ESP32 Pin Lists*.

2.3 Power Scheme

ESP32's digital pins are divided into three different power domains:

- VDD3P3_RTC
- VDD3P3_CPU
- VDD_SDIO

VDD3P3_RTC is also the input power supply for RTC and CPU.

VDD3P3_CPU is also the input power supply for CPU.

VDD_SDIO connects to the output of an internal LDO whose input is VDD3P3_RTC. When VDD_SDIO is connected to the same PCB net together with VDD3P3_RTC, the internal LDO is disabled automatically. The power scheme diagram is shown below:

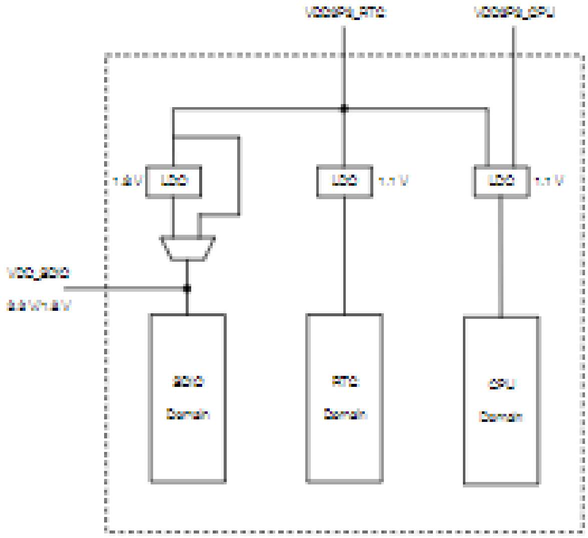


Figure 4: ESP32 Power Scheme

The internal LDO can be configured as having 1.8 V, or the same voltage as VDD3P3_RTC. It can be powered off via software to minimize the current of flash/SRAM during the Deep-sleep mode.

Notes on CHIP_PU:

- The illustration below shows the ESP32 power-up and reset timing. Details about the parameters are listed in Table 2.

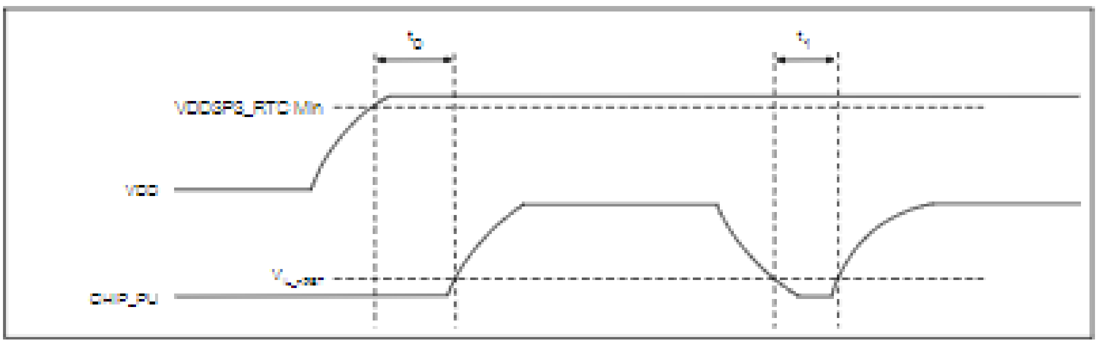


Figure 5: ESP32 Power-up and Reset Timing

Table 2: Description of ESP32 Power-up and Reset Timing Parameters

Parameters	Description	Min.	Unit
t_0	Time between the 3.3 V rails being brought up and CHIP_PU being activated	50	μs
t_1	Duration of CHIP_PU signal level < V_{IL_nRST} (refer to its value in Table 13 DC Characteristics) to reset the chip	50	μs

- In scenarios where ESP32 is powered on and off repeatedly by switching the power rails, while there is a large capacitor on the VDD33 rail and CHIP_PU and VDD33 are connected, simply switching off the CHIP_PU power rail and immediately switching it back on may cause an incomplete power discharge cycle and failure to reset the chip adequately.
  An additional discharge circuit may be required to accelerate the discharge of the large capacitor on rail VDD33, which will ensure proper power-on-reset when the ESP32 is powered up again. Please find the discharge circuit in Figure **ESP32-WROOM-32 Peripheral Schematics**, in *ESP32-WROOM-32 Datasheet*.
- When a battery is used as the power supply for the ESP32 series of chips and modules, a supply voltage supervisor is recommended, so that a boot failure due to low voltage is avoided. Users are recommended to pull CHIP_PU low if the power supply for ESP32 is below 2.3 V. For the reset circuit, please refer to Figure **ESP32-WROOM-32 Peripheral Schematics**, in *ESP32-WROOM-32 Datasheet*.

Notes on power supply:

- The operating voltage of ESP32 ranges from 2.3 V to 3.6 V. When using a single-power supply, the recommended voltage of the power supply is 3.3 V, and its recommended output current is 500 mA or more.
- When VDD_SDIO 1.8 V is used as the power supply for external flash/PSRAM, a 2-kohm grounding resistor should be added to VDD_SDIO. For the circuit design, please refer to Figure **ESP32-WROVER Schematics**, in *ESP32-WROVER Datasheet*.
- When the three digital power supplies are used to drive peripherals, e.g., 3.3 V flash, they should comply with the peripherals' specifications.

2.4 Strapping Pins

There are five strapping pins:

- MTDI
- GPIO0
- GPIO2
- MTDO
- GPIO5

Software can read the values of these five bits from register "GPIO_STRAPPING".

During the chip's system reset release (power-on-reset, RTC watchdog reset and brownout reset), the latches of the strapping pins sample the voltage level as strapping bits of "0" or "1", and hold these bits until the chip is powered down or shut down. The strapping bits configure the device's boot mode, the operating voltage of VDD_SDIO and other initial system settings.

Each strapping pin is connected to its internal pull-up/pull-down during the chip reset. Consequently, if a strapping pin is unconnected or the connected external circuit is high-impedance, the internal weak pull-up/pull-down will determine the default input level of the strapping pins.

To change the strapping bit values, users can apply the external pull-down/pull-up resistances, or use the host MCU's GPIOs to control the voltage level of these pins when powering on the chip.

After reset release, the strapping pins work as normal-function pins.

Refer to Table 3 for a detailed boot-mode configuration by strapping pins.

Table 3: Strapping Pins

Voltage of Internal LDO (VDD_SDIO)					
Pin	Default	3.3 V		1.8 V	
MTDI	Pull-down	0		1	
Booting Mode					
Pin	Default	SPI Boot		Download Boot	
GPIO0	Pull-up	1		0	
GPIO2	Pull-down	Don't-care		0	
Enabling/Disabling Debugging Log Print over U0TXD During Booting					
Pin	Default	U0TXD Active		U0TXD Silent	
MTDO	Pull-up	1		0	
Timing of SDIO Slave					
Pin	Default	FE Sampling FE Output	FE Sampling RE Output	RE Sampling FE Output	RE Sampling RE Output
MTDO	Pull-up	0	0	1	1
GPIO5	Pull-up	0	1	0	1

Note:

- FE: falling-edge, RE: rising-edge.
- Firmware can configure register bits to change the settings of "Voltage of Internal LDO (VDD_SDIO)" and "Timing of SDIO Slave", after booting.
- For ESP32 chips that contain an embedded flash, users need to note the logic level of MTDI. For example, ESP32-D2WD contains an embedded flash that operates at 1.8 V, therefore, the MTDI should be pulled high. ESP32-U4WDH contains an embedded flash that operates at 3.3 V, therefore, the MTDI should be low.

The illustration below shows the setup and hold times for the strapping pin before and after the CHIP_PU signal goes high. Details about the parameters are listed in Table 4.

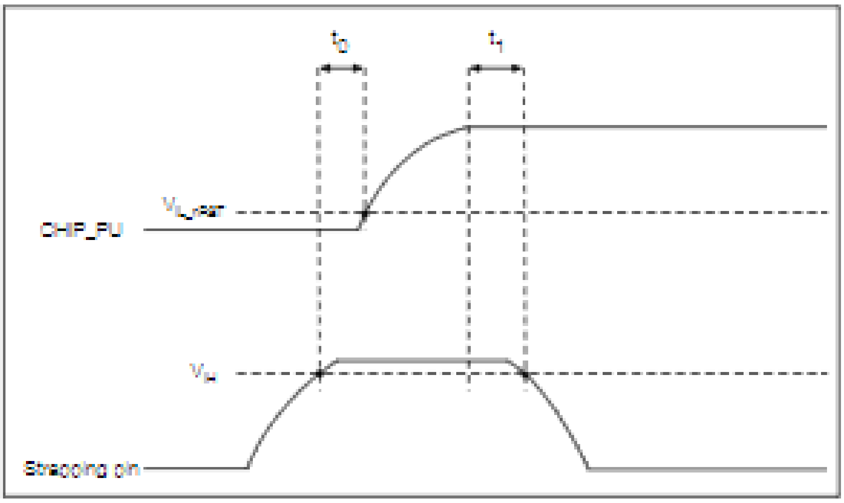


Figure 6: Setup and Hold Times for the Strapping Pin

Table 4: Parameter Descriptions of Setup and Hold Times for the Strapping Pin

Parameters	Description	Min.	Unit
t_0	Setup time before CHIP_PU goes from low to high	0	ms
t_1	Hold time after CHIP_PU goes high	1	ms

3. Functional Description

This chapter describes the functions integrated in ESP32.

3.1 CPU and Memory

3.1.1 CPU

ESP32 contains one or two low-power Xtensa® 32-bit LX6 microprocessor(s) with the following features:

- 7-stage pipeline to support the clock frequency of up to 240 MHz (160 MHz for ESP32-S0WD, ESP32-D2WD, and ESP32-U4WDH)
- 16/24-bit Instruction Set provides high code-density
- Support for Floating Point Unit
- Support for DSP instructions, such as a 32-bit multiplier, a 32-bit divider, and a 40-bit MAC
- Support for 32 interrupt vectors from about 70 interrupt sources

The single-/dual-CPU interfaces include:

- Xtensa RAM/ROM Interface for instructions and data
- Xtensa Local Memory Interface for fast peripheral register access
- External and internal interrupt sources
- JTAG for debugging

3.1.2 Internal Memory

ESP32's internal memory includes:

- 448 KB of ROM for booting and core functions
- 520 KB of on-chip SRAM for data and instructions
- 8 KB of SRAM in RTC, which is called RTC FAST Memory and can be used for data storage; it is accessed by the main CPU during RTC Boot from the Deep-sleep mode.
- 8 KB of SRAM in RTC, which is called RTC SLOW Memory and can be accessed by the co-processor during the Deep-sleep mode.
- 1 Kbit of eFuse: 256 bits are used for the system (MAC address and chip configuration) and the remaining 768 bits are reserved for customer applications, including flash-encryption and chip-ID.
- Embedded flash

Note:
Products in the ESP32 series differ from each other, in terms of their support for embedded flash and the size of it. For details, please refer to Section *7 Part Number and Ordering Information*.

3.1.3 External Flash and SRAM

ESP32 supports multiple external QSPI flash and SRAM chips. More details can be found in Chapter SPI in the *ESP32 Technical Reference Manual*. ESP32 also supports hardware encryption/decryption based on AES to protect developers' programs and data in flash.

ESP32 can access the external QSPI flash and SRAM through high-speed caches.

- Up to 16 MB of external flash can be mapped into CPU instruction memory space and read-only memory space simultaneously.
  - When external flash is mapped into CPU instruction memory space, up to 11 MB + 248 KB can be mapped at a time. Note that if more than 3 MB + 248 KB are mapped, cache performance will be reduced due to speculative reads by the CPU.
  - When external flash is mapped into read-only data memory space, up to 4 MB can be mapped at a time. 8-bit, 16-bit and 32-bit reads are supported.
- External SRAM can be mapped into CPU data memory space. SRAM up to 8 MB is supported and up to 4 MB can be mapped at a time. 8-bit, 16-bit and 32-bit reads and writes are supported.

Note:
After ESP32 is initialized, firmware can customize the mapping of external SRAM or flash into the CPU address space.

3.1.4 Memory Map

The structure of address mapping is shown in Figure 7. The memory and peripheral mapping of ESP32 is shown in Table 5.

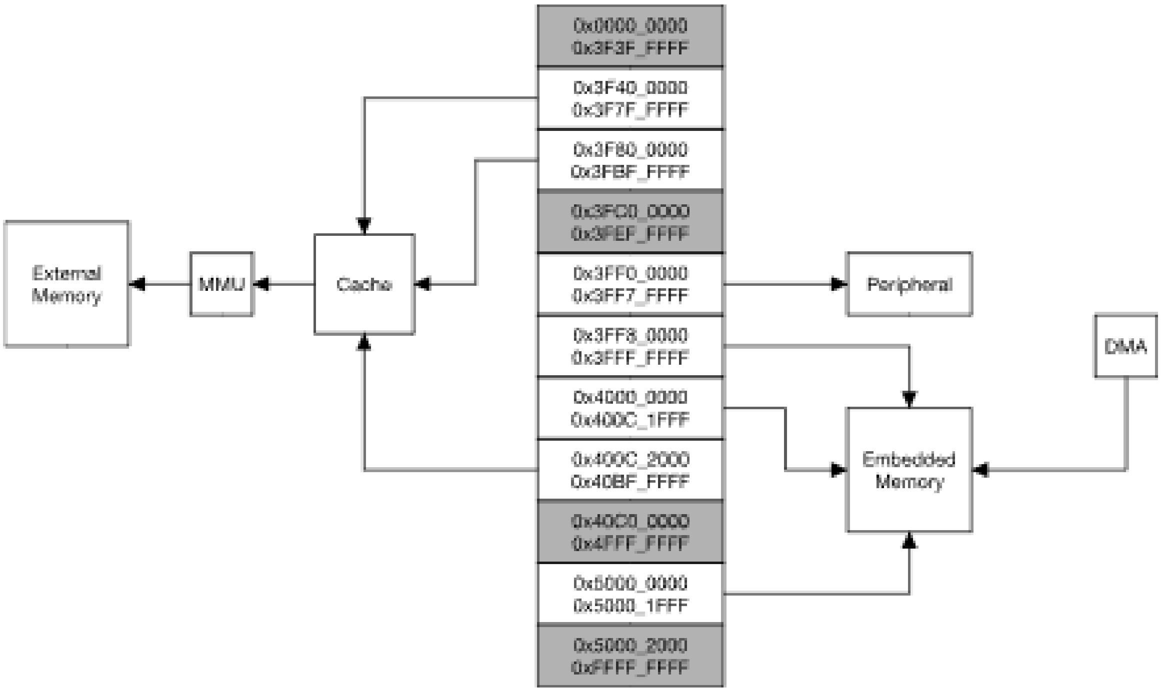


Figure 7: Address Mapping Structure

Table 5: Memory and Peripheral Mapping

Category	Target	Start Address	End Address	Size
Embedded Memory	Internal ROM 0	0x4000_0000	0x4005_FFFF	384 KB
	Internal ROM 1	0x3FF9_0000	0x3FF9_FFFF	64 KB
	Internal SRAM 0	0x4007_0000	0x4009_FFFF	192 KB
	Internal SRAM 1	0x3FFE_0000	0x3FFF_FFFF	128 KB
		0x400A_0000	0x400B_FFFF	
	Internal SRAM 2	0x3FFA_E000	0x3FFD_FFFF	200 KB
	RTC FAST Memory	0x3FF8_0000	0x3FF8_1FFF	8 KB
		0x400C_0000	0x400C_1FFF	
	RTC SLOW Memory	0x5000_0000	0x5000_1FFF	8 KB
External Memory	External Flash	0x3F40_0000	0x3F7F_FFFF	4 MB
		0x400C_2000	0x40BF_FFFF	11 MB+248 KB
	External RAM	0x3F80_0000	0x3FBF_FFFF	4 MB
Peripheral	DPort Register	0x3FF0_0000	0x3FF0_0FFF	4 KB
	AES Accelerator	0x3FF0_1000	0x3FF0_1FFF	4 KB
	RSA Accelerator	0x3FF0_2000	0x3FF0_2FFF	4 KB
	SHA Accelerator	0x3FF0_3000	0x3FF0_3FFF	4 KB
	Secure Boot	0x3FF0_4000	0x3FF0_4FFF	4 KB
	Cache MMU Table	0x3FF1_0000	0x3FF1_3FFF	16 KB
	PID Controller	0x3FF1_F000	0x3FF1_FFFF	4 KB
	UART0	0x3FF4_0000	0x3FF4_0FFF	4 KB
	SPI1	0x3FF4_2000	0x3FF4_2FFF	4 KB
	SPI0	0x3FF4_3000	0x3FF4_3FFF	4 KB
	GPIO	0x3FF4_4000	0x3FF4_4FFF	4 KB
	RTC	0x3FF4_8000	0x3FF4_8FFF	4 KB
	IO MUX	0x3FF4_9000	0x3FF4_9FFF	4 KB
	SDIO Slave	0x3FF4_B000	0x3FF4_BFFF	4 KB
	UDMA1	0x3FF4_C000	0x3FF4_CFFF	4 KB
	I2S0	0x3FF4_F000	0x3FF4_FFFF	4 KB
	UART1	0x3FF5_0000	0x3FF5_0FFF	4 KB
	I2C0	0x3FF5_3000	0x3FF5_3FFF	4 KB
	UDMA0	0x3FF5_4000	0x3FF5_4FFF	4 KB
	SDIO Slave	0x3FF5_5000	0x3FF5_5FFF	4 KB
	RMT	0x3FF5_6000	0x3FF5_6FFF	4 KB
	PCNT	0x3FF5_7000	0x3FF5_7FFF	4 KB
	SDIO Slave	0x3FF5_8000	0x3FF5_8FFF	4 KB
	LED PWM	0x3FF5_9000	0x3FF5_9FFF	4 KB
	Efuse Controller	0x3FF5_A000	0x3FF5_AFFF	4 KB
	Flash Encryption	0x3FF5_B000	0x3FF5_BFFF	4 KB
	PWM0	0x3FF5_E000	0x3FF5_EFFF	4 KB
	TIMG0	0x3FF5_F000	0x3FF5_FFFF	4 KB
	TIMG1	0x3FF6_0000	0x3FF6_0FFF	4 KB

Category	Target	Start Address	End Address	Size
Peripheral	SPI2	0x3FF6_4000	0x3FF6_4FFF	4 KB
	SPI3	0x3FF6_5000	0x3FF6_5FFF	4 KB
	SYSCON	0x3FF6_6000	0x3FF6_6FFF	4 KB
	I2C1	0x3FF6_7000	0x3FF6_7FFF	4 KB
	SDMMC	0x3FF6_8000	0x3FF6_8FFF	4 KB
	EMAC	0x3FF6_9000	0x3FF6_AFFF	8 KB
	PWM1	0x3FF6_C000	0x3FF6_CFFF	4 KB
	I2S1	0x3FF6_D000	0x3FF6_DFFF	4 KB
	UART2	0x3FF6_E000	0x3FF6_EFFF	4 KB
	PWM2	0x3FF6_F000	0x3FF6_FFFF	4 KB
	PWM3	0x3FF7_0000	0x3FF7_0FFF	4 KB
	RNG	0x3FF7_5000	0x3FF7_5FFF	4 KB

3.2 Timers and Watchdogs

3.2.1 64-bit Timers

There are four general-purpose timers embedded in the chip. They are all 64-bit generic timers which are based on 16-bit prescalers and 64-bit auto-reload-capable up/down-timers.

The timers feature:

- A 16-bit clock prescaler, from 2 to 65536
- A 64-bit timer
- Configurable up/down timer: incrementing or decrementing
- Halt and resume of time-base counter
- Auto-reload at alarming
- Software-controlled instant reload
- Level and edge interrupt generation

3.2.2 Watchdog Timers

The chip has three watchdog timers: one in each of the two timer modules (called the Main Watchdog Timer, or MWDT) and one in the RTC module (called the RTC Watchdog Timer, or RWDT). These watchdog timers are intended to recover from an unforeseen fault causing the application program to abandon its normal sequence. A watchdog timer has four stages. Each stage may trigger one of three or four possible actions upon the expiry of its programmed time period, unless the watchdog is fed or disabled. The actions are: interrupt, CPU reset, core reset, and system reset. Only the RWDT can trigger the system reset, and is able to reset the entire chip, including the RTC itself. A timeout value can be set for each stage individually.

During flash boot the RWDT and the first MWDT start automatically in order to detect, and recover from, booting problems.

The watchdogs have the following features:

- Four stages, each of which can be configured or disabled separately

- A programmable time period for each stage
- One of three or four possible actions (interrupt, CPU reset, core reset, and system reset) upon the expiry of each stage
- 32-bit expiry counter
- Write protection that prevents the RWDT and MWDT configuration from being inadvertently altered
- SPI flash boot protection
  If the boot process from an SPI flash does not complete within a predetermined time period, the watchdog will reboot the entire system.

3.3 System Clocks

3.3.1 CPU Clock

Upon reset, an external crystal clock source is selected as the default CPU clock. The external crystal clock source also connects to a PLL to generate a high-frequency clock (typically 160 MHz).

In addition, ESP32 has an internal 8 MHz oscillator. The application can select the clock source from the external crystal clock source, the PLL clock or the internal 8 MHz oscillator. The selected clock source drives the CPU clock directly, or after division, depending on the application.

3.3.2 RTC Clock

The RTC clock has five possible sources:

- external low-speed (32 kHz) crystal clock
- external crystal clock divided by 4
- internal RC oscillator (typically about 150 kHz, and adjustable)
- internal 8 MHz oscillator
- internal 31.25 kHz clock (derived from the internal 8 MHz oscillator divided by 256)

When the chip is in the normal power mode and needs faster CPU accessing, the application can choose the external high-speed crystal clock divided by 4 or the internal 8 MHz oscillator. When the chip operates in the low-power mode, the application chooses the external low-speed (32 kHz) crystal clock, the internal RC clock or the internal 31.25 kHz clock.

3.3.3 Audio PLL Clock

The audio clock is generated by the ultra-low-noise fractional-N PLL. More details can be found in Chapter Reset and Clock in the *ESP32 Technical Reference Manual*.

3.4 Radio

The radio module consists of the following blocks:

- 2.4 GHz receiver
- 2.4 GHz transmitter

- bias and regulators
- balun and transmit-receive switch
- clock generator

3.4.1 2.4 GHz Receiver

The 2.4 GHz receiver demodulates the 2.4 GHz RF signal to quadrature baseband signals and converts them to the digital domain with two 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 in the chip.

3.4.2 2.4 GHz Transmitter

The 2.4 GHz transmitter modulates the quadrature baseband signals to the 2.4 GHz RF signal, and drives the antenna with a high-powered Complementary Metal Oxide Semiconductor (CMOS) power amplifier. The use of digital calibration further improves the linearity of the power amplifier, enabling state-of-the-art performance in delivering up to +20.5 dBm of power for an 802.11b transmission and +18 dBm for an 802.11n transmission.

Additional calibrations are integrated to cancel any radio imperfections, such as:

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

These built-in calibration routines reduce the amount of time required for product testing, and render the testing equipment unnecessary.

3.4.3 Clock Generator

The clock generator produces quadrature clock signals of 2.4 GHz for both the receiver and the transmitter. All components of the clock generator are integrated into the chip, including all inductors, varactors, filters, 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 which ensure the best performance of the receiver and the transmitter.

3.5 Wi-Fi

ESP32 implements a TCP/IP and full 802.11 b/g/n Wi-Fi MAC protocol. It supports the Basic Service Set (BSS) STA and SoftAP operations under the Distributed Control Function (DCF). Power management is handled with minimal host interaction to minimize the active-duty period.

3.5.1 Wi-Fi Radio and Baseband

The ESP32 Wi-Fi Radio and Baseband support the following features:

- 802.11b/g/n
- 802.11n MCS0-7 in both 20 MHz and 40 MHz bandwidth
- 802.11n MCS32 (RX)
- 802.11n 0.4 μs guard-interval
- up to 150 Mbps of data rate
- Receiving STBC 2×1
- Up to 20.5 dBm of transmitting power
- Adjustable transmitting power
- Antenna diversity
  ESP32 supports antenna diversity with an external RF switch. One or more GPIOs control the RF switch and selects the best antenna to minimize the effects of channel fading.

3.5.2 Wi-Fi MAC

The ESP32 Wi-Fi MAC applies low-level protocol functions automatically. They are as follows:

- 4 × virtual Wi-Fi interfaces
- Simultaneous Infrastructure BSS Station mode/SoftAP mode/Promiscuous mode
- RTS protection, CTS protection, Immediate Block ACK
- Defragmentation
- TX/RX A-MPDU, RX A-MSDU
- TXOP
- WMM
- CCMP (CBC-MAC, counter mode), TKIP (MIC, RC4), WAPI (SMS4), WEP (RC4) and CRC
- Automatic beacon monitoring (hardware TSF)

3.6 Bluetooth

The chip integrates a Bluetooth link controller and Bluetooth baseband, which carry out the baseband protocols and other low-level link routines, such as modulation/demodulation, packet processing, bit stream processing, frequency hopping, etc.

3.6.1 Bluetooth Radio and Baseband

The Bluetooth Radio and Baseband support the following features:

- Class-1, class-2 and class-3 transmit output powers, and a dynamic control range of up to 24 dB
- $\pi/4$ DQPSK and 8 DPSK modulation
- High performance in NZIF receiver sensitivity with over 94 dBm of dynamic range

- Class-1 operation without external PA
- Internal SRAM allows full-speed data-transfer, mixed voice and data, and full piconet operation
- Logic for forward error correction, header error control, access code correlation, CRC, demodulation, encryption bit stream generation, whitening and transmit pulse shaping
- ACL, SCO, eSCO and AFH
- A-law, μ-law and CVSD digital audio CODEC in PCM interface
- SBC audio CODEC
- Power management for low-power applications
- SMP with 128-bit AES

3.6.2 Bluetooth Interface

- Provides UART HCI interface, up to 4 Mbps
- Provides SDIO / SPI HCI interface
- Provides PCM / I²S audio interface

3.6.3 Bluetooth Stack

The Bluetooth stack of the chip is compliant with the Bluetooth v4.2 BR/EDR and Bluetooth LE specifications.

3.6.4 Bluetooth Link Controller

The link controller operates in three major states: standby, connection and sniff. It enables multiple connections, and other operations, such as inquiry, page, and secure simple-pairing, and therefore enables Piconet and Scatternet. Below are the features:

- Classic Bluetooth
  - Device Discovery (inquiry, and inquiry scan)
  - Connection establishment (page, and page scan)
  - Multi-connections
  - Asynchronous data reception and transmission
  - Synchronous links (SCO/eSCO)
  - Master/Slave Switch
  - Adaptive Frequency Hopping and Channel assessment
  - Broadcast encryption
  - Authentication and encryption
  - Secure Simple-Pairing
  - Multi-point and scatternet management
  - Sniff mode
  - Connectionless Slave Broadcast (transmitter and receiver)

- Enhanced power control
- Ping

• Bluetooth Low Energy
  - Advertising
  - Scanning
  - Simultaneous advertising and scanning
  - Multiple connections
  - Asynchronous data reception and transmission
  - Adaptive Frequency Hopping and Channel assessment
  - Connection parameter update
  - Data Length Extension
  - Link Layer Encryption
  - LE Ping

3.7 RTC and Low-Power Management

With the use of advanced power-management technologies, ESP32 can switch between different power modes.

• Power modes
  - **Active mode:** The chip radio is powered on. The chip can receive, transmit, or listen.
  - **Modem-sleep mode:** The CPU is operational and the clock is configurable. The Wi-Fi/Bluetooth baseband and radio are disabled.
  - **Light-sleep mode:** The CPU is paused. The RTC memory and RTC peripherals, as well as the ULP co-processor are running. Any wake-up events (MAC, host, RTC timer, or external interrupts) will wake up the chip.
  - **Deep-sleep mode:** Only the RTC memory and RTC peripherals are powered on. Wi-Fi and Bluetooth connection data are stored in the RTC memory. The ULP co-processor is functional.
  - **Hibernation mode:** The internal 8-MHz oscillator and ULP co-processor are disabled. The RTC recovery memory is powered down. Only one RTC timer on the slow clock and certain RTC GPIOs are active. The RTC timer or the RTC GPIOs can wake up the chip from the Hibernation mode.

Table 6: Power Consumption by Power Modes

Power mode	Description			Power consumption
Active (RF working)	Wi-Fi Tx packet			Please refer to Table 15 for details.
	Wi-Fi/BT Tx packet			
	Wi-Fi/BT Rx and listening			
Modem-sleep	The CPU is powered on.	240 MHz *	Dual-core chip(s)	30 mA ~ 68 mA
			Single-core chip(s)	N/A
		160 MHz *	Dual-core chip(s)	27 mA ~ 44 mA
			Single-core chip(s)	27 mA ~ 34 mA
		Normal speed: 80 MHz	Dual-core chip(s)	20 mA ~ 31 mA

Power mode	Description			Power consumption
			Single-core chip(s)	20 mA ~ 25 mA
Light-sleep	-			0.8 mA
Deep-sleep	The ULP co-processor is powered on.			150 μA
	ULP sensor-monitored pattern			100 μA @1% duty
	RTC timer + RTC memory			10 μA
Hibernation	RTC timer only			5 μA
Power off	CHIP_PU is set to low level, the chip is powered off.			1 μA

Note:

- * Among the ESP32 series of SoCs, ESP32-D0WD-V3, ESP32-D0WDQ6-V3, ESP32-D0WD, and ESP32-D0WDQ6 have a maximum CPU frequency of 240 MHz, ESP32-D2WD, ESP32-S0WD, and ESP32-U4WDH have a maximum CPU frequency of 160 MHz.
- When Wi-Fi is enabled, the chip switches between Active and Modem-sleep modes. Therefore, power consumption changes accordingly.
- In Modem-sleep mode, the CPU frequency changes automatically. The frequency depends on the CPU load and the peripherals used.
- During Deep-sleep, when the ULP co-processor is powered on, peripherals such as GPIO and I^2C are able to operate.
- When the system works in the ULP sensor-monitored pattern, the ULP co-processor works with the ULP sensor periodically and the ADC works with a duty cycle of 1%, so the power consumption is 100 μA.

FORMULIR PERBAIKAN TUGAS AKHIR

Dalam pelaksanaan Tugas Akhir jenjang Diploma III, Program Studi Teknik Listrik, maka perlu adanya perbaikan Tugas Akhir mahsiswa/i dibawah ini :

Nama	: Muhammad Fani Irsad
N.I.M	: 1952032
Jurusan/Prodi	: Teknik Listrik DIII
Masa Bimbingan	: 6 (enam) bulan
JUDUL	: Rancang Bangun Alat Pengukuran Radiasi Sinar Ultraviolet dan Radiasi Matahari Berbasis IoT

NO	Penguji	Tanggal	Uraian	Paraf
1.	Penguji I	15/08/2023	1. Bab I Urutan penulisan tujuan dan rumusan masalah. 2. Bab II Cantumkan sumber pustakanya 3. Bab III Urutan penulisannya • Bagaimana cara merencanakan • Bagaimana cara membuat 4. Bab IV Langkah-langkah pengujian dan hasil pengujian 5. Bab V Kesimpulan menjawab tujuan	
2.	Penguji II	15/08/2023	1. Uji alat ini dengan yang sudah diuji di ITN, sejauh mana alat ini uji kelaikannya untuk digunakan.	

Disetujui :

Dosen Penguji I	Dosen Penguji II
Ir. H. Taufik Hidayat , MT	Ir. Choirul Saleh, MT
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Mengetahui

Dosen Pembimbing I	Dosen Pembimbing II
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FORMULIR BIMBINGAN TUGAS AKHIR

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N.I.M : 1952032
MASA BIMBINGAN :
JUDUL : Alat Pengukuran Radiasi Sinar Ultraviolet dan Radiasi Matahari Berbasis IoT

NO	Tanggal	Uraian	Paraf Pembimbing
1.	01/04 '23	BAB I : Acc Abstrak + Revisi Daftar Masalah	Ef
2.	18/04 '23	Acc BAB I + Abstrak tambahkan hasil perhitungan	Ef
3.	10/05 '23	Acc Abstrak . + BAB II : Revisi Sumber GB + [illegible]	Ef
4.	05/06 '23	BAB II : Tambahkan teori2 terkait + dg jurnal	Ef
5.	29/06 '23	Acc BAB II + BAB III : Perhitungan dr Sensor	Ef
6.	15/07 '23	~~Acc~~ BAB III : Diagram blok + flowchart	Ef
7.	18/07 '23	Pengolahan data utk Sensor	Ef
8.	24/07 '23	Acc BAB III .	Ef
9.	02/08 '23	BAB IV : Pengolahan dan Perhitungan utk data	Ef
10.	07/08 '23	Tambahkan / tampilkan hasil data	Ef
11	08/08 '23	Perbaiki kesimpulan	Ef
12	09/08 '23	Acc BAB V	Ef
13			
14			

Malang, 10 Juli 2023
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JUDUL : Alat Pengukuran Radiasi Sinar Ultraviolet dan Radiasi Matahari Berbasis IoT

NO	Tanggal	Uraian	Paraf Pembimbing
1.	10/4/23	Mengkonsep rancangan alat	[paraf]
2.	19/4/23	Memastikan rancangan alat berfungsi baik	[paraf]
3.	20/5/23	Mengkoreksi hasil rangkaian alat	[paraf]
4.	30/5/23	Mencoba sensor² yg ada pada alat	[paraf]
5.	7/6/23	Membuat program untuk menjalankan sensor	[paraf]
6.	18/6/23	Memastikan program pada sensor sudah benar	[paraf]
7.	9/7/23	Mengkoreksi hasil uji alat	[paraf]
8.	17/7/23	Mengkoreksi kembali rangkaian dan program	[paraf]
9.	28/7/23	Membuat program baru pada sensor	[paraf]
10.	3/8/23	Mengkoreksi hasil uji alat II	[paraf]
11	6/8/23	Memastikan rancang bangun alat berfungsi baik	[paraf]
12			
13			
14			

Malang, 10 Juli 2023
Dosen Pembimbing II,

[tanda tangan]

(Bima Romadhon Parada Dian Palevi, ST.MT)

NIP.P. 1031900575

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