# Read the Docs Template Documentation

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**Read the Docs**

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# Setup Toolchain

This is the documentation for Espressif IoT Developement Framework (esp-idf). ESP-IDF is the official development framework for the ESP32 chip.

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CHAPTER 1

# Set up of Toolchain for Windows

## Step 1: Quick Steps

Windows doesn't have a built-in "make" environment, so as well as installing the toolchain you will need a GNU-compatible environment. We use the **MSYS2_** environment to provide this. You don't need to use this environment all the time (you can use *Eclipse* or some other front-end), but it runs behind the scenes.

The quick setup is to download the Windows all-in-one toolchain & MSYS zip file from dl.espressif.com:

https://dl.espressif.com/dl/esp32_win32_msys2_environment_and_toolchain-20170330.zip

Unzip the zip file to `C:\` (or some other location, but this guide assumes `C:\`) and it will create an "msys32" directory with a pre-prepared environment.

## Alternative Step 1: Configure toolchain & environment from scratch

Rather than use the pre-prepared environment, you can alternatively follow this guide to set up the MSYS2 environment from scratch.

## Another Alternative Step 1: Just download a toolchain

If you already have an MSYS2 install or want to do things differently, you can download just the toolchain here:

https://dl.espressif.com/dl/xtensa-esp32-elf-win32-1.22.0-61-gab8375a-5.2.0.zip

**If you followed one of the above options for Step 1, you already have the toolchain and you won't need this download.**

**Important**: Just having this toolchain is *not enough* to use ESP-IDF on Windows. You will need GNU make, bash, and sed at minimum. The above environments provide all this, plus a host compiler (required for menuconfig support).

## Step 2: Getting the esp-idf repository from github

Open an MSYS2 terminal window by running `C:\msys32\mingw32.exe`. The environment in this window is a bash shell.

Change to the directory you want to clone the SDK into by typing a command like this one: `cd "C:/path/to/dir"` (note the forward-slashes in the path). Then type `git clone --recursive https://github.com/espressif/esp-idf.git`

If you'd rather use a Windows UI tool to manage your git repositories, this is also possible. A wide range are available.

*NOTE*: While cloning submodules, the `git clone` command may print some output starting `': not a valid identifier...`. This is a known issue but the git clone still succeeds without any problems.

## Step 3: Starting a project

ESP-IDF by itself does not build a binary to run on the ESP32. The binary "app" comes from a project in a different directory. Multiple projects can share the same ESP-IDF directory on your computer.

The easiest way to start a project is to download the Getting Started project from github.

The process is the same as for checking out the ESP-IDF from github. Change to the parent directory and run `git clone https://github.com/espressif/esp-idf-template.git`.

**IMPORTANT:** The esp-idf build system does not support spaces in paths to esp-idf or to projects.

You can also find a range of example projects under the "examples" directory in IDF. These example project directories can be copied to outside IDF in order to begin your own projects.

## Step 4: Configuring the project

Open an MSYS2 terminal window by running `C:\msys32\mingw32.exe`. The environment in this window is a bash shell.

Type a command like this to set the path to ESP-IDF directory: `export IDF_PATH="C:/path/to/esp-idf"` (note the forward-slashes not back-slashes for the path). If you don't want to run this command every time you open an MSYS2 window, create a new file in `C:/msys32/etc/profile.d/` and paste this line in - then it will be run each time you open an MYS2 terminal.

Use `cd` to change to the project directory (not the ESP-IDF directory.) Type `make menuconfig` to configure your project, then `make` to build it, `make clean` to remove built files, and `make flash` to flash (use the menuconfig to set the serial port for flashing.)

If you'd like to use the Eclipse IDE instead of running `make`, check out the *Eclipse guide*.

# CHAPTER 2

# Set up of Toolchain for Linux

## Step 0: Prerequisites

### Install some packages

To compile with ESP-IDF you need to get the following packages:

- Ubuntu and Debian:

```
sudo apt-get install git wget make libncurses-dev flex bison gperf python python-
↪serial
```

- Arch:

```
sudo pacman -S --needed gcc git make ncurses flex bison gperf python2-pyserial
```

## Step 1: Download binary toolchain for the ESP32

ESP32 toolchain for Linux is available for download from Espressif website:

- for 64-bit Linux:

```
https://dl.espressif.com/dl/xtensa-esp32-elf-linux64-1.22.0-61-gab8375a-5.2.0.tar.
↪gz
```

- for 32-bit Linux:

```
https://dl.espressif.com/dl/xtensa-esp32-elf-linux32-1.22.0-61-gab8375a-5.2.0.tar.
↪gz
```

Download this file, then extract it to the location you prefer, for example:

```
mkdir -p ~/esp
cd ~/esp
tar -xzf ~/Downloads/xtensa-esp32-elf-linux64-1.22.0-61-gab8375a-5.2.0.tar.gz
```

The toolchain will be extracted into `~/esp/xtensa-esp32-elf/` directory.

To use it, you will need to update your `PATH` environment variable in `~/.bash_profile` file. To make `xtensa-esp32-elf` available for all terminal sessions, add the following line to your `~/.bash_profile` file:

```
export PATH=$PATH:$HOME/esp/xtensa-esp32-elf/bin
```

Alternatively, you may create an alias for the above command. This way you can get the toolchain only when you need it. To do this, add different line to your `~/.bash_profile` file:

```
alias get_esp32="export PATH=$PATH:$HOME/esp/xtensa-esp32-elf/bin"
```

Then when you need the toolchain you can type `get_esp32` on the command line and the toolchain will be added to your `PATH`.

### Arch Linux Users

To run the precompiled gdb (xtensa-esp32-elf-gdb) in Arch Linux requires ncurses 5, but Arch uses ncurses 6. Backwards compatibility libraries are available in AUR for native and lib32 configurations: - https://aur.archlinux.org/packages/ncurses5-compat-libs/ - https://aur.archlinux.org/packages/lib32-ncurses5-compat-libs/

(Alternatively, use crosstool-NG to compile a gdb that links against ncurses 6.)

## Alternative Step 1: Compile the toolchain from source using crosstool-NG

Instead of downloading binary toolchain from Espressif website (Step 1 above) you may build the toolchain yourself.

If you can't think of a reason why you need to build it yourself, then probably it's better to stick with the binary version. However, here are some of the reasons why you might want to compile it from source:

- if you want to customize toolchain build configuration
- if you want to use a different GCC version (such as 4.8.5)
- if you want to hack gcc or newlib or libstdc++
- if you are curious and/or have time to spare
- if you don't trust binaries downloaded from the Internet

In any case, here are the steps to compile the toolchain yourself.

(Note: You will also need the prerequisite packages mentioned in step 0, above.)

- Install dependencies:
  - Ubuntu pre-16.04:

    ```
    sudo apt-get install gawk gperf grep gettext libncurses-dev python python-dev␣
    ↪automake bison flex texinfo help2man libtool
    ```

  - Ubuntu 16.04:

```
sudo apt-get install gawk gperf grep gettext python python-dev automake bison␣
↪flex texinfo help2man libtool libtool-bin
```

– Debian:

```
TODO
```

– Arch:

```
TODO
```

Download `crosstool-NG` and build it:

```
cd ~/esp
git clone -b xtensa-1.22.x https://github.com/espressif/crosstool-NG.git
cd crosstool-NG
./bootstrap && ./configure --enable-local && make install
```

Build the toolchain:

```
./ct-ng xtensa-esp32-elf
./ct-ng build
chmod -R u+w builds/xtensa-esp32-elf
```

Toolchain will be built in `~/esp/crosstool-NG/builds/xtensa-esp32-elf`. Follow instructions given in the previous section to add the toolchain to your `PATH`.

## Step 2: Getting ESP-IDF from github

Open terminal, navigate to the directory you want to clone ESP-IDF and clone it using `git clone` command:

```
cd ~/esp
git clone --recursive https://github.com/espressif/esp-idf.git
```

ESP-IDF will be downloaded into `~/esp/esp-idf`.

Note the `--recursive` option! If you have already cloned ESP-IDF without this option, run another command to get all the submodules:

```
cd ~/esp/esp-idf
git submodule update --init
```

**IMPORTANT:** The esp-idf build system does not support spaces in paths to esp-idf or to projects.

## Step 3: Starting a project

ESP-IDF by itself does not build a binary to run on the ESP32. The binary "app" comes from a project in a different directory. Multiple projects can share the same ESP-IDF directory.

The easiest way to start a project is to download the template project from GitHub:

```
cd ~/esp
git clone https://github.com/espressif/esp-idf-template.git myapp
```

This will download `esp-idf-template` project into `~/esp/myapp` directory.

**IMPORTANT:** The esp-idf build system does not support spaces in paths to esp-idf or to projects.

You can also find a range of example projects under the "examples" directory in IDF. These example project directories can be copied to outside IDF in order to begin your own projects.

## Step 4: Building and flashing the application

In terminal, go to the application directory which was obtained on the previous step:

```
cd ~/esp/myapp
```

Type a command like this to set the path to ESP-IDF directory:

```
export IDF_PATH=~/esp/esp-idf
```

At this point you may configure the serial port to be used for uploading. Run:

```
make menuconfig
```

Then navigate to "Serial flasher config" submenu and change value of "Default serial port" to match the serial port you will use. Also take a moment to explore other options which are configurable in `menuconfig`.

Special note for Arch Linux users: navigate to "SDK tool configuration" and change the name of "Python 2 interpreter" from `python` to `python2`.

Now you can build and flash the application. Run:

```
make flash
```

This will compile the application and all the ESP-IDF components, generate bootloader, partition table, and application binaries, and flash these binaries to your development board.

## Further reading

If you'd like to use the Eclipse IDE instead of running `make`, check out the Eclipse setup guide in this directory.

CHAPTER 3

# Set up of Toolchain for Mac OS

## Step 0: Prerequisites

- install pip:

```
sudo easy_install pip
```

- install pyserial

  sudo pip install pyserial

## Step 1: Download binary toolchain for the ESP32

ESP32 toolchain for macOS is available for download from Espressif website:

https://dl.espressif.com/dl/xtensa-esp32-elf-osx-1.22.0-61-gab8375a-5.2.0.tar.gz

Download this file, then extract it to the location you prefer, for example:

```
mkdir -p ~/esp
cd ~/esp
tar -xzf ~/Downloads/xtensa-esp32-elf-osx-1.22.0-61-gab8375a-5.2.0.tar.gz
```

The toolchain will be extracted into `~/esp/xtensa-esp32-elf/` directory.

To use it, you will need to update your `PATH` environment variable in `~/.profile` file. To make `xtensa-esp32-elf` available for all terminal sessions, add the following line to your `~/.profile` file:

```
export PATH=$PATH:$HOME/esp/xtensa-esp32-elf/bin
```

Alternatively, you may create an alias for the above command. This way you can get the toolchain only when you need it. To do this, add different line to your `~/.profile` file:

```
alias get_esp32="export PATH=$PATH:$HOME/esp/xtensa-esp32-elf/bin"
```

Then when you need the toolchain you can type `get_esp32` on the command line and the toolchain will be added to your `PATH`.

## Alternative Step 1: Compile the toolchain from source using crosstool-NG

Instead of downloading binary toolchain from Espressif website (Step 1 above) you may build the toolchain yourself.

If you can't think of a reason why you need to build it yourself, then probably it's better to stick with the binary version. However, here are some of the reasons why you might want to compile it from source:

- if you want to customize toolchain build configuration
- if you want to use a different GCC version (such as 4.8.5)
- if you want to hack gcc or newlib or libstdc++
- if you are curious and/or have time to spare
- if you don't trust binaries downloaded from the Internet

In any case, here are the steps to compile the toolchain yourself.

- Install dependencies:
  - Install either MacPorts or homebrew package manager. MacPorts needs a full XCode installation, while homebrew only needs XCode command line tools.
  - with MacPorts:

    ```
    sudo port install gsed gawk binutils gperf grep gettext wget libtool autoconf automake
    ```

  - with homebrew:

    ```
    brew install gnu-sed gawk binutils gperftools gettext wget help2man libtool autoconf automake
    ```

Create a case-sensitive filesystem image:

```
hdiutil create ~/esp/crosstool.dmg -volname "ctng" -size 10g -fs "Case-sensitive HFS+"
```

Mount it:

```
hdiutil mount ~/esp/crosstool.dmg
```

Create a symlink to your work directory:

```
cd ~/esp
ln -s /Volumes/ctng crosstool-NG
```

Download `crosstool-NG` and build it:

```
cd ~/esp
git clone -b xtensa-1.22.x https://github.com/espressif/crosstool-NG.git
```

```
cd crosstool-NG
./bootstrap && ./configure --enable-local && make install
```

Build the toolchain:

```
./ct-ng xtensa-esp32-elf
./ct-ng build
chmod -R u+w builds/xtensa-esp32-elf
```

Toolchain will be built in `~/esp/crosstool-NG/builds/xtensa-esp32-elf`. Follow instructions given in the previous section to add the toolchain to your `PATH`.

## Step 2: Getting ESP-IDF from github

Open Terminal.app, navigate to the directory you want to clone ESP-IDF and clone it using `git clone` command:

```
cd ~/esp
git clone --recursive https://github.com/espressif/esp-idf.git
```

ESP-IDF will be downloaded into `~/esp/esp-idf`.

Note the `--recursive` option! If you have already cloned ESP-IDF without this option, run another command to get all the submodules:

```
cd ~/esp/esp-idf
git submodule update --init
```

## Step 3: Starting a project

ESP-IDF by itself does not build a binary to run on the ESP32. The binary "app" comes from a project in a different directory. Multiple projects can share the same ESP-IDF directory.

The easiest way to start a project is to download the template project from GitHub:

```
cd ~/esp
git clone https://github.com/espressif/esp-idf-template.git myapp
```

This will download `esp-idf-template` project into `~/esp/myapp` directory.

**IMPORTANT:** The esp-idf build system does not support spaces in paths to esp-idf or to projects.

You can also find a range of example projects under the "examples" directory in IDF. These example project directories can be copied to outside IDF in order to begin your own projects.

## Step 4: Building and flashing the application

In Terminal.app, go to the application directory which was obtained on the previous step:

```
cd ~/esp/myapp
```

Type a command like this to set the path to ESP-IDF directory:

```
export IDF_PATH=~/esp/esp-idf
```

At this point you may configure the serial port to be used for uploading. Run:

```
make menuconfig
```

Then navigate to "Serial flasher config" submenu and change value of "Default serial port" to match the serial port you will use. Also take a moment to explore other options which are configurable in `menuconfig`.

If you don't know device name for the serial port of your development board, run this command two times, first with the board unplugged, then with the board plugged in. The port which appears the second time is the one you need:

```
ls /dev/tty.*
```

Now you can build and flash the application. Run:

```
make flash
```

This will compile the application and all the ESP-IDF components, generate bootloader, partition table, and application binaries, and flash these binaries to your development board.

## Further reading

If you'd like to use the Eclipse IDE instead of running `make`, check out the Eclipse setup guide in this directory.

CHAPTER 4

# Build and Flash with Make

## Finding a project

As well as the esp-idf-template project mentioned in the setup guide, ESP-IDF comes with some example projects on github in the examples directory.

Once you've found the project you want to work with, change to its directory and you can configure and build it:

## Configuring your project

*make menuconfig*

## Compiling your project

*make all*

... will compile app, bootloader and generate a partition table based on the config.

## Flashing your project

When *make all* finishes, it will print a command line to use esptool.py to flash the chip. However you can also do this from make by running:

*make flash*

This will flash the entire project (app, bootloader and partition table) to a new chip. The settings for serial port flashing can be configured with *make menuconfig*.

You don't need to run *make all* before running *make flash*, *make flash* will automatically rebuild anything which needs it.

## Compiling & Flashing Just the App

After the initial flash, you may just want to build and flash just your app, not the bootloader and partition table:

- *make app* - build just the app.
- *make app-flash* - flash just the app.

*make app-flash* will automatically rebuild the app if it needs it.

(There's no downside to reflashing the bootloader and partition table each time, if they haven't changed.)

## The Partition Table

Once you've compiled your project, the "build" directory will contain a binary file with a name like "my_app.bin". This is an ESP32 image binary that can be loaded by the bootloader.

A single ESP32's flash can contain multiple apps, as well as many different kinds of data (calibration data, filesystems, parameter storage, etc). For this reason a partition table is flashed to offset 0x4000 in the flash.

Each entry in the partition table has a name (label), type (app, data, or something else), subtype and the offset in flash where the partition is loaded.

The simplest way to use the partition table is to *make menuconfig* and choose one of the simple predefined partition tables:

- "Single factory app, no OTA"
- "Factory app, two OTA definitions"

In both cases the factory app is flashed at offset 0x10000. If you *make partition_table* then it will print a summary of the partition table.

For more details about *partition tables* and how to create custom variations, view the *documentation*.

# CHAPTER 5

# Build and Flash with Eclipse IDE

## Installing Eclipse IDE

The Eclipse IDE gives you a graphical integrated development environment for writing, compiling and debugging ESP-IDF projects.

- Start by installing the esp-idf for your platform (see files in this directory with steps for Windows, OS X, Linux).
- We suggest building a project from the command line first, to get a feel for how that process works. You also need to use the command line to configure your esp-idf project (via `make menuconfig`), this is not currently supported inside Eclipse.
- Download the Eclipse Installer for your platform from eclipse.org.
- When running the Eclipse Installer, choose "Eclipse for C/C++ Development" (in other places you'll see this referred to as CDT.)

## Windows Users

Using ESP-IDF with Eclipse on Windows requires different configuration steps. See the Eclipse IDE on Windows guide.

## Setting up Eclipse

Once your new Eclipse installation launches, follow these steps:

### Import New Project

- Eclipse makes use of the Makefile support in ESP-IDF. This means you need to start by creating an ESP-IDF project. You can use the idf-template project from github, or open one of the examples in the esp-idf examples subdirectory.

- Once Eclipse is running, choose File -> Import...
- In the dialog that pops up, choose "C/C++" -> "Existing Code as Makefile Project" and click Next.
- On the next page, enter "Existing Code Location" to be the directory of your IDF project. Don't specify the path to the ESP-IDF directory itself (that comes later). The directory you specify should contain a file named "Makefile" (the project Makefile).
- On the same page, under "Toolchain for Indexer Settings" choose "Cross GCC". Then click Finish.

## Project Properties

- The new project will appear under Project Explorer. Right-click the project and choose Properties from the context menu.
- Click on the "Environment" properties page under "C/C++ Build". Click "Add..." and enter name `BATCH_BUILD` and value `1`.
- Click "Add..." again, and enter name `IDF_PATH`. The value should be the full path where ESP-IDF is installed.
- Edit the `PATH` environment variable. Keep the current value, and append the path to the Xtensa toolchain that will installed as part of IDF setup (`something/xtensa-esp32-elf/bin`) if this is not already listed on the PATH.
- On macOS, add a `PYTHONPATH` environment variable and set it to `/Library/Frameworks/Python.framework/Versions/2.7/lib/python2.7/site-packages`. This is so that the system Python, which has pyserial installed as part of the setup steps, overrides any built-in Eclipse Python.

Navigate to "C/C++ General" -> "Preprocessor Include Paths" property page:

- Click the "Providers" tab
- In the list of providers, click "CDT Cross GCC Built-in Compiler Settings". Under "Command to get compiler specs", replace the text `${COMMAND}` at the beginning of the line with `xtensa-esp32-elf-gcc`. This means the full "Command to get compiler specs" should be `xtensa-esp32-elf-gcc ${FLAGS} -E -P -v -dD "${INPUTS}"`.
- In the list of providers, click "CDT GCC Build Output Parser" and type `xtensa-esp32-elf-` at the beginning of the Compiler command pattern. This means the full Compiler command pattern should be `xtensa-esp32-elf-(g?cc)|([gc]\+\+)|(clang)`

## Building in Eclipse

Before your project is first built, Eclipse may show a lot of errors and warnings about undefined values. This is because some source files are automatically generated as part of the esp-idf build process. These errors and warnings will go away after you build the project.

- Click OK to close the Properties dialog in Eclipse.
- Outside Eclipse, open a command line prompt. Navigate to your project directory, and run `make menuconfig` to configure your project's esp-idf settings. This step currently has to be run outside Eclipse.

*If you try to build without running a configuration step first, esp-idf will prompt for configuration on the command line - but Eclipse is not able to deal with this, so the build will hang or fail.*

- Back in Eclipse, choose Project -> Build to build your project.

**TIP**: If your project had already been built outside Eclipse, you may need to do a Project -> Clean before chosing Project -> Build. This is so Eclipse can see the compiler arguments for all source files. It uses these to determine the header include paths.

## Flash from Eclipse

You can integrate the "make flash" target into your Eclipse project to flash using esptool.py from the Eclipse UI:

- Right-click your project in Project Explorer (important to make sure you select the project, not a directory in the project, or Eclipse may find the wrong Makefile.)
- Select Make Targets -> Create from the context menu.
- Type "flash" as the target name. Leave the other options as their defaults.
- Now you can use Project -> Make Target -> Build (Shift+F9) to build the custom flash target, which will compile and flash the project.

Note that you will need to use "make menuconfig" to set the serial port and other config options for flashing. "make menuconfig" still requires a command line terminal (see the instructions for your platform.)

Follow the same steps to add `bootloader` and `partition_table` targets, if necessary.

CHAPTER 6

# IDF Monitor

The idf_monitor tool is a Python program which runs when the `make monitor` target is invoked in IDF.

It is mainly a serial terminal program which relays serial data to and from the target device's serial port, but it has some other IDF-specific xfeatures.

## Interacting With idf_monitor

- `Ctrl-]` will exit the monitor.
- `Ctrl-T Ctrl-H` will display a help menu with all other keyboard shortcuts.
- Any other key apart from `Ctrl-]` and `Ctrl-T` is sent through the serial port.

## Automatically Decoding Addresses

Any time esp-idf prints a hexadecimal code address of the form `0x4_______`, idf_monitor will use addr2line to look up the source code location and function name.

When an esp-idf app crashes and panics a register dump and backtrace such as this is produced:

```
Guru Meditation Error of type StoreProhibited occurred on core  0. Exception was␣
↪unhandled.
Register dump:
PC      : 0x400f360d  PS      : 0x00060330  A0      : 0x800dbf56  A1      : 0x3ffb7e00
A2      : 0x3ffb136c  A3      : 0x00000005  A4      : 0x00000000  A5      : 0x00000000
A6      : 0x00000000  A7      : 0x00000080  A8      : 0x00000000  A9      : 0x3ffb7dd0
A10     : 0x00000003  A11     : 0x00060f23  A12     : 0x00060f20  A13     : 0x3ffba6d0
A14     : 0x00000047  A15     : 0x0000000f  SAR     : 0x00000019  EXCCAUSE: 0x0000001d
EXCVADDR: 0x00000000  LBEG    : 0x4000c46c  LEND    : 0x4000c477  LCOUNT  : 0x00000000

Backtrace: 0x400f360d:0x3ffb7e00 0x400dbf56:0x3ffb7e20 0x400dbf5e:0x3ffb7e40␣
↪0x400dbf82:0x3ffb7e60 0x400d071d:0x3ffb7e90
```

idf_monitor will augment the dump:

```
Guru Meditation Error of type StoreProhibited occurred on core  0. Exception was␣
↪unhandled.
Register dump:
PC      : 0x400f360d  PS      : 0x00060330  A0      : 0x800dbf56  A1      : 0x3ffb7e00
0x400f360d: do_something_to_crash at /home/gus/esp/32/idf/examples/get-started/hello_
↪world/main/./hello_world_main.c:57
(inlined by) inner_dont_crash at /home/gus/esp/32/idf/examples/get-started/hello_
↪world/main/./hello_world_main.c:52
A2      : 0x3ffb136c  A3      : 0x00000005  A4      : 0x00000000  A5      : 0x00000000
A6      : 0x00000000  A7      : 0x00000080  A8      : 0x00000000  A9      : 0x3ffb7dd0
A10     : 0x00000003  A11     : 0x00060f23  A12     : 0x00060f20  A13     : 0x3ffba6d0
A14     : 0x00000047  A15     : 0x0000000f  SAR     : 0x00000019  EXCCAUSE: 0x0000001d
EXCVADDR: 0x00000000  LBEG    : 0x4000c46c  LEND    : 0x4000c477  LCOUNT  : 0x00000000

Backtrace: 0x400f360d:0x3ffb7e00 0x400dbf56:0x3ffb7e20 0x400dbf5e:0x3ffb7e40␣
↪0x400dbf82:0x3ffb7e60 0x400d071d:0x3ffb7e90
0x400f360d: do_something_to_crash at /home/gus/esp/32/idf/examples/get-started/hello_
↪world/main/./hello_world_main.c:57
(inlined by) inner_dont_crash at /home/gus/esp/32/idf/examples/get-started/hello_
↪world/main/./hello_world_main.c:52
0x400dbf56: still_dont_crash at /home/gus/esp/32/idf/examples/get-started/hello_world/
↪main/./hello_world_main.c:47
0x400dbf5e: dont_crash at /home/gus/esp/32/idf/examples/get-started/hello_world/main/.
↪/hello_world_main.c:42
0x400dbf82: app_main at /home/gus/esp/32/idf/examples/get-started/hello_world/main/./
↪hello_world_main.c:33
0x400d071d: main_task at /home/gus/esp/32/idf/components/esp32/./cpu_start.c:254
```

Behind the scenes, the command idf_monitor runs to decode each address is:

```
xtensa-esp32-elf-addr2line -pfia -e build/PROJECT.elf ADDRESS
```

# Launch GDB for GDBStub

By default, if an esp-idf app crashes then the panic handler prints registers and a stack dump as shown above, and then resets.

Optionally, the panic handler can be configured to run a serial "gdb stub" which can communicate with a gdb debugger program and allow memory to be read, variables and stack frames examined, etc. This is not as versatile as JTAG debugging, but no special hardware is required.

To enable the gdbstub, run `make menuconfig` and navigate to `Component config` -> `ESP32-specific` -> `Panic handler behaviour`, then set the value to `Invoke GDBStub`.

If this option is enabled and idf_monitor sees the gdb stub has loaded, it will automatically pause serial monitoring and run GDB with the correct arguments. After GDB exits, the board will be reset via the RTS serial line (if this is connected.)

Behind the scenes, the command idf_monitor runs is:

```
xtensa-esp32-elf-gdb -ex "set serial baud BAUD" -ex "target remote PORT" -ex␣
↪interrupt build/PROJECT.elf
```

## Quick Compile and Flash

The keyboard shortcut `Ctrl-T Ctrl-F` will pause idf_monitor, run the `make flash` target, then resume idf_monitor. Any changed source files will be recompiled before re-flashing.

The keyboard shortcut `Ctrl-T Ctrl-A` will pause idf-monitor, run the `make app-flash` target, then resume idf_monitor. This is similar to `make flash`, but only the main app is compiled and reflashed.

## Quick Reset

The keyboard shortcut `Ctrl-T Ctrl-R` will reset the target board via the RTS line (if it is connected.)

## Simple Monitor

Earlier versions of ESP-IDF used the pySerial command line program miniterm as a serial console program.

This program can still be run, via `make simple_monitor`.

idf_monitor is based on miniterm and shares the same basic keyboard shortcuts.

## Known Issues with idf_monitor

### Issues Observed on Windows

- If you are using the supported Windows environment and receive the error "winpty: command not found" then run `pacman -S winpty` to fix.
- Arrow keys and some other special keys in gdb don't work, due to Windows Console limitations.
- Occasionally when "make" exits, it may stall for up to 30 seconds before idf_monitor resumes.
- Occasionally when "gdb" is run, it may stall for a short time before it begins communicating with the gdbstub.

CHAPTER 7

# General Notes About ESP-IDF Programming

## Application startup flow

This note explains various steps which happen before `app_main` function of an ESP-IDF application is called.

The high level view of startup process is as follows:

1. First-stage bootloader in ROM loads second-stage bootloader image to RAM (IRAM & DRAM) from flash offset 0x1000.
2. Second-stage bootloader loads partition table and main app image from flash. Main app incorporates both RAM segments and read-only segments mapped via flash cache.
3. Main app image executes. At this point the second CPU and RTOS scheduler can be started.

This process is explained in detail in the following sections.

### First stage bootloader

After SoC reset, PRO CPU will start running immediately, executing reset vector code, while APP CPU will be held in reset. During startup process, PRO CPU does all the initialization. APP CPU reset is de-asserted in the `call_start_cpu0` function of application startup code. Reset vector code is located at address 0x40000400 in the mask ROM of the ESP32 chip and can not be modified.

Startup code called from the reset vector determines the boot mode by checking `GPIO_STRAP_REG` register for bootstrap pin states. Depending on the reset reason, the following takes place:

1. Reset from deep sleep: if the value in `RTC_CNTL_STORE6_REG` is non-zero, and CRC value of RTC memory in `RTC_CNTL_STORE7_REG` is valid, use `RTC_CNTL_STORE6_REG` as an entry point address and jump immediately to it. If `RTC_CNTL_STORE6_REG` is zero, or `RTC_CNTL_STORE7_REG` contains invalid CRC, or once the code called via `RTC_CNTL_STORE6_REG` returns, proceed with boot as if it was a power-on reset. **Note**: to run customized code at this point, a deep sleep stub mechanism is provided. Please see *deep sleep* documentation for this.

2. For power-on reset, software SOC reset, and watchdog SOC reset: check the `GPIO_STRAP_REG` register if UART or SDIO download mode is requested. If this is the case, configure UART or SDIO, and wait for code to be downloaded. Otherwise, proceed with boot as if it was due to software CPU reset.
3. For software CPU reset and watchdog CPU reset: configure SPI flash based on EFUSE values, and attempt to load the code from flash. This step is described in more detail in the next paragraphs. If loading code from flash fails, unpack BASIC interpreter into the RAM and start it. Note that RTC watchdog is still enabled when this happens, so unless any input is received by the interpreter, watchdog will reset the SOC in a few hundred milliseconds, repeating the whole process. If the interpreter receives any input from the UART, it disables the watchdog.

Application binary image is loaded from flash starting at address 0x1000. First 4kB sector of flash is used to store secure boot IV and signature of the application image. Please check secure boot documentation for details about this.

## Second stage bootloader

In ESP-IDF, the binary image which resides at offset 0x1000 in flash is the second stage bootloader. Second stage bootloader source code is available in components/bootloader directory of ESP-IDF. Note that this arrangement is not the only one possible with the ESP32 chip. It is possible to write a fully featured application which would work when flashed to offset 0x1000, but this is out of scope of this document. Second stage bootloader is used in ESP-IDF to add flexibility to flash layout (using partition tables), and allow for various flows associated with flash encryption, secure boot, and over-the-air updates (OTA) to take place.

When the first stage bootloader is finished checking and loading the second stage bootloader, it jumps to the second stage bootloader entry point found in the binary image header.

Second stage bootloader reads the partition table found at offset 0x8000. See *partition tables* documentation for more information. The bootloader finds factory and OTA partitions, and decides which one to boot based on data found in *OTA info* partition.

For the selected partition, second stage bootloader copies data and code sections which are mapped into IRAM and DRAM to their load addresses. For sections which have load addresses in DROM and IROM regions, flash MMU is configured to provide the correct mapping. Note that the second stage bootloader configures flash MMU for both PRO and APP CPUs, but it only enables flash MMU for PRO CPU. Reason for this is that second stage bootloader code is loaded into the memory region used by APP CPU cache. The duty of enabling cache for APP CPU is passed on to the application. Once code is loaded and flash MMU is set up, second stage bootloader jumps to the application entry point found in the binary image header.

Currently it is not possible to add application-defined hooks to the bootloader to customize application partition selection logic. This may be required to load different application image depending on a state of a GPIO, for example. Such customization features will be added to ESP-IDF in the future. For now, bootloader can be customized by copying bootloader component into application directory and making necessary changes there. ESP-IDF build system will compile the component in application directory instead of ESP-IDF components directory in this case.

## Application startup

ESP-IDF application entry point is `call_start_cpu0` function found in `components/esp32/cpu_start.c`. Two main things this function does are to enable heap allocator and to make APP CPU jump to its entry point, `call_start_cpu1`. The code on PRO CPU sets the entry point for APP CPU, de-asserts APP CPU reset, and waits for a global flag to be set by the code running on APP CPU, indicating that it has started. Once this is done, PRO CPU jumps to `start_cpu0` function, and APP CPU jumps to `start_cpu1` function.

Both `start_cpu0` and `start_cpu1` are weak functions, meaning that they can be overridden in the application, if some application-specific change to initialization sequence is needed. Default implementation of `start_cpu0` enables or initializes components depending on choices made in `menuconfig`. Please see source code of this function in `components/esp32/cpu_start.c` for an up to date list of steps performed. Note that any C++ global constructors present in the application will be called at this stage. Once all essential components are initialized, *main task* is created and FreeRTOS scheduler is started.

While PRO CPU does initialization in `start_cpu0` function, APP CPU spins in `start_cpu1` function, waiting for the scheduler to be started on the PRO CPU. Once the scheduler is started on the PRO CPU, code on the APP CPU starts the scheduler as well.

Main task is the task which runs `app_main` function. Main task stack size and priority can be configured in `menuconfig`. Application can use this task for initial application-specific setup, for example to launch other tasks. Application can also use main task for event loops and other general purpose activities. If `app_main` function returns, main task is deleted.

## Application memory layout

ESP32 chip has flexible memory mapping features. This section describes how ESP-IDF uses these features by default.

Application code in ESP-IDF can be placed into one of the following memory regions.

### IRAM (instruction RAM)

ESP-IDF allocates part of *Internal SRAM0* region (defined in the Technical Reference Manual) for instruction RAM. Except for the first 64 kB block which is used for PRO and APP CPU caches, the rest of this memory range (i.e. from `0x40080000` to `0x400A0000`) is used to store parts of application which need to run from RAM.

A few components of ESP-IDF and parts of WiFi stack are placed into this region using the linker script.

If some application code needs to be placed into IRAM, it can be done using `IRAM_ATTR` define:

```
#include "esp_attr.h"

void IRAM_ATTR gpio_isr_handler(void* arg)
{
        // ...
}
```

Here are the cases when parts of application may or should be placed into IRAM.

- ISR handlers must always be placed into IRAM. Furthermore, ISR handlers may only call functions placed into IRAM or functions present in ROM. *Note 1:* all FreeRTOS APIs are currently placed into IRAM, so are safe to call from ISR handlers. *Note 1:* all constant data used by ISR handlers and functions called from ISR handlers (including, but not limited to, `const char` arrays), must be placed into DRAM using `DRAM_ATTR`.
- Some timing critical code may be placed into IRAM to reduce the penalty associated with loading the code from flash. ESP32 reads code and data from flash via a 32 kB cache. In some cases, placing a function into IRAM may reduce delays caused by a cache miss.

### IROM (code executed from Flash)

If a function is not explicitly placed into IRAM or RTC memory, it is placed into flash. The mechanism by which Flash MMU is used to allow code execution from flash is described in the Technical Reference Manual. ESP-IDF places the code which should be executed from flash starting from the beginning of `0x400D0000 -- 0x40400000` region. Upon startup, second stage bootloader initializes Flash MMU to map the location in flash where code is located into the beginning of this region. Access to this region is transparently cached using two 32kB blocks in `0x40070000` — `0x40080000` range.

Note that the code outside `0x40000000 -- 0x40400000` region may not be reachable with Window ABI `CALLx` instructions, so special care is required if `0x40400000 -- 0x40800000` or `0x40800000 -- 0x40C00000` regions are used by the application. ESP-IDF doesn't use these regions by default.

### RTC fast memory

The code which has to run after wake-up from deep sleep mode has to be placed into RTC memory. Please check detailed description in *deep sleep* documentation.

### DRAM (data RAM)

Non-constant static data and zero-initialized data is placed by the linker into the 256 kB `0x3FFB0000 -- 0x3FFF0000` region. Note that this region is reduced by 64kB (by shifting start address to `0x3FFC0000`) if Bluetooth stack is used. Length of this region is also reduced by 16 kB or 32kB if trace memory is used. All space which is left in this region after placing static data there is used for the runtime heap.

Constant data may also be placed into DRAM, for example if it is used in an ISR handler (see notes in IRAM section above). To do that, `DRAM_ATTR` define can be used:

```
DRAM_ATTR const char[] format_string = "%p %x";
char buffer[64];
sprintf(buffer, format_string, ptr, val);
```

Needless to say, it is not advised to use `printf` and other output functions in ISR handlers. For debugging purposes, use `ESP_EARLY_LOGx` macros when logging from ISR handlers. Make sure that both `TAG` and format string are placed into `DRAM` in that case.

### DROM (data stored in Flash)

By default, constant data is placed by the linker into a 4 MB region (`0x3F400000 -- 0x3F800000`) which is used to access external flash memory via Flash MMU and cache. Exceptions to this are literal constants which are embedded by the compiler into application code.

### RTC slow memory

Global and static variables used by code which runs from RTC memory (i.e. deep sleep stub code) must be placed into RTC slow memory. Please check detailed description in *deep sleep* documentation.

CHAPTER 8

# Build System

This document explains the Espressif IoT Development Framework build system and the concept of "components"

Read this document if you want to know how to organise a new ESP-IDF project.

We recommend using the esp-idf-template project as a starting point for your project.

## Using the Build System

The esp-idf README file contains a description of how to use the build system to build your project.

## Overview

An ESP-IDF project can be seen as an amalgamation of a number of components. For example, for a webserver that shows the current humidity, there could be:

- The ESP32 base libraries (libc, rom bindings etc)
- The WiFi drivers
- A TCP/IP stack
- The FreeRTOS operating system
- A webserver
- A driver for the humidity sensor
- Main code tying it all together

ESP-IDF makes these components explicit and configurable. To do that, when a project is compiled, the build environment will look up all the components in the ESP-IDF directories, the project directories and (optionally) in additional custom component directories. It then allows the user to configure the ESP-IDF project using a a text-based menu system to customize each component. After the components in the project are configured, the build process will compile the project.

## Concepts

- A "project" is a directory that contains all the files and configuration to build a single "app" (executable), as well as additional supporting output such as a partition table, data/filesystem partitions, and a bootloader.
- "Project configuration" is held in a single file called sdkconfig in the root directory of the project. This configuration file is modified via `make menuconfig` to customise the configuration of the project. A single project contains exactly one project configuration.
- An "app" is an executable which is built by esp-idf. A single project will usually build two apps - a "project app" (the main executable, ie your custom firmware) and a "bootloader app" (the initial bootloader program which launches the project app).
- "components" are modular pieces of standalone code which are compiled into static libraries (.a files) and linked into an app. Some are provided by esp-idf itself, others may be sourced from other places.

Some things are not part of the project:

- "ESP-IDF" is not part of the project. Instead it is standalone, and linked to the project via the `IDF_PATH` environment variable which holds the path of the `esp-idf` directory. This allows the IDF framework to be decoupled from your project.
- The toolchain for compilation is not part of the project. The toolchain should be installed in the system command line PATH, or the path to the toolchain can be set as part of the compiler prefix in the project configuration.

## Example Project

An example project directory tree might look like this:

```
- myProject/
             - Makefile
             - sdkconfig
             - components/ - component1/ - component.mk
                                         - Kconfig
                                         - src1.c
                           - component2/ - component.mk
                                         - Kconfig
                                         - src1.c
                                         - include/ - component2.h
             - main/       - src1.c
                           - src2.c
                           - component.mk

             - build/
```

This example "myProject" contains the following elements:

- A top-level project Makefile. This Makefile set the `PROJECT_NAME` variable and (optionally) defines other project-wide make variables. It includes the core `$(IDF_PATH)/make/project.mk` makefile which implements the rest of the ESP-IDF build system.
- "sdkconfig" project configuration file. This file is created/updated when "make menuconfig" runs, and holds configuration for all of the components in the project (including esp-idf itself). The "sdkconfig" file may or may not be added to the source control system of the project.
- Optional "components" directory contains components that are part of the project. A project does not have to contain custom components of this kind, but it can be useful for structuring reusable code or including third party components that aren't part of ESP-IDF.

- "main" directory is a special "pseudo-component" that contains source code for the project itself. "main" is a default name, the Makefile variable `SRCDIRS` defaults to this but can be set to look for pseudo-components in other directories.
- "build" directory is where build output is created. After the make process is run, this directory will contain interim object files and libraries as well as final binary output files. This directory is usually not added to source control or distributed with the project source code.

Component directories contain a component makefile - `component.mk`. This may contain variable definitions to control the build process of the component, and its integration into the overall project. See *Component Makefiles* for more details.

Each component may also include a `Kconfig` file defining the *component configuration* options that can be set via the project configuration. Some components may also include `Kconfig.projbuild` and `Makefile.projbuild` files, which are special files for *overriding parts of the project*.

## Project Makefiles

Each project has a single Makefile that contains build settings for the entire project. By default, the project Makefile can be quite minimal.

### Minimal Example Makefile

```
PROJECT_NAME := myProject

include $(IDF_PATH)/make/project.mk
```

### Mandatory Project Variables

- `PROJECT_NAME`: Name of the project. Binary output files will use this name - ie myProject.bin, myProject.elf.

### Optional Project Variables

These variables all have default values that can be overridden for custom behaviour. Look in `make/project.mk` for all of the implementation details.

- `PROJECT_PATH`: Top-level project directory. Defaults to the directory containing the Makefile. Many other project variables are based on this variable. The project path cannot contain spaces.
- `BUILD_DIR_BASE`: The build directory for all objects/libraries/binaries. Defaults to `$(PROJECT_PATH)/build`.
- `COMPONENT_DIRS`: Directories to search for components. Defaults to *$(IDF_PATH)/components*, *$(PROJECT_PATH)/components* and `EXTRA_COMPONENT_DIRS`. Override this variable if you don't want to search for components in the esp-idf & project `components` directories.
- `EXTRA_COMPONENT_DIRS`: Optional list of additional directories to search for components. Components themselves are in sub-directories of these directories, this is a top-level directory containing the component directories.
- `COMPONENTS`: A list of component names to build into the project. Defaults to all components found in the COMPONENT_DIRS directories.

- `SRCDIRS`: Directories under the main project directory which contain project-specific "pseudo-components". Defaults to 'main'. The difference between specifying a directory here and specifying it under `EXTRA_COMPONENT_DIRS` is that a directory in `SRCDIRS` is a component itself (contains a file "component.mk"), whereas a directory in `EXTRA_COMPONENT_DIRS` contains component directories which contain a file "component.mk". See the *Example Project* for a concrete case of this.

## Component Makefiles

Each project contains one or more components, which can either be part of esp-idf or added from other component directories.

A component is any sub-directory that contains a *component.mk* file[1].

### Minimal Component Makefile

The minimal `component.mk` file is an empty file(!). If the file is empty, the default component behaviour is set:

- All source files in the same directory as the makefile (`*.c`, `*.cpp`, `*.S`) will be compiled into the component library
- A sub-directory "include" will be added to the global include search path for all other components.
- The component library will be linked into the project app.

See *example component makefiles* for more complete component makefile examples.

Note that there is a difference between an empty `component.mk` file (which invokes default component build behaviour) and no `component.mk` file (which means no default component build behaviour will occur.) It is possible for a component to have no *component.mk* file, if it only contains other files which influence the project configuration or build process.

### Preset Component Variables

The following component-specific variables are available for use inside `component.mk`, but should not be modified:

- `COMPONENT_PATH`: The component directory. Evaluates to the absolute path of the directory containing `component.mk`. The component path cannot contain spaces.
- `COMPONENT_NAME`: Name of the component. Defaults to the name of the component directory.
- `COMPONENT_BUILD_DIR`: The component build directory. Evaluates to the absolute path of a directory inside *$(BUILD_DIR_BASE)* where this component's source files are to be built. This is also the Current Working Directory any time the component is being built, so relative paths in make targets, etc. will be relative to this directory.
- `COMPONENT_LIBRARY`: Name of the static library file (relative to the component build directory) that will be built for this component. Defaults to `$(COMPONENT_NAME).a`.

The following variables are set at the project level, but exported for use in the component build:

- `PROJECT_NAME`: Name of the project, as set in project Makefile
- `PROJECT_PATH`: Absolute path of the project directory containing the project Makefile.
- `COMPONENTS`: Name of all components that are included in this build.

[1] Actually, some components in esp-idf are "pure configuration" components that don't have a component.mk file, only a Makefile.projbuild and/or Kconfig.projbuild file. However, these components are unusual and most components have a component.mk file.

- CONFIG_*: Each value in the project configuration has a corresponding variable available in make. All names begin with CONFIG_.
- CC, LD, AR, OBJCOPY: Full paths to each tool from the gcc xtensa cross-toolchain.
- HOSTCC, HOSTLD, HOSTAR: Full names of each tool from the host native toolchain.
- IDF_VER: Git version of ESP-IDF (produced by git describe)

If you modify any of these variables inside component.mk then this will not prevent other components from building but it may make your component hard to build and/or debug.

### Optional Project-Wide Component Variables

The following variables can be set inside component.mk to control build settings across the entire project:

- COMPONENT_ADD_INCLUDEDIRS: Paths, relative to the component directory, which will be added to the include search path for all components in the project. Defaults to include if not overridden. If an include directory is only needed to compile this specific component, add it to COMPONENT_PRIV_INCLUDEDIRS instead.
- COMPONENT_ADD_LDFLAGS: Add linker arguments to the LDFLAGS for the app executable. Defaults to -l$(COMPONENT_NAME). If adding pre-compiled libraries to this directory, add them as absolute paths - ie $(COMPONENT_PATH)/libwhatever.a
- COMPONENT_DEPENDS: Optional list of component names that should be compiled before this component. This is not necessary for link-time dependencies, because all component include directories are available at all times. It is necessary if one component generates an include file which you then want to include in another component. Most components do not need to set this variable.
- COMPONENT_ADD_LINKER_DEPS: Optional list of component-relative paths to files which should trigger a re-link of the ELF file if they change. Typically used for linker script files and binary libraries. Most components do not need to set this variable.

The following variable only works for components that are part of esp-idf itself:

- COMPONENT_SUBMODULES: Optional list of git submodule paths (relative to COMPONENT_PATH) used by the component. These will be checked (and initialised if necessary) by the build process. This variable is ignored if the component is outside the IDF_PATH directory.

### Optional Component-Specific Variables

The following variables can be set inside component.mk to control the build of that component:

- COMPONENT_PRIV_INCLUDEDIRS: Directory paths, must be relative to the component directory, which will be added to the include search path for this component's source files only.
- COMPONENT_EXTRA_INCLUDES: Any extra include paths used when compiling the component's source files. These will be prefixed with '-I' and passed as-is to the compiler. Similar to the COMPONENT_PRIV_INCLUDEDIRS variable, except these paths are not expanded relative to the component directory.
- COMPONENT_SRCDIRS: Directory paths, must be relative to the component directory, which will be searched for source files (*.cpp, *.c, *.S). Defaults to '.', ie the component directory itself. Override this to specify a different list of directories which contain source files.
- COMPONENT_OBJS: Object files to compile. Default value is a .o file for each source file that is found in COMPONENT_SRCDIRS. Overriding this list allows you to exclude source files in COMPONENT_SRCDIRS that would otherwise be compiled. See *Specifying source files*

- `COMPONENT_EXTRA_CLEAN`: Paths, relative to the component build directory, of any files that are generated using custom make rules in the component.mk file and which need to be removed as part of `make clean`. See *Source Code Generation* for an example.
- `COMPONENT_OWNBUILDTARGET` & *COMPONENT_OWNCLEANTARGET*: These targets allow you to fully override the default build behaviour for the component. See *Fully Overriding The Component Makefile* for more details.
- `CFLAGS`: Flags passed to the C compiler. A default set of `CFLAGS` is defined based on project settings. Component-specific additions can be made via `CFLAGS +=`. It is also possible (although not recommended) to override this variable completely for a component.
- `CPPFLAGS`: Flags passed to the C preprocessor (used for .c, .cpp and .S files). A default set of `CPPFLAGS` is defined based on project settings. Component-specific additions can be made via `CPPFLAGS +=`. It is also possible (although not recommended) to override this variable completely for a component.
- `CXXFLAGS`: Flags passed to the C++ compiler. A default set of `CXXFLAGS` is defined based on project settings. Component-specific additions can be made via `CXXFLAGS +=`. It is also possible (although not recommended) to override this variable completely for a component.

To apply compilation flags to a single source file, you can add a variable override as a target, ie:

```
apps/dhcpserver.o: CFLAGS += -Wno-unused-variable
```

This can be useful if there is upstream code that emits warnings.

## Component Configuration

Each component can also have a Kconfig file, alongside `component.mk`. This contains contains configuration settings to add to the "make menuconfig" for this component.

These settings are found under the "Component Settings" menu when menuconfig is run.

To create a component KConfig file, it is easiest to start with one of the KConfig files distributed with esp-idf.

For an example, see *Adding conditional configuration*.

## Preprocessor Definitions

ESP-IDF build systems adds the following C preprocessor definitions on the command line:

- `ESP_PLATFORM` — Can be used to detect that build happens within ESP-IDF.
- `IDF_VER` — Defined to a git version string. E.g. `v2.0` for a tagged release or `v1.0-275-g0efaa4f` for an arbitrary commit.

## Build Process Internals

### Top Level: Project Makefile

- "make" is always run from the project directory and the project makefile, typically named Makefile.
- The project makefile sets `PROJECT_NAME` and optionally customises other *optional project variables*
- The project makefile includes `$(IDF_PATH)/make/project.mk` which contains the project-level Make logic.

- `project.mk` fills in default project-level make variables and includes make variables from the project configuration. If the generated makefile containing project configuration is out of date, then it is regenerated (via targets in `project_config.mk`) and then the make process restarts from the top.
- `project.mk` builds a list of components to build, based on the default component directories or a custom list of components set in *optional project variables*.
- Each component can set some *optional project-wide component variables*. These are included via generated makefiles named `component_project_vars.mk` - there is one per component. These generated makefiles are included into `project.mk`. If any are missing or out of date, they are regenerated (via a recursive make call to the component makefile) and then the make process restarts from the top.
- *Makefile.projbuild* files from components are included into the make process, to add extra targets or configuration.
- By default, the project makefile also generates top-level build & clean targets for each component and sets up *app* and *clean* targets to invoke all of these sub-targets.
- In order to compile each component, a recursive make is performed for the component makefile.

To better understand the project make process, have a read through the `project.mk` file itself.

### Second Level: Component Makefiles

- Each call to a component makefile goes via the `$(IDF_PATH)/make/component_wrapper.mk` wrapper makefile.
- The `component_wrapper.mk` is called with the current directory set to the component build directory, and the `COMPONENT_MAKEFILE` variable is set to the absolute path to `component.mk`.
- `component_wrapper.mk` sets default values for all *component variables*, then includes the *component.mk* file which can override or modify these.
- If `COMPONENT_OWNBUILDTARGET` and `COMPONENT_OWNCLEANTARGET` are not defined, default build and clean targets are created for the component's source files and the prerequisite `COMPONENT_LIBRARY` static library file.
- The `component_project_vars.mk` file has its own target in `component_wrapper.mk`, which is evaluated from `project.mk` if this file needs to be rebuilt due to changes in the component makefile or the project configuration.

To better understand the component make process, have a read through the `component_wrapper.mk` file and some of the `component.mk` files included with esp-idf.

## Running Make Non-Interactively

When running `make` in a situation where you don't want interactive prompts (for example: inside an IDE or an automated build system) append `BATCH_BUILD=1` to the make arguments (or set it as an environment variable).

Setting `BATCH_BUILD` implies the following:

- Verbose output (same as `V=1`, see below). If you don't want verbose output, also set `V=0`.
- If the project configuration is missing new configuration items (from new components or esp-idf updates) then the project use the default values, instead of prompting the user for each item.
- If the build system needs to invoke `menuconfig`, an error is printed and the build fails.

## Debugging The Make Process

Some tips for debugging the esp-idf build system:

- Appending `V=1` to the make arguments (or setting it as an environment variable) will cause make to echo all commands executed, and also each directory as it is entered for a sub-make.
- Running `make -w` will cause make to echo each directory as it is entered for a sub-make - same as `V=1` but without also echoing all commands.
- Running `make --trace` (possibly in addition to one of the above arguments) will print out every target as it is built, and the dependency which caused it to be built.
- Running `make -p` prints a (very verbose) summary of every generated target in each makefile.

For more debugging tips and general make information, see the *GNU Make Manual*.

## Overriding Parts of the Project

### Makefile.projbuild

For components that have build requirements that must be evaluated in the top-level project make pass, you can create a file called `Makefile.projbuild` in the component directory. This makefile is included when `project.mk` is evaluated.

For example, if your component needs to add to CFLAGS for the entire project (not just for its own source files) then you can set `CFLAGS +=` in Makefile.projbuild.

`Makefile.projbuild` files are used heavily inside esp-idf, for defining project-wide build features such as `esptool.py` command line arguments and the `bootloader` "special app".

Note that `Makefile.projbuild` isn't necessary for the most common component uses - such as adding include directories to the project, or LDFLAGS to the final linking step. These values can be customised via the `component.mk` file itself. See *Optional Project-Wide Component Variables* for details.

Take care when setting variables or targets in this file. As the values are included into the top-level project makefile pass, they can influence or break functionality across all components!

### KConfig.projbuild

This is an equivalent to *Makefile.projbuild* for *component configuration* KConfig files. If you want to include configuration options at the top-level of menuconfig, rather than inside the "Component Configuration" sub-menu, then these can be defined in the KConfig.projbuild file alongside the `component.mk` file.

Take care when adding configuration values in this file, as they will be included across the entire project configuration. Where possible, it's generally better to create a KConfig file for *component configuration*.

## Example Component Makefiles

Because the build environment tries to set reasonable defaults that will work most of the time, component.mk can be very small or even empty (see *Minimal Component Makefile*). However, overriding *component variables* is usually required for some functionality.

Here are some more advanced examples of `component.mk` makefiles:

### Adding source directories

By default, sub-directories are ignored. If your project has sources in sub-directories instead of in the root of the component then you can tell that to the build system by setting `COMPONENT_SRCDIRS`:

```
COMPONENT_SRCDIRS := src1 src2
```

This will compile all source files in the src1/ and src2/ sub-directories instead.

### Specifying source files

The standard component.mk logic adds all .S and .c files in the source directories as sources to be compiled unconditionally. It is possible to circumvent that logic and hard-code the objects to be compiled by manually setting the `COMPONENT_OBJS` variable to the name of the objects that need to be generated:

```
COMPONENT_OBJS := file1.o file2.o thing/filea.o thing/fileb.o anotherthing/main.o
COMPONENT_SRCDIRS := . thing anotherthing
```

Note that `COMPONENT_SRCDIRS` must be set as well.

### Adding conditional configuration

The configuration system can be used to conditionally compile some files depending on the options selected in `make menuconfig`:

`Kconfig`:

```
config FOO_ENABLE_BAR
    bool "Enable the BAR feature."
    help
        This enables the BAR feature of the FOO component.
```

`component.mk`:

```
COMPONENT_OBJS := foo_a.o foo_b.o

ifdef CONFIG_FOO_BAR
COMPONENT_OBJS += foo_bar.o foo_bar_interface.o
endif
```

See the *GNU Make Manual* for conditional syntax that can be used use in makefiles.

### Source Code Generation

Some components will have a situation where a source file isn't supplied with the component itself but has to be generated from another file. Say our component has a header file that consists of the converted binary data of a BMP file, converted using a hypothetical tool called bmp2h. The header file is then included in as C source file called graphics_lib.c:

```
COMPONENT_EXTRA_CLEAN := logo.h

graphics_lib.o: logo.h

logo.h: $(COMPONENT_PATH)/logo.bmp
    bmp2h -i $^ -o $@
```

In this example, graphics_lib.o and logo.h will be generated in the current directory (the build directory) while logo.bmp comes with the component and resides under the component path. Because logo.h is a generated file, it needs to be cleaned when make clean is called which why it is added to the COMPONENT_EXTRA_CLEAN variable.

### Cosmetic Improvements

Because logo.h is a generated file, it needs to be cleaned when make clean is called which why it is added to the COMPONENT_EXTRA_CLEAN variable.

Adding logo.h to the `graphics_lib.o` dependencies causes it to be generated before `graphics_lib.c` is compiled.

If a a source file in another component included `logo.h`, then this component's name would have to be added to the other component's `COMPONENT_DEPENDS` list to ensure that the components were built in-order.

### Embedding Binary Data

Sometimes you have a file with some binary or text data that you'd like to make available to your component - but you don't want to reformat the file as C source.

You can set a variable COMPONENT_EMBED_FILES in component.mk, giving the names of the files to embed in this way:

```
COMPONENT_EMBED_FILES := server_root_cert.der
```

Or if the file is a string, you can use the variable COMPONENT_EMBED_TXTFILES. This will embed the contents of the text file as a null-terminated string:

```
COMPONENT_EMBED_TXTFILES := server_root_cert.pem
```

The file's contents will be added to the .rodata section in flash, and are available via symbol names as follows:

```
extern const uint8_t server_root_cert_pem_start[] asm("_binary_server_root_cert_pem_
↪start");
extern const uint8_t server_root_cert_pem_end[]   asm("_binary_server_root_cert_pem_
↪end");
```

The names are generated from the full name of the file, as given in COMPONENT_EMBED_FILES. Characters /, ., etc. are replaced with underscores. The _binary prefix in the symbol name is added by objcopy and is the same for both text and binary files.

For an example of using this technique, see protocols/https_request - the certificate file contents are loaded from the text .pem file at compile time.

## Fully Overriding The Component Makefile

Obviously, there are cases where all these recipes are insufficient for a certain component, for example when the component is basically a wrapper around another third-party component not originally intended to be compiled under this build system. In that case, it's possible to forego the esp-idf build system entirely by setting COMPONENT_OWNBUILDTARGET and possibly COMPONENT_OWNCLEANTARGET and defining your own targets named `build` and `clean` in `component.mk` target. The build target can do anything as long as it creates $(COMPONENT_LIBRARY) for the project make process to link into the app binary.

(Actually, even this is not strictly necessary - if the COMPONENT_ADD_LDFLAGS variable is set then the component can instruct the linker to link other binaries instead.)

### Custom sdkconfig defaults

For example projects or other projects where you don't want to specify a full sdkconfig configuration, but you do want to override some key values from the esp-idf defaults, it is possible to create a file `sdkconfig.defaults` in the project directory. This file will be used when running `make defconfig`, or creating a new config from scratch.

To override the name of this file, set the `SDKCONFIG_DEFAULTS` environment variable.

CHAPTER 9

# Debugging

## OpenOCD setup for ESP32

The ESP31 and ESP32 have two powerful Xtensa cores, allowing for a great variety of program architectures. The FreeRTOS OS that comes with ESP-IDF is capable of multi-core pre-emptive multithreading, allowing for an intuitive way of writing software.

The downside of the ease of programming is that debugging without the right tools is harder: figuring out a bug that is caused by two threads, maybe even running simultaneously on two different CPU cores, can take a long time when all you have are printf statements. A better and in many cases quicker way to debug such problems is by using a debugger, connected to the processors over a debug port.

Espressif has ported OpenOCD to support the ESP32 processor and the multicore FreeRTOS that will be the foundation of most ESP32 apps, and has written some tools to help with features OpenOCD does not support natively. These are all available for free, and this document describes how to install and use them.

## JTAG adapter hardware

You will need a JTAG adapter that is compatible with both the voltage levels on the ESP32 as well as with the OpenOCD software. The JTAG port on the ESP32 is an industry-standard JTAG port which lacks (and does not need) the TRST pin. The JTAG I/O pins all are powered from the VDD_3P3_RTC pin (which normally would be powered by a 3.3V rail) so the JTAG adapter needs to be able to work with JTAG pins in that voltage range. On the software side, OpenOCD supports a fair amount of JTAG adapters. See http://openocd.org/doc/html/Debug-Adapter-Hardware.html for an (unfortunately slightly incomplete) list of the adapters OpenOCD works with. This page lists SWD-compatible adapters as well; take note that the ESP32 does not support SWD.

At Espressif, we have tested the TIAO USB Multi-protocol Adapter board as well as the Flyswatter2, which are both USB2.0 high-speed devices and give a good throughput. We also tested a J-link-compatible and an EasyOpenJTAG adapter; both worked as well but are somewhat slower.

The minimal signalling to get a working JTAG connection are TDI, TDO, TCK, TMS and Gnd. Some JTAG debuggers also need a connection from the ESP32 power line to a line called e.g. Vtar to set the working voltage. SRST can optionally be connected to the CH_PD of the ESP32, although for now, support in OpenOCD for that line is pretty minimal.

## Installing OpenOCD

The sources for the ESP32-enabled variant of OpenOCD are available from Espressifs Github. To download the source, use the following commands:

```
git clone --recursive https://github.com/espressif/openocd-esp32.git
cd openocd-esp32
```

For compilation of OpenOCD, please refer to the README, README.OSX and README.Windows file in the openocd-esp32 directory. You can skip the `make install` step if you want.

## Configuring the ESP32 target in OpenOCD

After OpenOCD is compiled (and optionally installed) and the JTAG adapter is connected to the ESP32 board, everything is ready to invoke OpenOCD for the first time. To do this, OpenOCD needs to be told what JTAG adapter to use as well as what type of board and processor the JTAG adapter is connected to. It is the easiest to do both using a configuration file. A template configuration file (esp32.cfg) is included in the same directory as this file. A way to use this would be:

- Copy esp32.cfg to the openocd-esp32 directory
- Edit the copied esp32.cfg file. Most importantly, change the `source [find interface/ftdi/tumpa.cfg]` line to reflect the physical JTAG adapter connected.
- Open a terminal and `cd` to the openocd-esp32 directory.
- Run `./src/openocd -s ./tcl -f ./esp32.cfg` to start OpenOCD

You should now see something like this:

```
user@machine:~/esp32/openocd-esp32$ ./src/openocd -s ./tcl/ -f ../openocd-esp32-tools/
↪esp32.cfg
Open On-Chip Debugger 0.10.0-dev-00446-g6e13a97-dirty (2016-08-23-16:36)
Licensed under GNU GPL v2
For bug reports, read
http://openocd.org/doc/doxygen/bugs.html
none separate
adapter speed: 200 kHz
Info : clock speed 200 kHz
Info : JTAG tap: esp32.cpu0 tap/device found: 0x120034e5 (mfg: 0x272 (Tensilica),␣
↪part: 0x2003, ver: 0x1)
Info : JTAG tap: esp32.cpu1 tap/device found: 0x120034e5 (mfg: 0x272 (Tensilica),␣
↪part: 0x2003, ver: 0x1)
Info : esp32.cpu0: Debug controller was reset (pwrstat=0x5F, after clear 0x0F).
Info : esp32.cpu0: Core was reset (pwrstat=0x5F, after clear 0x0F).
```

- If you see an error indicating permission problems, please see the 'Permissions delegation' bit in the OpenOCD README
- If you see JTAG errors (...all ones/...all zeroes) please check your connections and see if everything is powered on.

## Connecting a debugger to OpenOCD

OpenOCD should now be ready to accept gdb connections. If you have compiled the ESP32 toolchain using Crosstool-NG, or if you have downloaded a precompiled toolchain from the Espressif website, you should already have xtensa-esp32-elf-gdb, a version of gdb that can be used for this. First, make sure the project you want to debug is compiled and flashed into the ESP32's SPI flash. Then, in a different console than OpenOCD is running in, invoke gdb. For example, for the template app, you would do this like such:

```
cd esp-idf-template
xtensa-esp32-elf-gdb -ex 'target remote localhost:3333' ./build/app-template.elf
```

This should give you a gdb prompt.

## FreeRTOS support

OpenOCD has explicit support for the ESP-IDF FreeRTOS; FreeRTOS detection can be disabled in esp32.conf. When enabled, gdb can see FreeRTOS tasks as threads. Viewing them all can be done using the gdb `i threads` command, changing to a certain task is done with `thread x`, with x being the number of the thread. All threads can be switched to except for a thread actually running on the other CPU, please see `ESP32 quirks` for more information.

## ESP32 quirks

Normal gdb breakpoints (`b myFunction`) can only be set in IRAM, because that memory is writable. Setting these types of breakpoints in code in flash will not work. Instead, use a hardware breakpoint (`hb myFunction`). The esp32 supports 2 hardware breakpoints. It also supports two watchpoint, so two variables can be watched for change or read by the gdb command `watch myVariable`.

Connecting gdb to the APP or PRO cpu happens by changing the port gdb connects to. `target remote localhost:3333` connects to the PRO CPU, `target remote localhost:3334` to the APP CPU. Hardware-wise, when one CPU is halted because of debugging reasons, the other one will be halted as well; resuming also happens simultaneously.

Because gdb only sees the system from the point of view of the selected CPU, only the FreeRTOS tasks that are suspended and the task running on the CPU gdb is connected to, will be shown correctly. The task that was active on the other cpu can be inspected, but its state may be wildly inconsistent.

The ESP-IDF code has the option of compiling in various support options for OpenOCD: it can stop execution when the first thread is started and break the system if a panic or unhandled exception is thrown. Both options are enabled by default but can be disabled using the esp-idf configuration menu. Please see the `make menuconfig` menu for more details.

Normally, under OpenOCD, a board can be reset by entering 'mon reset' or 'mon reset halt' into gdb. For the ESP32, these commands work more or less, but have side effects. First of all, an OpenOCD reset only resets the CPU cores, not the peripherals, which may lead to undefined behaviour if software assumes the after-reset state of peripherals. Secondly, 'mon reset halt' stops before FreeRTOS is initialized. OpenOCD assumes (in the default configuration, you can change this by editing esp32.cfg) a running FreeRTOS and may get confused.

CHAPTER 10

# ESP32 Core Dump

## Overview

ESP-IDF provides support to generate core dumps on unrecoverable software errors. This useful technique allows post-mortem analysis of software state at the moment of failure. Upon the crash system enters panic state, prints some information and halts or reboots depending configuration. User can choose to generate core dump in order to analyse the reason of failure on PC later on. Core dump contains snapshots of all tasks in the system at the moment of failure. Snapshots include tasks control blocks (TCB) and stacks. So it is possible to find out what task, at what instruction (line of code) and what callstack of that task lead to the crash. ESP-IDF provides special script *espcoredump.py* to help users to retrieve and analyse core dumps. This tool provides two commands for core dumps analysis:

- info_corefile - prints crashed task's registers, callstack, list of available tasks in the system, memory regions and contents of memory stored in core dump (TCBs and stacks)
- dbg_corefile - creates core dump ELF file and runs GDB debug session with this file. User can examine memory, variables and tasks states manually. Note that since not all memory is saved in core dump only values of variables allocated on stack will be meaningfull

## Configuration

There are a number of core dump related configuration options which user can choose in configuration menu of the application (*make menuconfig*).

1. Core dump data destination (*Components -> ESP32-specific config -> Core dump destination*):

- Disable core dump generation
- Save core dump to flash
- Print core dump to UART

2. Logging level of core dump module (*Components -> ESP32-specific config -> Core dump module logging level*). Value is a number from 0 (no output) to 5 (most verbose).

3. Delay before core dump will be printed to UART (*Components -> ESP32-specific config -> Core dump print to UART delay*). Value is in ms.

## Save core dump to flash

When this option is selected core dumps are saved to special partition on flash. When using default partition table files which are provided with ESP-IDF it automatically allocates necessary space on flash, But if user wants to use its own layout file together with core dump feature it should define separate partition for core dump as it is shown below:

```
# Name,   Type, SubType, Offset,  Size
# Note: if you change the phy_init or app partition offset, make sure to change the
↪offset in Kconfig.projbuild
nvs,      data, nvs,     0x9000,  0x6000
phy_init, data, phy,     0xf000,  0x1000
factory,  app,  factory, 0x10000, 1M
coredump, data, coredump,,        64K
```

There are no special requrements for partition name. It can be choosen according to the user application needs, but partition type should be 'data' and sub-type should be 'coredump'. Also when choosing partition size note that core dump data structure introduces constant overhead of 20 bytes and per-task overhead of 12 bytes. This overhead does not include size of TCB and stack for every task. So partirion size should be at least 20 + max tasks number x (12 + TCB size + max task stack size) bytes.

The example of generic command to analyze core dump from flash is: *espcoredump.py -p </path/to/serial/port> info_corefile </path/to/program/elf/file>* or *espcoredump.py -p </path/to/serial/port> dbg_corefile </path/to/program/elf/file>*

## Print core dump to UART

When this option is selected base64-encoded core dumps are printed on UART upon system panic. In this case user should save core dump text body to some file manually and then run the following command: *espcoredump.py info_corefile -t b64 -c </path/to/saved/base64/text> </path/to/program/elf/file>* or *espcoredump.py dbg_corefile -t b64 -c </path/to/saved/base64/text> </path/to/program/elf/file>*

Base64-encoded body of core dump will be between the following header and footer:

```
================= CORE DUMP START =================
<body of base64-encoded core dump, save it to file on disk>
================= CORE DUMP END ===================
```

## Running 'espcoredump.py'

Generic command syntax:

*espcoredump.py [options] command [args]*

**Script Options**

- –chip,-c {auto,esp32}. Target chip type. Supported values are *auto* and *esp32*.
- –port,-p PORT. Serial port device.
- –baud,-b BAUD. Serial port baud rate used when flashing/reading.

**Commands**

- info_corefile. Retrieve core dump and print useful info.
- dbg_corefile. Retrieve core dump and start GDB session with it.

**Command Arguments**

- –gdb,-g GDB. Path to gdb to use for data retrieval.
- –core,-c CORE. Path to core dump file to use (if skipped core dump will be read from flash).
- –core-format,-t CORE_FORMAT. Specifies that file passed with "-c" is an ELF ("elf"), dumped raw binary ("raw") or base64-encoded ("b64") format.
- –off,-o OFF. Ofsset of coredump partition in flash (type "make partition_table" to see it).
- –save-core,-s SAVE_CORE. Save core to file. Othwerwise temporary core file will be deleted. Ignored with "-c".
- –print-mem,-m Print memory dump. Used only with "info_corefile".

CHAPTER 11

# Partition Tables

## Overview

A single ESP32's flash can contain multiple apps, as well as many different kinds of data (calibration data, filesystems, parameter storage, etc). For this reason a partition table is flashed to offset 0x8000 in the flash.

Partition table length is 0xC00 bytes (maximum 95 partition table entries). If the partition table is signed due to *secure boot*, the signature is appended after the table data.

Each entry in the partition table has a name (label), type (app, data, or something else), subtype and the offset in flash where the partition is loaded.

The simplest way to use the partition table is to *make menuconfig* and choose one of the simple predefined partition tables:

- "Single factory app, no OTA"
- "Factory app, two OTA definitions"

In both cases the factory app is flashed at offset 0x10000. If you *make partition_table* then it will print a summary of the partition table.

## Built-in Partition Tables

Here is the summary printed for the "Single factory app, no OTA" configuration:

```
# Espressif ESP32 Partition Table
# Name,   Type, SubType, Offset,  Size
nvs,      data, nvs,     0x9000,  0x6000
phy_init, data, phy,     0xf000,  0x1000
factory,  app,  factory, 0x10000, 1M
```

- At a 0x10000 (64KB) offset in the flash is the app labelled "factory". The bootloader will run this app by default.
- There are also two data regions defined in the partition table for storing NVS library partition and PHY init data.

Here is the summary printed for the "Factory app, two OTA definitions" configuration:

```
# Espressif ESP32 Partition Table
# Name,    Type, SubType, Offset,   Size
nvs,       data, nvs,     0x9000,   0x4000
otadata,   data, ota,     0xd000,   0x2000
phy_init,  data, phy,     0xf000,   0x1000
factory,   0,    0,       0x10000,  1M
ota_0,     0,    ota_0,   ,         1M
ota_1,     0,    ota_1,   ,         1M
```

- There are now three app partition definitions.
- The type of all three are set as "app", but the subtype varies between the factory app at 0x10000 and the next two "OTA" apps.
- There is also a new "ota data" slot, which holds the data for OTA updates. The bootloader consults this data in order to know which app to execute. If "ota data" is empty, it will execute the factory app.

## Creating Custom Tables

If you choose "Custom partition table CSV" in menuconfig then you can also enter the name of a CSV file (in the project directory) to use for your partition table. The CSV file can describe any number of definitions for the table you need.

The CSV format is the same format as printed in the summaries shown above. However, not all fields are required in the CSV. For example, here is the "input" CSV for the OTA partition table:

```
# Name,    Type, SubType, Offset,    Size
nvs,       data, nvs,     0x9000,   0x4000
otadata,   data, ota,     0xd000,   0x2000
phy_init,  data, phy,     0xf000,   0x1000
factory,   app,  factory, 0x10000,   1M
ota_0,     app,  ota_0,   ,          1M
ota_1,     app,  ota_1,   ,          1M
```

- Whitespace between fields is ignored, and so is any line starting with # (comments).
- Each non-comment line in the CSV file is a partition definition.
- Only the offset for the first partition is supplied. The gen_esp32part.py tool fills in each remaining offset to start after the preceding partition.

### Name field

Name field can be any meaningful name. It is not significant to the ESP32. Names longer than 16 characters will be truncated.

### Type field

Partition type field can be specified as app (0) or data (1). Or it can be a number 0-254 (or as hex 0x00-0xFE). Types 0x00-0x3F are reserved for esp-idf core functions.

If your application needs to store data, please add a custom partition type in the range 0x40-0xFE.

The bootloader ignores any partition types other than app (0) & data (1).

### Subtype

The 8-bit subtype field is specific to a given partition type.

esp-idf currently only specifies the meaning of the subtype field for "app" and "data" partition types.

#### App Subtypes

When type is "app", the subtype field can be specified as factory (0), ota_0 (0x10) ... ota_15 (0x1F) or test (0x20).

- factory (0) is the default app partition. The bootloader will execute the factory app unless there it sees a partition of type data/ota, in which case it reads this partition to determine which OTA image to boot.
  - OTA never updates the factory partition.
  - If you want to conserve flash usage in an OTA project, you can remove the factory partition and use ota_0 instead.
- ota_0 (0x10) ... ota_15 (0x1F) are the OTA app slots. Refer to the *OTA documentation* for more details, which then use the OTA data partition to configure which app slot the bootloader should boot. If using OTA, an application should have at least two OTA application slots (ota_0 & ota_1). Refer to the *OTA documentation* for more details.
- test (0x2) is a reserved subtype for factory test procedures. It is not currently supported by the esp-idf bootloader.

#### Data Subtypes

When type is "data", the subtype field can be specified as ota (0), phy (1), nvs (2).

- ota (0) is the *OTA data partition* which stores information about the currently selected OTA application. This partition should be 0x2000 bytes in size. Refer to the *OTA documentation* for more details.
- phy (1) is for storing PHY initialisation data. This allows PHY to be configured per-device, instead of in firmware.
  - In the default configuration, the phy partition is not used and PHY initialisation data is compiled into the app itself. As such, this partition can be removed from the partition table to save space.
  - To load PHY data from this partition, run `make menuconfig` and enable "Component Config" -> "PHY" -> "Use a partition to store PHY init data". You will also need to flash your devices with phy init data as the esp-idf build system does not do this automatically.
- nvs (2) is for the *Non-Volatile Storage (NVS) API*.
  - NVS is used to store per-device PHY calibration data (different to initialisation data).
  - NVS is used to store WiFi data if the *esp_wifi_set_storage(WIFI_STORAGE_FLASH)* initialisation function is used.
  - The NVS API can also be used for other application data.
  - It is strongly recommended that you include an NVS partition of at least 0x3000 bytes in your project.
  - If using NVS API to store a lot of data, increase the NVS partition size from the default 0x6000 bytes.

Other data subtypes are reserved for future esp-idf uses.

### Offset & Size

Only the first offset field is required (we recommend using 0x10000). Partitions with blank offsets will start after the previous partition.

App partitions have to be at offsets aligned to 0x10000 (64K). If you leave the offset field blank, the tool will automatically align the partition. If you specify an unaligned offset for an app partition, the tool will return an error.

Sizes and offsets can be specified as decimal numbers, hex numbers with the prefix 0x, or size multipliers K or M (1024 and 1024*1024 bytes).

## Generating Binary Partition Table

The partition table which is flashed to the ESP32 is in a binary format, not CSV. The tool partition_table/gen_esp32part.py is used to convert between CSV and binary formats.

If you configure the partition table CSV name in `make menuconfig` and then `make partition_table`, this conversion is done as part of the build process.

To convert CSV to Binary manually:

```
python gen_esp32part.py --verify input_partitions.csv binary_partitions.bin
```

To convert binary format back to CSV:

```
python gen_esp32part.py --verify binary_partitions.bin input_partitions.csv
```

To display the contents of a binary partition table on stdout (this is how the summaries displayed when running *make partition_table* are generated:

```
python gen_esp32part.py binary_partitions.bin
```

`gen_esp32part.py` takes one optional argument, `--verify`, which will also verify the partition table during conversion (checking for overlapping partitions, unaligned partitions, etc.)

## Flashing the partition table

- `make partition_table-flash`: will flash the partition table with esptool.py.
- `make flash`: Will flash everything including the partition table.

A manual flashing command is also printed as part of `make partition_table`.

Note that updating the partition table doesn't erase data that may have been stored according to the old partition table. You can use `make erase_flash` (or `esptool.py erase_flash`) to erase the entire flash contents.

CHAPTER 12

# Flash Encryption

Flash Encryption is a feature for encrypting the contents of the ESP32's attached SPI flash. When flash encryption is enabled, physical readout of the SPI flash is not sufficient to recover most flash contents.

Flash Encryption is separate from the *Secure Boot* feature, and you can use flash encryption without enabling secure boot. However we recommend using both features together for a secure environment.

**IMPORTANT: Enabling flash encryption limits your options for further updates of your ESP32. Make sure to read this document (including :ref:'flash-encryption-limitations') and understand the implications of enabling flash encryption.**

## Background

- The contents of the flash are encrypted using AES with a 256 bit key. The flash encryption key is stored in efuse internal to the chip, and is (by default) protected from software access.
- Flash access is transparent via the flash cache mapping feature of ESP32 - any flash regions which are mapped to the address space will be transparently decrypted when read.
- Encryption is applied by flashing the ESP32 with plaintext data, and (if encryption is enabled) the bootloader encrypts the data in place on first boot.
- Not all of the flash is encrypted. The following kinds of flash data are encrypted:
  - Bootloader
  - Secure boot bootloader digest (if secure boot is enabled)
  - Partition Table
  - All "app" type partitions
  - Any partition marked with the "encrypt" flag in the partition table

    It may be desirable for some data partitions to remain unencrypted for ease of access, or to use flash-friendly update algorithms that are ineffective if the data is encrypted. "NVS" partitions for non-volatile storage cannot be encrypted.

- The flash encryption key is stored in efuse key block 1, internal to the ESP32 chip. By default, this key is read- and write-protected so software cannot access it or change it.
- The *flash encryption algorithm* is AES-256, where the key is "tweaked" with the offset address of each 32 byte block of flash. This means every 32 byte block (two consecutive 16 byte AES blocks) is encrypted with a unique key derived from the flash encryption key.
- Although software running on the chip can transparently decrypt flash contents, by default it is made impossible for the UART bootloader to decrypt (or encrypt) data when flash encryption is enabled.
- If flash encrption may be enabled, the programmer must take certain precautions when writing code that *uses encrypted flash*.

## Flash Encryption Initialisation

This is the default (and recommended) flash encryption initialisation process. It is possible to customise this process for development or other purposes, see *Flash Encryption Advanced Features* for details.

**IMPORTANT: Once flash encryption is enabled on first boot, the hardware allows a maximum of 3 subsequent flash updates via serial re-flashing.** A special procedure (documented in *Serial Flashing*) must be followed to perform these updates.

- If secure boot is enabled, no physical re-flashes are possible.
- OTA updates can be used to update flash content without counting towards this limit.
- When enabling flash encryption in development, use a *pregenerated flash encryption key* to allow physically re-flashing an unlimited number of times with pre-encrypted data.**

Process to enable flash encryption:

- The bootloader must be compiled with flash encryption support enabled. In `make menuconfig`, navigate to "Security Features" and select "Yes" for "Enable flash encryption on boot".
- If enabling Secure Boot at the same time, it is best to simultaneously select those options now. Read the *Secure Boot* documentation first.
- Build and flash the bootloader, partition table and factory app image as normal. These partitions are initially written to the flash unencrypted.
- On first boot, the bootloader sees *FLASH_CRYPT_CNT efuse* is set to 0 (factory default) so it generates a flash encryption key using the hardware random number generator. This key is stored in efuse. The key is read and write protected against further software access.
- All of the encrypted partitions are then encrypted in-place by the bootloader. Encrypting in-place can take some time (up to a minute for large partitions.)

**IMPORTANT: Do not interrupt power to the ESP32 while the first boot encryption pass is running. If power is interrupted, the flash contents will be corrupted and require flashing with unencrypted data again. A reflash like this will not count towards the flashing limit.**

- Once flashing is complete. efuses are blown (by default) to disable encrypted flash access while the UART bootloader is running. See *Enabling UART Bootloader Encryption/Decryption* for advanced details.
- The `FLASH_CRYPT_CONFIG` efuse is also burned to the maximum value (`0xF`) to maximise the number of key bits which are tweaked in the flash algorithm. See *Setting FLASH_CRYPT_CONFIG* for advanced details.
- Finally, the *FLASH_CRYPT_CNT efuse* is burned with the initial value 1. It is this efuse which activates the transparent flash encryption layer, and limits the number of subsequent reflashes. See the *Updating Encrypted Flash* section for details about *FLASH_CRYPT_CNT efuse*.

- The bootloader resets itself to reboot from the newly encrypted flash.

# Using Encrypted Flash

ESP32 app code can check if flash encryption is currently enabled by calling `esp_flash_encryption_enabled()`.

Once flash encryption is enabled, some care needs to be taken when accessing flash contents from code.

## Scope of Flash Encryption

Whenever the *FLASH_CRYPT_CNT efuse* is set to a value with an odd number of bits set, all flash content which is accessed via the MMU's flash cache is transparently decrypted. This includes:

- Executable application code in flash (IROM).
- All read-only data stored in flash (DROM).
- Any data accessed via `esp_spi_flash_mmap()`.
- The software bootloader image when it is read by the ROM bootloader.

**IMPORTANT: The MMU flash cache unconditionally decrypts all data. Data which is stored unencrypted in the flash will be "transparently decrypted" via the flash cache and appear to software like random garbage.**

## Reading Encrypted Flash

To read data without using a flash cache MMU mapping, we recommend using the partition read function `esp_partition_read()`. When using this function, data will only be decrypted when it is read from an encrypted partition. Other partitions will be read unencrypted. In this way, software can access encrypted and non-encrypted flash in the same way.

Data which is read via other SPI read APIs are not decrypted:

- Data read via `esp_spi_flash_read()` is not decrypted
- Data read via ROM function `SPIRead()` is not decrypted (this function is not supported in esp-idf apps).
- Data stored using the Non-Volatile Storage (NVS) API is always stored and read decrypted.

## Writing Encrypted Flash

Where possible, we recommend using the partition write function `esp_partition_write`. When using this function, data will only be encrypted when writing to encrypted partitions. Data will be written to other partitions unencrypted. In this way, software can access encrypted and non-encrypted flash in the same way.

The `esp_spi_flash_write` function will write data when the write_encrypted parameter is set to true. Otherwise, data will be written unencrypted.

The ROM function `SPI_Encrypt_Write` will write encrypted data to flash, the ROM function `SPIWrite` will write unencrypted to flash. (these function are not supported in esp-idf apps).

The minimum write size for unencrypted data is 4 bytes (and the alignment is 4 bytes). Because data is encrypted in blocks, the minimum write size for encrypted data is 16 bytes (and the alignment is 16 bytes.)

# Updating Encrypted Flash

## OTA Updates

OTA updates to encrypted partitions will automatically write encrypted, as long as the `esp_partition_write` function is used.

## Serial Flashing

Provided secure boot is not used, the *FLASH_CRYPT_CNT efuse* allows the flash to be updated with new plaintext data via serial flashing (or other physical methods), up to 3 additional times.

The process involves flashing plaintext data, and then bumping the value of *FLASH_CRYPT_CNT efuse* which causes the bootloader to re-encrypt this data.

### Limited Updates

Only 4 serial flash update cycles of this kind are possible, including the initial encrypted flash.

After the fourth time encryption is disabled, *FLASH_CRYPT_CNT efuse* has the maximum value *0xFF* and encryption is permanently disabled.

Using *OTA Updates* or *Reflashing via Pregenerated Flash Encryption Key* allows you to exceed this limit.

### Cautions With Serial Flashing

- When reflashing via serial, reflash every partition that was initially written with plaintext data (including bootloader). It is possible to skip app partitions which are not the "currently selected" OTA partition (these will not be re-encrypted unless a plaintext app image is found there.) However any partition marked with the "encrypt" flag will be unconditionally re-encrypted, meaning that any already encrypted data will be encrypted twice and corrupted.
  - Using `make flash` should flash all partitions which need to be flashed.
- If secure boot is enabled, you can't reflash via serial at all unless you used the "Reflashable" option for Secure Boot, pre-generated a key and burned it to the ESP32 (refer to *Secure Boot* docs.). In this case you can re-flash a plaintext secure boot digest and bootloader image at offset 0x0. It is necessary to re-flash this digest before flashing other plaintext data.

### Serial Re-Flashing Procedure

- Build the application as usual.
- Flash the device with plaintext data as usual (`make flash` or `esptool.py` commands.) Flash all previously encrypted partitions, including the bootloader (see previous section).
- At this point, the device will fail to boot (message is `flash read err, 1000`) because it expects to see an encrypted bootloader, but the bootloader is plaintext.
- Burn the *FLASH_CRYPT_CNT efuse* by running the command `espefuse.py burn_efuse FLASH_CRYPT_CNT`. espefuse.py will automatically increment the bit count by 1, which disables encryption.
- Reset the device and it will re-encrypt plaintext partitions, then burn the *FLASH_CRYPT_CNT efuse* again to re-enable encryption.

### Disabling Serial Updates

To prevent further plaintext updates via serial, use espefuse.py to write protect the *FLASH_CRYPT_CNT efuse* after flash encryption has been enabled (ie after first boot is complete):

```
espefuse.py --port PORT write_protect_efuse FLASH_CRYPT_CNT
```

This prevents any further modifications to disable or re-enable flash encryption.

## Reflashing via Pregenerated Flash Encryption Key

It is possible to pregenerate a flash encryption key on the host computer and burn it into the ESP32's efuse key block. This allows data to be pre-encrypted on the host and flashed to the ESP32 without needing a plaintext flash update.

This is useful for development, because it removes the 4 time reflashing limit. It also allows reflashing with secure boot enabled, because the bootloader doesn't need to be reflashed each time.

**IMPORTANT This method is intended to assist with development only, not for production devices. If pregenerating flash encryption for production, ensure the keys are generated from a high quality random number source and do not share the same flash encryption key across multiple devices.**

### Pregenerating a Flash Encryption Key

Flash encryption keys are 32 bytes of random data. You can generate a random key with espsecure.py:

```
espsecure.py generate_flash_encryption_key my_flash_encryption_key.bin
```

(The randomness of this data is only as good as the OS and it's Python installation's random data source.)

Alternatively, if you're using *secure boot* and have a secure boot signing key then you can generate a deterministic SHA-256 digest of the secure boot private signing key and use this as the flash encryption key:

```
espsecure.py digest_private-key --keyfile secure_boot_signing_key.pem my_flash_
↪encryption_key.bin
```

(The same 32 bytes is used as the secure boot digest key if you enable *reflashable mode* for secure boot.)

Generating the flash encryption key from the secure boot signing key in this way means that you only need to store one key file. However this method is **not at all suitable** for production devices.

### Burning Flash Encryption Key

Once you have generated a flash encryption key, you need to burn it to the ESP32's efuse key block. **This must be done before first encrypted boot**, otherwise the ESP32 will generate a random key that software can't access or modify.

To burn a key to the device (one time only):

```
espefuse.py --port PORT burn_key flash_encryption my_flash_encryption_key.bin
```

### First Flash with pregenerated key

After flashing the key, follow the same steps as for default *Flash Encryption Initialisation* and flash a plaintext image for the first boot. The bootloader will enable flash encryption using the pre-burned key and encrypt all partitions.

### Reflashing with pregenerated key

After encryption is enabled on first boot, reflashing an encrypted image requires an additional manual step. This is where we pre-encrypt the data that we wish to update in flash.

Suppose that this is the normal command used to flash plaintext data:

```
esptool.py --port /dev/ttyUSB0 --baud 115200 write_flash 0x10000 build/my-app.bin
```

Binary app image `build/my-app.bin` is written to offset `0x10000`. This file name and offset need to be used to encrypt the data, as follows:

```
espsecure.py encrypt_flash_data --keyfile my_flash_encryption_key.bin --address␣
↪0x10000 -o build/my-app-encrypted.bin build/my-app.bin
```

This example command will encrypts `my-app.bin` using the supplied key, and produce an encrypted file `my-app-encrypted.bin`. Be sure that the address argument matches the address where you plan to flash the binary.

Then, flash the encrypted binary with esptool.py:

```
esptool.py --port /dev/ttyUSB0 --baud 115200 write_flash 0x10000 build/my-app-
↪encrypted.bin
```

No further steps or efuse manipulation is necessary, because the data is already encrypted when we flash it.

## Disabling Flash Encryption

If you've accidentally enabled flash encryption for some reason, the next flash of plaintext data will soft-brick the ESP32 (the device will reboot continously, printing the error `flash read err, 1000`).

You can disable flash encryption again by writing *FLASH_CRYPT_CNT efuse*:

- First, run `make menuconfig` and uncheck "Enable flash encryption boot" under "Security Features".
- Exit menuconfig and save the new configuration.
- Run `make menuconfig` again and double-check you really disabled this option! *If this option is left enabled, the bootloader will immediately re-enable encryption when it boots*.
- Run `make flash` to build and flash a new bootloader and app, without flash encryption enabled.
- **Run `espefuse.py` (in `components/esptool_py/esptool`) to disable the *FLASH_CRYPT_CNT efuse*)::**
  espefuse.py burn_efuse FLASH_CRYPT_CNT

Reset the ESP32 and flash encryption should be disabled, the bootloader will boot as normal.

## Limitations of Flash Encryption

Flash Encryption prevents plaintext readout of the encrypted flash, to protect firmware against unauthorised readout and modification. It is important to understand the limitations of the flash encryption system:

- Flash encryption is only as strong as the key. For this reason, we recommend keys are generated on the device during first boot (default behaviour). If generating keys off-device (see *Reflashing via Pregenerated Flash Encryption Key*), ensure proper procedure is followed.

- Not all data is stored encrypted. If storing data on flash, check if the method you are using (library, API, etc.) supports flash encryption.
- Flash encryption does not prevent an attacker from understanding the high-level layout of the flash. This is because the same AES key is used for every pair of adjacent 16 byte AES blocks. When these adjacent 16 byte blocks contain identical content (such as empty or padding areas), these blocks will encrypt to produce matching pairs of encrypted blocks. This may allow an attacker to make high-level comparisons between encrypted devices (ie to tell if two devices are probably running the same firmware version).
- For the same reason, an attacker can always tell when a pair of adjacent 16 byte blocks (32 byte aligned) contain identical content. Keep this in mind if storing sensitive data on the flash, design your flash storage so this doesn't happen (using a counter byte or some other non-identical value every 16 bytes is sufficient).
- Flash encryption alone may not prevent an attacker from modifying the firmware of the device. To prevent unauthorised firmware from runningon the device, use flash encryption in combination with *Secure Boot*.

## Flash Encryption Advanced Features

The following information is useful for advanced use of flash encryption:

### Encrypted Partition Flag

Some partitions are encrypted by default. Otherwise, it is possible to mark any partition as requiring encryption:

In the *partition table* description CSV files, there is a field for flags.

Usually left blank, if you write "encrypted" in this field then the partition will be marked as encrypted in the partition table, and data written here will be treated as encrypted (same as an app partition):

```
# Name,    Type, SubType, Offset,  Size, Flags
nvs,       data, nvs,     0x9000,  0x6000
phy_init, data, phy,     0xf000,  0x1000
factory,   app,  factory, 0x10000, 1M
secret_data, 0x40, 0x01, 0x20000, 256K, encrypted
```

- None of the default partition tables include any encrypted data partitions.
- It is not necessary to mark "app" partitions as encrypted, they are always treated as encrypted.
- The "encrypted" flag does nothing if flash encryption is not enabled.
- It is possible to mark the optional `phy` partition with `phy_init` data as encrypted, if you wish to protect this data from physical access readout or modification.
- It is not possible to mark the `nvs` partition as encrypted.

### Enabling UART Bootloader Encryption/Decryption

By default, on first boot the flash encryption process will burn efuses `DISABLE_DL_ENCRYPT`, `DISABLE_DL_DECRYPT` and `DISABLE_DL_CACHE`:

- `DISABLE_DL_ENCRYPT` disables the flash encryption operations when running in UART bootloader boot mode.
- `DISABLE_DL_DECRYPT` disables transparent flash decryption when running in UART bootloader mode, even if *FLASH_CRYPT_CNT efuse* is set to enable it in normal operation.

- DISABLE_DL_CACHE disables the entire MMU flash cache when running in UART bootloader mode.

It is possible to burn only some of these efuses, and write-protect the rest (with unset value 0) before the first boot, in order to preserve them. For example:

```
espefuse.py --port PORT burn_efuse DISABLE_DL_DECRYPT
espefuse.py --port PORT write_protect_efuse DISABLE_DL_ENCRYPT
```

(Note that all 3 of these efuses are disabled via one write protect bit, so write protecting one will write protect all of them. For this reason, it's necessary to set any bits before write-protecting.)

**IMPORTANT**: Write protecting these efuses to keep them unset is not currently very useful, as esptool.py does not support writing or reading encrypted flash.

**IMPORTANT**: If DISABLE_DL_DECRYPT is left unset (0) this effectively makes flash encryption useless, as an attacker with physical access can use UART bootloader mode (with custom stub code) to read out the flash contents.

### Setting FLASH_CRYPT_CONFIG

The FLASH_CRYPT_CONFIG efuse determines the number of bits in the flash encryption key which are "tweaked" with the block offset. See *Flash Encryption Algorithm* for details.

First boot of the bootloader always sets this value to the maximum *0xF*.

It is possible to write these efuse manually, and write protect it before first boot in order to select different tweak values. This is not recommended.

It is strongly recommended to never write protect FLASH_CRYPT_CONFIG when it the value is zero. If this efuse is set to zero, no bits in the flash encryption key are tweaked and the flash encryption algorithm is equivalent to AES ECB mode.

## Technical Details

The following sections provide some reference information about the operation of flash encryption.

### FLASH_CRYPT_CNT efuse

FLASH_CRYPT_CNT is an 8-bit efuse field which controls flash encryption. Flash encryption enables or disables based on the number of bits in this efuse which are set to "1":

- When an even number of bits (0,2,4,6,8) are set: Flash encryption is disabled, any encrypted data cannot be decrypted.
  - If the bootloader was built with "Enable flash encryption on boot" then it will see this situation and immediately re-encrypt the flash wherever it finds unencrypted data. Once done, it sets another bit in the efuse to '1' meaning an odd number of bits are now set.
    1. On first plaintext boot, bit count has brand new value 0 and bootloader changes it to bit count 1 (value 0x01) following encryption.
    2. After next plaintext flash update, bit count is manually updated to 2 (value 0x03). After re-encrypting the bootloader changes efuse bit count to 3 (value 0x07).
    3. After next plaintext flash, bit count is manually updated to 4 (value 0x0F). After re-encrypting the bootloader changes efuse bit count to 5 (value 0x1F).

4. After final plaintext flash, bit count is manually updated to 6 (value 0x3F). After re-encrypting the bootloader changes efuse bit count to 7 (value 0x7F).

- When an odd number of bits (1,3,5,7) are set: Transparent reading of encrypted flash is enabled.
- After all 8 bits are set (efuse value 0xFF): Transparent reading of encrypted flash is disabled, any encrypted data is permanently inaccessible. Bootloader will normally detect this condition and halt. To avoid use of this state to load unauthorised code, secure boot must be used or *FLASH_CRYPT_CNT efuse* must be write-protected.

## Flash Encryption Algorithm

- AES-256 operates on 16 byte blocks of data. The flash encryption engine encrypts and decrypts data in 32 byte blocks, two AES blocks in series.
- AES algorithm is used inverted in flash encryption, so the flash encryption "encrypt" operation is AES decrypt and the "decrypt" operation is AES encrypt. This is for performance reasons and does not alter the effectiveness of the algorithm.
- The main flash encryption key is stored in efuse (BLK2) and by default is protected from further writes or software readout.
- Each 32 byte block (two adjacent 16 byte AES blocks) is encrypted with a unique key. The key is derived from the main flash encryption key in efuse, XORed with the offset of this block in the flash (a "key tweak").
- The specific tweak depends on the setting of `FLASH_CRYPT_CONFIG` efuse. This is a 4 bit efuse, where each bit enables XORing of a particular range of the key bits:
  - Bit 1, bits 0-66 of the key are XORed.
  - Bit 2, bits 67-131 of the key are XORed.
  - Bit 3, bits 132-194 of the key are XORed.
  - Bit 4, bits 195-256 of the key are XORed.

  It is recommended that `FLASH_CRYPT_CONFIG` is always left to set the default value *0xF*, so that all key bits are XORed with the block offset. See *Setting FLASH_CRYPT_CONFIG* for details.
- The high 19 bits of the block offset (bit 5 to bit 23) are XORed with the main flash encryption key. This range is chosen for two reasons: the maximum flash size is 16MB (24 bits), and each block is 32 bytes so the least significant 5 bits are always zero.
- There is a particular mapping from each of the 19 block offset bits to the 256 bits of the flash encryption key, to determine which bit is XORed with which. See the variable `_FLASH_ENCRYPTION_TWEAK_PATTERN` in the espsecure.py source code for the complete mapping.
- To see the full flash encryption algorithm implemented in Python, refer to the *_flash_encryption_operation()* function in the espsecure.py source code.

# CHAPTER 13

# Secure Boot

Secure Boot is a feature for ensuring only your code can run on the chip. Data loaded from flash is verified on each reset.

Secure Boot is separate from the *Flash Encryption* feature, and you can use secure boot without encrypting the flash contents. However we recommend using both features together for a secure environment.

**IMPORTANT: Enabling secure boot limits your options for further updates of your ESP32. Make sure to read this document throughly and understand the implications of enabling secure boot.**

## Background

- Most data is stored in flash. Flash access does not need to be protected from physical access in order for secure boot to function, because critical data is stored (non-software-accessible) in Efuses internal to the chip.
- Efuses are used to store the secure bootloader key (in efuse block 2), and also a single Efuse bit (ABS_DONE_0) is burned (written to 1) to permanently enable secure boot on the chip. For more details about efuse, see the (forthcoming) chapter in the Technical Reference Manual.
- To understand the secure boot process, first familiarise yourself with the standard *ESP-IDF boot process*.
- Both stages of the boot process (initial software bootloader load, and subsequent partition & app loading) are verified by the secure boot process, in a "chain of trust" relationship.

## Secure Boot Process Overview

This is a high level overview of the secure boot process. Step by step instructions are supplied under *How To Enable Secure Boot*. Further in-depth details are supplied under *Technical Details*:

1. The options to enable secure boot are provided in the `make menuconfig` hierarchy, under "Secure Boot Configuration".

2. Secure Boot defaults to signing images and partition table data during the build process. The "Secure boot private signing key" config item is a file path to a ECDSA public/private key pair in a PEM format file.
3. The software bootloader image is built by esp-idf with secure boot support enabled and the public key (signature verification) portion of the secure boot signing key compiled in. This software bootloader image is flashed at offset 0x1000.
4. On first boot, the software bootloader follows the following process to enable secure boot:
   - Hardware secure boot support generates a device secure bootloader key (generated via hardware RNG, then stored read/write protected in efuse), and a secure digest. The digest is derived from the key, an IV, and the bootloader image contents.
   - The secure digest is flashed at offset 0x0 in the flash.
   - Depending on Secure Boot Configuration, efuses are burned to disable JTAG and the ROM BASIC interpreter (it is strongly recommended these options are turned on.)
   - Bootloader permanently enables secure boot by burning the ABS_DONE_0 efuse. The software bootloader then becomes protected (the chip will only boot a bootloader image if the digest matches.)
5. On subsequent boots the ROM bootloader sees that the secure boot efuse is burned, reads the saved digest at 0x0 and uses hardware secure boot support to compare it with a newly calculated digest. If the digest does not match then booting will not continue. The digest and comparison are performed entirely by hardware, and the calculated digest is not readable by software. For technical details see *Secure Boot Hardware Support*.
6. When running in secure boot mode, the software bootloader uses the secure boot signing key (the public key of which is embedded in the bootloader itself, and therefore validated as part of the bootloader) to verify the signature appended to all subsequent partition tables and app images before they are booted.

# Keys

The following keys are used by the secure boot process:

- "secure bootloader key" is a 256-bit AES key that is stored in Efuse block 2. The bootloader can generate this key itself from the internal hardware random number generator, the user does not need to supply it (it is optionally possible to supply this key, see *Re-Flashable Software Bootloader*). The Efuse holding this key is read & write protected (preventing software access) before secure boot is enabled.
- "secure boot signing key" is a standard ECDSA public/private key pair (see *Image Signing Algorithm*) in PEM format.
  - The public key from this key pair (for signature verificaton but not signature creation) is compiled into the software bootloader and used to verify the second stage of booting (partition table, app image) before booting continues. The public key can be freely distributed, it does not need to be kept secret.
  - The private key from this key pair *must be securely kept private*, as anyone who has this key can authenticate to any bootloader that is configured with secure boot and the matching public key.

# How To Enable Secure Boot

1. Run `make menuconfig`, navigate to "Secure Boot Configuration" and select the option "One-time Flash". (To understand the alternative "Reflashable" choice, see *Re-Flashable Software Bootloader*.)
2. Select a name for the secure boot signing key. This option will appear after secure boot is enabled. The file can be anywhere on your system. A relative path will be evaluated from the project directory. The file does not need to exist yet.

3. Set other menuconfig options (as desired). Pay particular attention to the "Bootloader Config" options, as you can only flash the bootloader once. Then exit menuconfig and save your configuration
4. The first time you run `make`, if the signing key is not found then an error message will be printed with a command to generate a signing key via `espsecure.py generate_signing_key`.

   **IMPORTANT** A signing key generated this way will use the best random number source available to the OS and its Python installation (*/dev/urandom* on OSX/Linux and *CryptGenRandom()* on Windows). If this random number source is weak, then the private key will be weak.

   **IMPORTANT** For production environments, we recommend generating the keypair using openssl or another industry standard encryption program. See *Generating Secure Boot Signing Key* for more details.
5. Run `make bootloader` to build a secure boot enabled bootloader. The output of `make` will include a prompt for a flashing command, using `esptool.py write_flash`.
6. When you're ready to flash the bootloader, run the specified command (you have to enter it yourself, this step is not performed by make) and then wait for flashing to complete. **Remember this is a one time flash, you can't change the bootloader after this!**.
7. Run `make flash` to build and flash the partition table and the just-built app image. The app image will be signed using the signing key you generated in step 4.

   *NOTE*: `make flash` doesn't flash the bootloader if secure boot is enabled.
8. Reset the ESP32 and it will boot the software bootloader you flashed. The software bootloader will enable secure boot on the chip, and then it verifies the app image signature and boots the app. You should watch the serial console output from the ESP32 to verify that secure boot is enabled and no errors have occured due to the build configuration.

**NOTE** Secure boot won't be enabled until after a valid partition table and app image have been flashed. This is to prevent accidents before the system is fully configured.

9. On subsequent boots, the secure boot hardware will verify the software bootloader has not changed (using the secure bootloader key) and then the software bootloader will verify the signed partition table and app image (using the public key portion of the secure boot signing key).

## Re-Flashable Software Bootloader

Configuration "Secure Boot: One-Time Flash" is the recommended configuration for production devices. In this mode, each device gets a unique key that is never stored outside the device.

However, an alternative mode "Secure Boot: Reflashable" is also available. This mode allows you to supply a 256-bit key file that is used for the secure bootloader key. As you have the key file, you can generate new bootloader images and secure boot digests for them.

In the esp-idf build process, this 256-bit key file is derived from the app signing key generated during the generate_signing_key step above. The private key's SHA-256 digest is used as the 256-bit secure bootloader key. This is a convenience so you only need to generate/protect a single private key.

**NOTE**: Although it's possible, we strongly recommend not generating one secure boot key and flashing it to every device in a production environment. The "One-Time Flash" option is recommended for production environments.

To enable a reflashable bootloader:

1. In the `make menuconfig` step, select "Bootloader Config" -> "Secure Boot" -> "Reflashable".
2. Follow the steps shown above to choose a signing key file, and generate the key file.

3. Run `make bootloader`. A 256-bit key file will be created, derived from the private key that is used for signing. Two sets of flashing steps will be printed - the first set of steps includes an `espefuse.py burn_key` command which is used to write the bootloader key to efuse. (Flashing this key is a one-time-only process.) The second set of steps can be used to reflash the bootloader with a pre-calculated digest (generated during the build process).
4. Resume from *Step 6 of the one-time flashing process*, to flash the bootloader and enable secure boot. Watch the console log output closely to ensure there were no errors in the secure boot configuration.

## Generating Secure Boot Signing Key

The build system will prompt you with a command to generate a new signing key via `espsecure.py generate_signing_key`. This uses the python-ecdsa library, which in turn uses Python's os.urandom() as a random number source.

The strength of the signing key is proportional to (a) the random number source of the system, and (b) the correctness of the algorithm used. For production devices, we recommend generating signing keys from a system with a quality entropy source, and using the best available EC key generation utilities.

For example, to generate a signing key using the openssl command line:

`` ` openssl ecparam -name prime256v1 -genkey -noout -out my_secure_boot_signing_key.pem ` ``

Remember that the strength of the secure boot system depends on keeping the signing key private.

## Remote Signing of Images

For production builds, it can be good practice to use a remote signing server rather than have the signing key on the build machine (which is the default esp-idf secure boot configuration). The espsecure.py command line program can be used to sign app images & partition table data for secure boot, on a remote system.

To use remote signing, disable the option "Sign binaries during build". The private signing key does not need to be present on the build system. However, the public (signature verification) key is required because it is compiled into the bootloader (and can be used to verify image signatures during OTA updates.

To extract the public key from the private key:

```
espsecure.py extract_public_key --keyfile PRIVATE_SIGNING_KEY PUBLIC_VERIFICATION_KEY
```

The path to the public signature verification key needs to be specified in the menuconfig under "Secure boot public signature verification key" in order to build the secure bootloader.

After the app image and partition table are built, the build system will print signing steps using espsecure.py:

```
espsecure.py sign_data --keyfile PRIVATE_SIGNING_KEY BINARY_FILE
```

The above command appends the image signature to the existing binary. You can use the *–output* argument to write the signed binary to a separate file:

```
espsecure.py sign_data --keyfile PRIVATE_SIGNING_KEY --output SIGNED_BINARY_FILE␣
↪BINARY_FILE
```

## Secure Boot Best Practices

- Generate the signing key on a system with a quality source of entropy.
- Keep the signing key private at all times. A leak of this key will compromise the secure boot system.
- Do not allow any third party to observe any aspects of the key generation or signing process using espsecure.py. Both processes are vulnerable to timing or other side-channel attacks.
- Enable all secure boot options in the Secure Boot Configuration. These include flash encryption, disabling of JTAG, disabling BASIC ROM interpeter, and disabling the UART bootloader encrypted flash access.
- Use secure boot in combination with *flash encryption* to prevent local readout of the flash contents.

## Technical Details

The following sections contain low-level reference descriptions of various secure boot elements:

### Secure Boot Hardware Support

The first stage of secure boot verification (checking the software bootloader) is done via hardware. The ESP32's Secure Boot support hardware can perform three basic operations:

1. Generate a random sequence of bytes from a hardware random number generator.
2. Generate a digest from data (usually the bootloader image from flash) using a key stored in Efuse block 2. The key in Efuse can (& should) be read/write protected, which prevents software access. For full details of this algorithm see *Secure Bootloader Digest Algorithm*. The digest can only be read back by software if Efuse ABS_DONE_0 is *not* burned (ie still 0).
3. Generate a digest from data (usually the bootloader image from flash) using the same algorithm as step 2 and compare it to a pre-calculated digest supplied in a buffer (usually read from flash offset 0x0). The hardware returns a true/false comparison without making the digest available to software. This function is available even when Efuse ABS_DONE_0 is burned.

### Secure Bootloader Digest Algorithm

Starting with an "image" of binary data as input, this algorithm generates a digest as output. The digest is sometimes referred to as an "abstract" in hardware documentation.

For a Python version of this algorithm, see the `espsecure.py` tool in the components/esptool_py directory (specifically, the `digest_secure_bootloader` command).

Items marked with (^) are to fulfill hardware restrictions, as opposed to cryptographic restrictions.

1. Prefix the image with a 128 byte randomly generated IV.
2. If the image length is not modulo 128, pad the image to a 128 byte boundary with 0xFF. (^)
3. For each 16 byte plaintext block of the input image: - Reverse the byte order of the plaintext input block (^) - Apply AES256 in ECB mode to the plaintext block. - Reverse the byte order of the ciphertext output block. (^) - Append to the overall ciphertext output.
4. Byte-swap each 4 byte word of the ciphertext (^)
5. Calculate SHA-512 of the ciphertext.

Output digest is 192 bytes of data: The 128 byte IV, followed by the 64 byte SHA-512 digest.

## Image Signing Algorithm

Deterministic ECDSA as specified by RFC 6979.

- Curve is NIST256p (openssl calls this curve "prime256v1", it is also sometimes called secp256r1).
- Hash function is SHA256.
- Key format used for storage is PEM.
  - In the bootloader, the public key (for signature verification) is flashed as 64 raw bytes.
- Image signature is 68 bytes - a 4 byte version word (currently zero), followed by a 64 bytes of signature data. These 68 bytes are appended to an app image or partition table data.

## Manual Commands

Secure boot is integrated into the esp-idf build system, so `make` will automatically sign an app image if secure boot is enabled. `make bootloader` will produce a bootloader digest if menuconfig is configured for it.

However, it is possible to use the `espsecure.py` tool to make standalone signatures and digests.

To sign a binary image:

```
espsecure.py sign_data --keyfile ./my_signing_key.pem --output ./image_signed.bin␣
↪image-unsigned.bin
```

Keyfile is the PEM file containing an ECDSA private signing key.

To generate a bootloader digest:

```
espsecure.py digest_secure_bootloader --keyfile ./securebootkey.bin --output ./
↪bootloader-digest.bin build/bootloader/bootloader.bin
```

Keyfile is the 32 byte raw secure boot key for the device. To flash this digest onto the device:

```
esptool.py write_flash 0x0 bootloader-digest.bin
```

CHAPTER 14

# Deep Sleep Wake Stubs

ESP32 supports running a "deep sleep wake stub" when coming out of deep sleep. This function runs immediately as soon as the chip wakes up - before any normal initialisation, bootloader, or ESP-IDF code has run. After the wake stub runs, the SoC can go back to sleep or continue to start ESP-IDF normally.

Deep sleep wake stub code is loaded into "RTC Fast Memory" and any data which it uses must also be loaded into RTC memory. RTC memory regions hold their contents during deep sleep.

## Rules for Wake Stubs

Wake stub code must be carefully written:

- As the SoC has freshly woken from sleep, most of the peripherals are in reset states. The SPI flash is unmapped.
- The wake stub code can only call functions implemented in ROM or loaded into RTC Fast Memory (see below.)
- The wake stub code can only access data loaded in RTC memory. All other RAM will be unintiailised and have random contents. The wake stub can use other RAM for temporary storage, but the contents will be overwritten when the SoC goes back to sleep or starts ESP-IDF.
- RTC memory must include any read-only data (.rodata) used by the stub.
- Data in RTC memory is initialised whenever the SoC restarts, except when waking from deep sleep. When waking from deep sleep, the values which were present before going to sleep are kept.
- Wake stub code is a part of the main esp-idf app. During normal running of esp-idf, functions can call the wake stub functions or access RTC memory. It is as if these were regular parts of the app.

## Implementing A Stub

The wake stub in esp-idf is called `esp_wake_deep_sleep()`. This function runs whenever the SoC wakes from deep sleep. There is a default version of this function provided in esp-idf, but the default function is weak-linked so if your app contains a function named `esp_wake_deep_sleep()` then this will override the default.

If supplying a custom wake stub, the first thing it does should be to call `esp_default_wake_deep_sleep()`.

It is not necessary to implement `esp_wake_deep_sleep()` in your app in order to use deep sleep. It is only necessary if you want to have special behaviour immediately on wake.

If you want to swap between different deep sleep stubs at runtime, it is also possible to do this by calling the `esp_set_deep_sleep_wake_stub()` function. This is not necessary if you only use the default `esp_wake_deep_sleep()` function.

All of these functions are declared in the `esp_deepsleep.h` header under components/esp32.

# Loading Code Into RTC Memory

Wake stub code must be resident in RTC Fast Memory. This can be done in one of two ways.

The first way is to use the `RTC_IRAM_ATTR` attribute to place a function into RTC memory:

```
void RTC_IRAM_ATTR esp_wake_deep_sleep(void) {
    esp_default_wake_deep_sleep();
    // Add additional functionality here
}
```

The second way is to place the function into any source file whose name starts with `rtc_wake_stub`. Files names `rtc_wake_stub*` have their contents automatically put into RTC memory by the linker.

The first way is simpler for very short and simple code, or for source files where you want to mix "normal" and "RTC" code. The second way is simpler when you want to write longer pieces of code for RTC memory.

# Loading Data Into RTC Memory

Data used by stub code must be resident in RTC Slow Memory. This memory is also used by the ULP.

Specifying this data can be done in one of two ways:

The first way is to use the `RTC_DATA_ATTR` and `RTC_RODATA_ATTR` to specify any data (writeable or read-only, respectivley) which should be loaded into RTC slow memory:

```
RTC_DATA_ATTR int wake_count;

void RTC_IRAM_ATTR esp_wake_deep_sleep(void) {
    esp_default_wake_deep_sleep();
    static RTC_RODATA_ATTR const char fmt_str[] = "Wake count %d\n";
    ets_printf(fmt_str, wake_count++);
}
```

Unfortunately, any string constants used in this way must be declared as arrays and marked with RTC_RODATA_ATTR, as shown in the example above.

The second way is to place the data into any source file whose name starts with `rtc_wake_stub`.

For example, the equivalent example in `rtc_wake_stub_counter.c`:

```
int wake_count;

void RTC_IRAM_ATTR esp_wake_deep_sleep(void) {
    esp_default_wake_deep_sleep();
```

```
    ets_printf("Wake count %d\n", wake_count++);
}
```

The second way is a better option if you need to use strings, or write other more complex code.

CHAPTER 15

# ULP coprocessor programming

## ULP coprocessor instruction set

This document provides details about the instructions used by ESP32 ULP coprocessor assembler.

ULP coprocessor has 4 16-bit general purpose registers, labeled R0, R1, R2, R3. It also has an 8-bit counter register (stage_cnt) which can be used to implement loops. Stage count regiter is accessed using special instructions.

ULP coprocessor can access 8k bytes of RTC_SLOW_MEM memory region. Memory is addressed in 32-bit word units. It can also access peripheral registers in RTC_CNTL, RTC_IO, and SENS peripherals.

All instructions are 32-bit. Jump instructions, ALU instructions, peripheral register and memory access instructions are executed in 1 cycle. Instructions which work with peripherals (TSENS, ADC, I2C) take variable number of cycles, depending on peripheral operation.

The instruction syntax is case insensitive. Upper and lower case letters can be used and intermixed arbitrarily. This is true both for register names and instruction names.

### Note about addressing

ESP32 ULP coprocessor's JUMP, ST, LD instructions which take register as an argument (jump address, store/load base address) expect the argument to be expressed in 32-bit words.

Consider the following example program:

```
entry:
        NOP
        NOP
        NOP
        NOP
loop:
        MOVE R1, loop
        JUMP R1
```

When this program is assembled and linked, address of label `loop` will be equal to 16 (expressed in bytes). However *JUMP* instruction expects the address stored in register to be expressed in 32-bit words. To account for this common use case, assembler will convert the address of label *loop* from bytes to words, when generating `MOVE` instruction, so the code generated code will be equivalent to:

```
0000    NOP
0004    NOP
0008    NOP
000c    NOP
0010    MOVE R1, 4
0014    JUMP R1
```

The other case is when the argument of `MOVE` instruction is not a label but a constant. In this case assembler will use the value as is, without any conversion:

```
.set        val, 0x10
MOVE        R1, val
```

In this case, value loaded into R1 will be `0x10`.

Similar considerations apply to `LD` and `ST` instructions. Consider the following code:

```
        .global array
array:  .long 0
        .long 0
        .long 0
        .long 0

        MOVE R1, array
        MOVE R2, 0x1234
        ST R2, R1, 0      // write value of R2 into the first array element,
                          // i.e. array[0]

        ST R2, R1, 4      // write value of R2 into the second array element
                          // (4 byte offset), i.e. array[1]

        ADD R1, R1, 2     // this increments address by 2 words (8 bytes)
        ST R2, R1, 0      // write value of R2 into the third array element,
                          // i.e. array[2]
```

## NOP - no operation

**Syntax: NOP**

**Operands:** None

**Description:** No operation is performed. Only the PC is incremented.

**Example**:

```
1:    NOP
```

## ADD - Add to register

**Syntax: ADD** *Rdst, Rsrc1, Rsrc2*

**ADD** *Rdst, Rsrc1, imm*

**Operands:**

- *Rdst* - Register R[0..3]
- *Rsrc1* - Register R[0..3]
- *Rsrc2* - Register R[0..3]
- *Imm* - 16-bit signed value

**Description:** The instruction adds source register to another source register or to a 16-bit signed value and stores result to the destination register.

**Examples**:

```
1:    ADD R1, R2, R3         //R1 = R2 + R3

2:    Add R1, R2, 0x1234     //R1 = R2 + 0x1234

3:    .set value1, 0x03      //constant value1=0x03
      Add R1, R2, value1     //R1 = R2 + value1


4:    .global label          //declaration of variable label
      Add R1, R2, label      //R1 = R2 + label
        ...
      label: nop             //definition of variable label
```

## SUB - Subtract from register

**Syntax:** **SUB** *Rdst, Rsrc1, Rsrc2*

**SUB** *Rdst, Rsrc1, imm*

**Operands:**

- *Rdst* - Register R[0..3]
- *Rsrc1* - Register R[0..3]
- *Rsrc2* - Register R[0..3]
- *Imm* - 16-bit signed value

**Description:** The instruction subtracts the source register from another source register or subtracts 16-bit signed value from a source register, and stores result to the destination register.

**Examples:**:

```
1:         SUB R1, R2, R3             //R1 = R2 - R3

2:         sub R1, R2, 0x1234         //R1 = R2 - 0x1234

3:         .set value1, 0x03          //constant value1=0x03
           SUB R1, R2, value1         //R1 = R2 - value1
4:         .global label              //declaration of variable label
           SUB R1, R2, label          //R1 = R2 - label
             ....
  label:   nop                        //definition of variable label
```

## AND - Logical AND of two operands

**Syntax: AND** *Rdst, Rsrc1, Rsrc2*

**AND** *Rdst, Rsrc1, imm*

**Operands:**

- *Rdst* - Register R[0..3]
- *Rsrc1* - Register R[0..3]
- *Rsrc2* - Register R[0..3]
- *Imm* - 16-bit signed value

**Description:** The instruction does logical AND of a source register and another source register or 16-bit signed value and stores result to the destination register.

**Example**:

```
1:        AND R1, R2, R3          //R1 = R2 & R3

2:        AND R1, R2, 0x1234      //R1 = R2 & 0x1234

3:        .set value1, 0x03       //constant value1=0x03
          AND R1, R2, value1      //R1 = R2 & value1

4:        .global label           //declaration of variable label
          AND R1, R2, label       //R1 = R2 & label
              ...
  label:  nop                     //definition of variable label
```

## OR - Logical OR of two operands

**Syntax OR** *Rdst, Rsrc1, Rsrc2*

**OR** *Rdst, Rsrc1, imm*

**Operands**

- *Rdst* - Register R[0..3]
- *Rsrc1* - Register R[0..3]
- *Rsrc2* - Register R[0..3]
- *Imm* - 16-bit signed value

**Description** The instruction does logical OR of a source register and another source register or 16-bit signed value and stores result to the destination register.

**Examples**:

```
1:       OR R1, R2, R3           //R1 = R2 \| R3

2:       OR R1, R2, 0x1234       //R1 = R2 \| 0x1234

3:       .set value1, 0x03       //constant value1=0x03
         OR R1, R2, value1       //R1 = R2 \| value1

4:       .global label           //declaration of variable label
```

```
        OR R1, R2, label         //R1 = R2 \|label
        ...
 label: nop                      //definition of variable label
```

## LSH - Logical Shift Left

**Syntax** **LSH** *Rdst, Rsrc1, Rsrc2*

**LSH** *Rdst, Rsrc1, imm*

**Operands**

- *Rdst* - Register R[0..3]
- *Rsrc1* - Register R[0..3]
- *Rsrc2* - Register R[0..3]
- *Imm* - 16-bit signed value

**Description** The instruction does logical shift to left of source register to number of bits from another source register or 16-bit signed value and store result to the destination register.

**Examples**:

```
1:        LSH R1, R2, R3            //R1 = R2 << R3

2:        LSH R1, R2, 0x03          //R1 = R2 << 0x03

3:        .set value1, 0x03         //constant value1=0x03
          LSH R1, R2, value1        //R1 = R2 << value1

4:        .global label             //declaration of variable label
          LSH R1, R2, label         //R1 = R2 << label
          ...
  label:  nop                        //definition of variable label
```

## RSH - Logical Shift Right

**Syntax** **RSH** *Rdst, Rsrc1, Rsrc2*

**RSH** *Rdst, Rsrc1, imm*

**Operands** *Rdst* - Register R[0..3] *Rsrc1* - Register R[0..3] *Rsrc2* - Register R[0..3] *Imm* - 16-bit signed value

**Description** The instruction does logical shift to right of source register to number of bits from another source register or 16-bit signed value and store result to the destination register.

**Examples**:

```
1:         RSH R1, R2, R3              //R1 = R2 >> R3

2:         RSH R1, R2, 0x03            //R1 = R2 >> 0x03

3:         .set value1, 0x03           //constant value1=0x03
           RSH R1, R2, value1          //R1 = R2 >> value1

4:         .global label               //declaration of variable label
```

```
        RSH R1, R2, label           //R1 = R2 >> label
label:  nop                         //definition of variable label
```

### MOVE – Move to register

**Syntax** **MOVE** *Rdst, Rsrc*

**MOVE** *Rdst, imm*

**Operands**

- *Rdst* – Register R[0..3]
- *Rsrc* – Register R[0..3]
- *Imm* – 16-bit signed value

**Description** The instruction move to destination register value from source register or 16-bit signed value.

Note that when a label is used as an immediate, the address of the label will be converted from bytes to words. This is because LD, ST, and JUMP instructions expect the address register value to be expressed in words rather than bytes. To avoid using an extra instruction

**Examples**:

```
1:        MOVE       R1, R2            //R1 = R2 >> R3

2:        MOVE       R1, 0x03          //R1 = R2 >> 0x03

3:        .set       value1, 0x03      //constant value1=0x03
          MOVE       R1, value1        //R1 = value1

4:        .global     label            //declaration of label
          MOVE        R1, label        //R1 = address_of(label) / 4
          ...
  label:  nop                          //definition of label
```

### ST – Store data to the memory

**Syntax** **ST** *Rsrc, Rdst, offset*

**Operands**

- *Rsrc* – Register R[0..3], holds the 16-bit value to store
- *Rdst* – Register R[0..3], address of the destination, in 32-bit words
- *Offset* – 10-bit signed value, offset in bytes

**Description** The instruction stores the 16-bit value of Rsrc to the lower half-word of memory with address Rdst+offset. The upper half-word is written with the current program counter (PC), expressed in words, shifted left by 5 bits:

```
Mem[Rdst + offset / 4]{31:0} = {PC[10:0], 5'b0, Rsrc[15:0]}
```

The application can use higher 16 bits to determine which instruction in the ULP program has written any particular word into memory.

**Examples**:

```
1:         ST  R1, R2, 0x12        //MEM[R2+0x12] = R1

2:         .data                   //Data section definition
  Addr1:   .word      123          // Define label Addr1 16 bit
           .set       offs, 0x00   // Define constant offs
           .text                   //Text section definition
           MOVE       R1, 1        // R1 = 1
           MOVE       R2, Addr1    // R2 = Addr1
           ST         R1, R2, offs // MEM[R2 +  0] = R1
                                   // MEM[Addr1 + 0] will be 32'h600001
```

## LD – Load data from the memory

**Syntax** **LD** *Rdst, Rsrc, offset*

**Operands** *Rdst* – Register R[0..3], destination

*Rsrc* – Register R[0..3], holds address of destination, in 32-bit words

*Offset* – 10-bit signed value, offset in bytes

**Description** The instruction loads lower 16-bit half-word from memory with address Rsrc+offset into the destination register Rdst:

```
Rdst[15:0] = Mem[Rsrc + offset / 4][15:0]
```

**Examples**:

```
1:         LD  R1, R2, 0x12            //R1 = MEM[R2+0x12]

2:         .data                       //Data section definition
  Addr1:   .word      123              // Define label Addr1 16 bit
           .set       offs, 0x00       // Define constant offs
           .text                       //Text section definition
           MOVE       R1, 1            // R1 = 1
           MOVE       R2, Addr1        // R2 = Addr1 / 4 (address of label is␣
↪converted into words)
           LD         R1, R2, offs     // R1 = MEM[R2 +  0]
                                       // R1 will be 123
```

## JUMP – Jump to an absolute address

**Syntax** **JUMP** *Rdst*

**JUMP** *ImmAddr*

**JUMP** *Rdst, Condition*

**JUMP** *ImmAddr, Condition*

**Operands**

- *Rdst* – Register R[0..3] containing address to jump to (expressed in 32-bit words)
- *ImmAddr* – 13 bits address (expressed in bytes), aligned to 4 bytes
- ***Condition***:
  - EQ – jump if last ALU operation result was zero

- OV – jump if last ALU has set overflow flag

**Description** The instruction makes jump to the specified address. Jump can be either unconditional or based on an ALU flag.

**Examples**:

```
1:        JUMP       R1            // Jump to address in R1 (address in R1 is in 32-
↪bit words)

2:        JUMP       0x120, EQ     // Jump to address 0x120 (in bytes) if ALU result␣
↪is zero

3:        JUMP       label         // Jump to label
          ...
  label:  nop                      // Definition of label

4:        .global    label         // Declaration of global label

          MOVE       R1, label     // R1 = label (value loaded into R1 is in words)
          JUMP       R1            // Jump to label
          ...
  label:  nop                      // Definition of label
```

## JUMPR – Jump to a relative offset (condition based on R0)

**Syntax** **JUMPR** *Step, Threshold, Condition*

**Operands**

- *Step* – relative shift from current position, in bytes
- *Threshold* – threshold value for branch condition
- ***Condition***:
  - *GE* (greater or equal) – jump if value in R0 >= threshold
  - *LT* (less than) – jump if value in R0 < threshold

**Description** The instruction makes a jump to a relative address if condition is true. Condition is the result of comparison of R0 register value and the threshold value.

**Examples**:

```
1:pos:    JUMPR       16, 20, GE   // Jump to address (position + 16 bytes) if value␣
↪in R0 >= 20

2:        // Down counting loop using R0 register
          MOVE        R0, 16       // load 16 into R0
  label:  SUB         R0, R0, 1    // R0--
          NOP                      // do something
          JUMPR       label, 1, GE // jump to label if R0 >= 1
```

## JUMPS – Jump to a relative address (condition based on stage count)

**Syntax** **JUMPS** *Step, Threshold, Condition*

**Operands**

- *Step* – relative shift from current position, in bytes
- *Threshold* – threshold value for branch condition
- ***Condition***:
  - *EQ* (equal) – jump if value in stage_cnt == threshold
  - *LT* (less than) – jump if value in stage_cnt < threshold
  - *GT* (greater than) – jump if value in stage_cnt > threshold

**Description** The instruction makes a jump to a relative address if condition is true. Condition is the result of comparison of count register value and threshold value.

**Examples**:

```
1:pos:    JUMPS     16, 20, EQ     // Jump to (position + 16 bytes) if stage_cnt == 20

2:        // Up counting loop using stage count register
          STAGE_RST                  // set stage_cnt to 0
  label:  STAGE_INC  1               // stage_cnt++
          NOP                        // do something
          JUMPS       label, 16, LT  // jump to label if stage_cnt < 16
```

## STAGE_RST – Reset stage count register

**Syntax** **STAGE_RST**

**Operands** No operands

**Description** The instruction sets the stage count register to 0

**Examples**:

```
1:       STAGE_RST      // Reset stage count register
```

## STAGE_INC – Increment stage count register

**Syntax** **STAGE_INC** *Value*

**Operands**

- *Value* – 8 bits value

**Description** The instruction increments stage count register by given value.

**Examples**:

```
1:        STAGE_INC      10          // stage_cnt += 10

2:        // Up counting loop example:
          STAGE_RST                  // set stage_cnt to 0
  label:  STAGE_INC  1               // stage_cnt++
          NOP                        // do something
          JUMPS      label, 16, LT   // jump to label if stage_cnt < 16
```

## STAGE_DEC – Decrement stage count register

**Syntax** **STAGE_DEC** *Value*

**Operands**

- *Value* – 8 bits value

**Description** The instruction decrements stage count register by given value.

**Examples**:

```
1:        STAGE_DEC      10        // stage_cnt -= 10;

2:        // Down counting loop exaple
          STAGE_RST                // set stage_cnt to 0
          STAGE_INC  16            // increment stage_cnt to 16
  label:  STAGE_DEC  1             // stage_cnt--;
          NOP                      // do something
          JUMPS      label, 0, GT  // jump to label if stage_cnt > 0
```

## HALT – End the program

**Syntax** **HALT**

**Operands** No operands

**Description** The instruction halt the processor to the power down mode

**Examples**:

```
1:       HALT      // Move chip to powerdown
```

## WAKE – wakeup the chip

**Syntax** **WAKE**

**Operands** No operands

**Description** The instruction sends an interrupt from ULP to RTC controller.

- If the SoC is in deep sleep mode, and ULP wakeup is enabled, this causes the SoC to wake up.
- If the SoC is not in deep sleep mode, and ULP interrupt bit (RTC_CNTL_ULP_CP_INT_ENA) is set in RTC_CNTL_INT_ENA_REG register, RTC interrupt will be triggered.

**Examples**:

```
1:        WAKE                      // Trigger wake up
          REG_WR 0x006, 24, 24, 0   // Stop ULP timer (clear RTC_CNTL_ULP_CP_SLP_
↪TIMER_EN)
          HALT                      // Stop the ULP program
          // After these instructions, SoC will wake up,
          // and ULP will not run again until started by the main program.
```

## SLEEP – set ULP wakeup timer period

**Syntax** **SLEEP** *sleep_reg*

**Operands**

- *sleep_reg* – 0..4, selects one of `SENS_ULP_CP_SLEEP_CYCx_REG` registers.

**Description** The instruction selects which of the `SENS_ULP_CP_SLEEP_CYCx_REG` (x = 0..4) register values is to be used by the ULP wakeup timer as wakeup period. By default, the value from `SENS_ULP_CP_SLEEP_CYC0_REG` is used.

**Examples**:

```
1:        SLEEP     1         // Use period set in SENS_ULP_CP_SLEEP_CYC1_REG

2:        .set sleep_reg, 4   // Set constant
          SLEEP  sleep_reg    // Use period set in SENS_ULP_CP_SLEEP_CYC4_REG
```

## WAIT – wait some number of cycles

**Syntax** **WAIT** *Cycles*

**Operands**

- *Cycles* – number of cycles for wait

**Description** The instruction delays for given number of cycles.

**Examples**:

```
1:        WAIT     10         // Do nothing for 10 cycles

2:        .set  wait_cnt, 10  // Set a constant
          WAIT  wait_cnt      // wait for 10 cycles
```

## TSENS – do measurement with temperature sensor

**Syntax**

- **TSENS** *Rdst, Wait_Delay*

**Operands**

- *Rdst* – Destination Register R[0..3], result will be stored to this register
- *Wait_Delay* – number of cycles used to perform the measurement

**Description** The instruction performs measurement using TSENS and stores the result into a general purpose register.

**Examples**:

```
1:        TSENS     R1, 1000     // Measure temperature sensor for 1000 cycles,
                                 // and store result to R1
```

## ADC – do measurement with ADC

**Syntax** **ADC** *Rdst, Sar_sel, Mux, Cycles*

**Operands**

- *Rdst* – Destination Register R[0..3], result will be stored to this register
- *Sar_sel* – selected ADC : 0=SARADC0, 1=SARADC1
- *Mux* - selected PAD, SARADC Pad[Mux+1] is enabled
- *Cycle* – number of cycles used to perform measurement

**Description** The instruction makes measurements from ADC.

**Examples**:

```
1:        ADC      R1, 0, 1, 100 // Measure value using ADC1 pad 2,
                                 // for 100 cycles and move result to R1
```

## REG_RD – read from peripheral register

**Syntax** **REG_RD** *Addr, High, Low*

**Operands**

- *Addr* – register address, in 32-bit words
- *High* – High part of R0
- *Low* – Low part of R0

**Description** The instruction reads up to 16 bits from a peripheral register into a general purpose register: `R0 = REG[Addr][High:Low]`.

This instruction can access registers in RTC_CNTL, RTC_IO, and SENS peripherals. Address of the the register, as seen from the ULP, can be calculated from the address of the same register on the DPORT bus as follows:

```
addr_ulp = (addr_dport - DR_REG_RTCCNTL_BASE) / 4
```

**Examples**:

```
1:        REG_RD      0x120, 2, 0     // load 4 bits: R0 = {12'b0, REG[0x120][7:4]}
```

## REG_WR – write to peripheral register

**Syntax** **REG_WR** *Addr, High, Low, Data*

**Operands**

- *Addr* – register address, in 32-bit words.
- *High* – High part of R0
- *Low* – Low part of R0
- *Data* – value to write, 8 bits

**Description** The instruction writes up to 8 bits from a general purpose register into a peripheral register. `REG[Addr][High:Low] = data`

This instruction can access registers in RTC_CNTL, RTC_IO, and SENS peripherals. Address of the the register, as seen from the ULP, can be calculated from the address of the same register on the DPORT bus as follows:

```
addr_ulp = (addr_dport - DR_REG_RTCCNTL_BASE) / 4
```

**Examples**:

```
1:        REG_WR      0x120, 7, 0, 0x10   // set 8 bits: REG[0x120][7:0] = 0x10
```

## Convenience macros for peripheral registers access

ULP source files are passed through C preprocessor before the assembler. This allows certain macros to be used to facilitate access to peripheral registers.

Some existing macros are defined in `soc/soc_ulp.h` header file. These macros allow access to the fields of peripheral registers by their names. Peripheral registers names which can be used with these macros are the ones defined in `soc/rtc_cntl_reg.h`, `soc/rtc_io_reg.h`, and `soc/sens_reg.h`.

**READ_RTC_REG(rtc_reg, low_bit, bit_width)** Read up to 16 bits from rtc_reg[low_bit + bit_width - 1 : low_bit] into R0. For example:

```
#include "soc/soc_ulp.h"
#include "soc/rtc_cntl_reg.h"

/* Read 16 lower bits of RTC_CNTL_TIME0_REG into R0 */
READ_RTC_REG(RTC_CNTL_TIME0_REG, 0, 16)
```

**READ_RTC_FIELD(rtc_reg, field)** Read from a field in rtc_reg into R0, up to 16 bits. For example:

```
#include "soc/soc_ulp.h"
#include "soc/sens_reg.h"

/* Read 8-bit SENS_TSENS_OUT field of SENS_SAR_SLAVE_ADDR3_REG into R0 */
READ_RTC_REG(SENS_SAR_SLAVE_ADDR3_REG, SENS_TSENS_OUT)
```

**WRITE_RTC_REG(rtc_reg, low_bit, bit_width, value)** Write immediate value into rtc_reg[low_bit + bit_width - 1 : low_bit], bit_width <= 8. For example:

```
#include "soc/soc_ulp.h"
#include "soc/rtc_io_reg.h"

/* Set BIT(2) of RTC_GPIO_OUT_DATA_W1TS field in RTC_GPIO_OUT_W1TS_REG */
WRITE_RTC_REG(RTC_GPIO_OUT_W1TS_REG, RTC_GPIO_OUT_DATA_W1TS_S + 2, 1, 1)
```

**WRITE_RTC_FIELD(rtc_reg, field, value)** Write immediate value into a field in rtc_reg, up to 8 bits. For example:

```
#include "soc/soc_ulp.h"
#include "soc/rtc_cntl_reg.h"

/* Set RTC_CNTL_ULP_CP_SLP_TIMER_EN field of RTC_CNTL_STATE0_REG to 0 */
READ_RTC_REG(RTC_CNTL_STATE0_REG, RTC_CNTL_ULP_CP_SLP_TIMER_EN, 0)
```

## Programming ULP coprocessor using C macros

In addition to the existing binutils port for the ESP32 ULP coprocessor, it is possible to generate programs for the ULP by embedding assembly-like macros into an ESP32 application. Here is an example how this can be done:

```
const ulp_insn_t program[] = {
    I_MOVI(R3, 16),         // R3 <- 16
    I_LD(R0, R3, 0),        // R0 <- RTC_SLOW_MEM[R3 + 0]
    I_LD(R1, R3, 1),        // R1 <- RTC_SLOW_MEM[R3 + 1]
    I_ADDR(R2, R0, R1),     // R2 <- R0 + R1
    I_ST(R2, R3, 2),        // R2 -> RTC_SLOW_MEM[R2 + 2]
    I_HALT()
};
size_t load_addr = 0;
size_t size = sizeof(program)/sizeof(ulp_insn_t);
ulp_process_macros_and_load(load_addr, program, &size);
ulp_run(load_addr);
```

The `program` array is an array of `ulp_insn_t`, i.e. ULP coprocessor instructions. Each `I_XXX` preprocessor define translates into a single 32-bit instruction. Arguments of these preprocessor defines can be register numbers (`R0 -- R3`) and literal constants. See *ULP coprocessor instruction defines* section for descriptions of instructions and arguments they take.

Load and store instructions use addresses expressed in 32-bit words. Address 0 corresponds to the first word of `RTC_SLOW_MEM` (which is address 0x50000000 as seen by the main CPUs).

To generate branch instructions, special `M_` preprocessor defines are used. `M_LABEL` define can be used to define a branch target. Label identifier is a 16-bit integer. `M_Bxxx` defines can be used to generate branch instructions with target set to a particular label.

Implementation note: these `M_` preprocessor defines will be translated into two `ulp_insn_t` values: one is a token value which contains label number, and the other is the actual instruction. `ulp_process_macros_and_load` function resolves the label number to the address, modifies the branch instruction to use the correct address, and removes the the extra `ulp_insn_t` token which contains the label numer.

Here is an example of using labels and branches:

```
const ulp_insn_t program[] = {
    I_MOVI(R0, 34),         // R0 <- 34
    M_LABEL(1),             // label_1
    I_MOVI(R1, 32),         // R1 <- 32
    I_LD(R1, R1, 0),        // R1 <- RTC_SLOW_MEM[R1]
    I_MOVI(R2, 33),         // R2 <- 33
    I_LD(R2, R2, 0),        // R2 <- RTC_SLOW_MEM[R2]
    I_SUBR(R3, R1, R2),     // R3 <- R1 - R2
    I_ST(R3, R0, 0),        // R3 -> RTC_SLOW_MEM[R0 + 0]
    I_ADDI(R0, R0, 1),      // R0++
    M_BL(1, 64),            // if (R0 < 64) goto label_1
    I_HALT(),
};
RTC_SLOW_MEM[32] = 42;
RTC_SLOW_MEM[33] = 18;
size_t load_addr = 0;
size_t size = sizeof(program)/sizeof(ulp_insn_t);
ulp_process_macros_and_load(load_addr, program, &size);
ulp_run(load_addr);
```

## Functions

esp_err_t **ulp_process_macros_and_load**(uint32_t *load_addr*, **const** ulp_insn_t **program*, size_t **psize*)

Resolve all macro references in a program and load it into RTC memory.

**Return**

- ESP_OK on success
- ESP_ERR_NO_MEM if auxiliary temporary structure can not be allocated
- one of ESP_ERR_ULP_xxx if program is not valid or can not be loaded

**Parameters**

- `load_addr`: address where the program should be loaded, expressed in 32-bit words
- `program`: ulp_insn_t array with the program
- `psize`: size of the program, expressed in 32-bit words

esp_err_t **ulp_run**(uint32_t *entry_point*)

Run the program loaded into RTC memory.

**Return** ESP_OK on success

**Parameters**

- `entry_point`: entry point, expressed in 32-bit words

## Error codes

**ESP_ERR_ULP_BASE** 0x1200

Offset for ULP-related error codes

**ESP_ERR_ULP_SIZE_TOO_BIG** (*ESP_ERR_ULP_BASE* + 1)

Program doesn't fit into RTC memory reserved for the ULP

**ESP_ERR_ULP_INVALID_LOAD_ADDR** (*ESP_ERR_ULP_BASE* + 2)

Load address is outside of RTC memory reserved for the ULP

**ESP_ERR_ULP_DUPLICATE_LABEL** (*ESP_ERR_ULP_BASE* + 3)

More than one label with the same number was defined

**ESP_ERR_ULP_UNDEFINED_LABEL** (*ESP_ERR_ULP_BASE* + 4)

Branch instructions references an undefined label

**ESP_ERR_ULP_BRANCH_OUT_OF_RANGE** (*ESP_ERR_ULP_BASE* + 5)

Branch target is out of range of B instruction (try replacing with BX)

## ULP coprocessor registers

ULP co-processor has 4 16-bit general purpose registers. All registers have same functionality, with one exception. R0 register is used by some of the compare-and-branch instructions as a source register.

These definitions can be used for all instructions which require a register.

**R0** 0

general purpose register 0

**R1** 1
general purpose register 1

**R2** 2
general purpose register 2

**R3** 3
general purpose register 3

## ULP coprocessor instruction defines

**I_DELAY** (cycles_) { .delay = {\ .opcode = OPCODE_DELAY, \ .unused = 0, \ .cycles = cycles_ } }
Delay (nop) for a given number of cycles

**I_HALT** { .halt = {\ .unused = 0, \ .opcode = OPCODE_HALT } }
Halt the coprocessor.

This instruction halts the coprocessor, but keeps ULP timer active. As such, ULP program will be restarted again by timer. To stop the program and prevent the timer from restarting the program, use I_END(0) instruction.

**I_END** I_WR_REG_BIT(RTC_CNTL_STATE0_REG, RTC_CNTL_ULP_CP_SLP_TIMER_EN_S, 0)
Stop ULP program timer.

This is a convenience macro which disables the ULP program timer. Once this instruction is used, ULP program will not be restarted anymore until ulp_run function is called.

ULP program will continue running after this instruction. To stop the currently running program, use I_HALT().

**I_ST** (reg_val, reg_addr, offset_) { .st = { \ .dreg = reg_val, \ .sreg = reg_addr, \ .unused1 = 0, \ .offset = offset_, \ .unused2 = 0, \ .sub_opcode = SUB_OPCODE_ST, \ .opcode = OPCODE_ST } }
Store value from register reg_val into RTC memory.

The value is written to an offset calculated by adding value of reg_addr register and offset_ field (this offset is expressed in 32-bit words). 32 bits written to RTC memory are built as follows:

- bits [31:21] hold the PC of current instruction, expressed in 32-bit words
- bits [20:16] = 5'b1
- bits [15:0] are assigned the contents of reg_val

RTC_SLOW_MEM[addr + offset_] = { 5'b0, insn_PC[10:0], val[15:0] }

**I_LD** (reg_dest, reg_addr, offset_) { .ld = { \ .dreg = reg_dest, \ .sreg = reg_addr, \ .unused1 = 0, \ .offset = offset_, \ .unused2 = 0, \ .opcode = OPCODE_LD } }
Load value from RTC memory into reg_dest register.

Loads 16 LSBs from RTC memory word given by the sum of value in reg_addr and value of offset_.

**I_WR_REG** (reg, low_bit, high_bit, val) {.wr_reg = {\ .addr = (reg & 0xff) / sizeof(uint32_t), \ .periph_sel = SOC_REG_TO_ULP_PERIPH_SEL(reg), \ .data = val, \ .low = low_bit, \ .high = high_bit, \ .opcode = OPCODE_WR_REG } }
Write literal value to a peripheral register

reg[high_bit : low_bit] = val This instruction can access RTC_CNTL_, RTC_IO_, and SENS_ peripheral registers.

**I_RD_REG** (reg, low_bit, high_bit) {.rd_reg = {\ .addr = (reg & 0xff) / sizeof(uint32_t), \ .periph_sel = SOC_REG_TO_ULP_PERIPH_SEL(reg), \ .unused = 0, \ .low = low_bit, \ .high = high_bit, \ .opcode = OPCODE_RD_REG } }
Read from peripheral register into R0

R0 = reg[high_bit : low_bit] This instruction can access RTC_CNTL_, RTC_IO_, and SENS_ peripheral registers.

**`I_BL`**(pc_offset, imm_value) { .b = { \ .imm = imm_value, \ .cmp = B_CMP_L, \ .offset = abs(pc_offset), \ .sign = (pc_offset >= 0) ? 0 : 1, \ .sub_opcode = SUB_OPCODE_B, \ .opcode = OPCODE_BRANCH } }

Branch relative if R0 less than immediate value.

pc_offset is expressed in words, and can be from -127 to 127 imm_value is a 16-bit value to compare R0 against

**`I_BGE`**(pc_offset, imm_value) { .b = { \ .imm = imm_value, \ .cmp = B_CMP_GE, \ .offset = abs(pc_offset), \ .sign = (pc_offset >= 0) ? 0 : 1, \ .sub_opcode = SUB_OPCODE_B, \ .opcode = OPCODE_BRANCH } }

Branch relative if R0 greater or equal than immediate value.

pc_offset is expressed in words, and can be from -127 to 127 imm_value is a 16-bit value to compare R0 against

**`I_BXR`**(reg_pc) { .bx = { \ .dreg = reg_pc, \ .addr = 0, \ .unused = 0, \ .reg = 1, \ .type = BX_JUMP_TYPE_DIRECT, \ .sub_opcode = SUB_OPCODE_BX, \ .opcode = OPCODE_BRANCH } }

Unconditional branch to absolute PC, address in register.

reg_pc is the register which contains address to jump to. Address is expressed in 32-bit words.

**`I_BXI`**(imm_pc) { .bx = { \ .dreg = 0, \ .addr = imm_pc, \ .unused = 0, \ .reg = 0, \ .type = BX_JUMP_TYPE_DIRECT, \ .sub_opcode = SUB_OPCODE_BX, \ .opcode = OPCODE_BRANCH } }

Unconditional branch to absolute PC, immediate address.

Address imm_pc is expressed in 32-bit words.

**`I_BXZR`**(reg_pc) { .bx = { \ .dreg = reg_pc, \ .addr = 0, \ .unused = 0, \ .reg = 1, \ .type = BX_JUMP_TYPE_ZERO, \ .sub_opcode = SUB_OPCODE_BX, \ .opcode = OPCODE_BRANCH } }

Branch to absolute PC if ALU result is zero, address in register.

reg_pc is the register which contains address to jump to. Address is expressed in 32-bit words.

**`I_BXZI`**(imm_pc) { .bx = { \ .dreg = 0, \ .addr = imm_pc, \ .unused = 0, \ .reg = 0, \ .type = BX_JUMP_TYPE_ZERO, \ .sub_opcode = SUB_OPCODE_BX, \ .opcode = OPCODE_BRANCH } }

Branch to absolute PC if ALU result is zero, immediate address.

Address imm_pc is expressed in 32-bit words.

**`I_BXFR`**(reg_pc) { .bx = { \ .dreg = reg_pc, \ .addr = 0, \ .unused = 0, \ .reg = 1, \ .type = BX_JUMP_TYPE_OVF, \ .sub_opcode = SUB_OPCODE_BX, \ .opcode = OPCODE_BRANCH } }

Branch to absolute PC if ALU overflow, address in register

reg_pc is the register which contains address to jump to. Address is expressed in 32-bit words.

**`I_BXFI`**(imm_pc) { .bx = { \ .dreg = 0, \ .addr = imm_pc, \ .unused = 0, \ .reg = 0, \ .type = BX_JUMP_TYPE_OVF, \ .sub_opcode = SUB_OPCODE_BX, \ .opcode = OPCODE_BRANCH } }

Branch to absolute PC if ALU overflow, immediate address

Address imm_pc is expressed in 32-bit words.

**`I_ADDR`**(reg_dest, reg_src1, reg_src2) { .alu_reg = { \ .dreg = reg_dest, \ .sreg = reg_src1, \ .treg = reg_src2, \ .unused = 0, \ .sel = ALU_SEL_ADD, \ .sub_opcode = SUB_OPCODE_ALU_REG, \ .opcode = OPCODE_ALU } }

Addition: dest = src1 + src2

**I_SUBR** (reg_dest, reg_src1, reg_src2) { .alu_reg = { \ .dreg = reg_dest, \ .sreg = reg_src1, \ .treg = reg_src2, \ .unused = 0, \ .sel = ALU_SEL_SUB, \ .sub_opcode = SUB_OPCODE_ALU_REG, \ .opcode = OPCODE_ALU } }
Subtraction: dest = src1 - src2

**I_ANDR** (reg_dest, reg_src1, reg_src2) { .alu_reg = { \ .dreg = reg_dest, \ .sreg = reg_src1, \ .treg = reg_src2, \ .unused = 0, \ .sel = ALU_SEL_AND, \ .sub_opcode = SUB_OPCODE_ALU_REG, \ .opcode = OPCODE_ALU } }
Logical AND: dest = src1 & src2

**I_ORR** (reg_dest, reg_src1, reg_src2) { .alu_reg = { \ .dreg = reg_dest, \ .sreg = reg_src1, \ .treg = reg_src2, \ .unused = 0, \ .sel = ALU_SEL_OR, \ .sub_opcode = SUB_OPCODE_ALU_REG, \ .opcode = OPCODE_ALU } }
Logical OR: dest = src1 | src2

**I_MOVR** (reg_dest, reg_src) { .alu_reg = { \ .dreg = reg_dest, \ .sreg = reg_src, \ .treg = 0, \ .unused = 0, \ .sel = ALU_SEL_MOV, \ .sub_opcode = SUB_OPCODE_ALU_REG, \ .opcode = OPCODE_ALU } }
Copy: dest = src

**I_LSHR** (reg_dest, reg_src, reg_shift) { .alu_reg = { \ .dreg = reg_dest, \ .sreg = reg_src, \ .treg = reg_shift, \ .unused = 0, \ .sel = ALU_SEL_LSH, \ .sub_opcode = SUB_OPCODE_ALU_REG, \ .opcode = OPCODE_ALU } }
Logical shift left: dest = src << shift

**I_RSHR** (reg_dest, reg_src, reg_shift) { .alu_reg = { \ .dreg = reg_dest, \ .sreg = reg_src, \ .treg = reg_shift, \ .unused = 0, \ .sel = ALU_SEL_RSH, \ .sub_opcode = SUB_OPCODE_ALU_REG, \ .opcode = OPCODE_ALU } }
Logical shift right: dest = src >> shift

**I_ADDI** (reg_dest, reg_src, imm_) { .alu_imm = { \ .dreg = reg_dest, \ .sreg = reg_src, \ .imm = imm_, \ .unused = 0, \ .sel = ALU_SEL_ADD, \ .sub_opcode = SUB_OPCODE_ALU_IMM, \ .opcode = OPCODE_ALU } }
Add register and an immediate value: dest = src1 + imm

**I_SUBI** (reg_dest, reg_src, imm_) { .alu_imm = { \ .dreg = reg_dest, \ .sreg = reg_src, \ .imm = imm_, \ .unused = 0, \ .sel = ALU_SEL_SUB, \ .sub_opcode = SUB_OPCODE_ALU_IMM, \ .opcode = OPCODE_ALU } }
Subtract register and an immediate value: dest = src - imm

**I_ANDI** (reg_dest, reg_src, imm_) { .alu_imm = { \ .dreg = reg_dest, \ .sreg = reg_src, \ .imm = imm_, \ .unused = 0, \ .sel = ALU_SEL_AND, \ .sub_opcode = SUB_OPCODE_ALU_IMM, \ .opcode = OPCODE_ALU } }
Logical AND register and an immediate value: dest = src & imm

**I_ORI** (reg_dest, reg_src, imm_) { .alu_imm = { \ .dreg = reg_dest, \ .sreg = reg_src, \ .imm = imm_, \ .unused = 0, \ .sel = ALU_SEL_OR, \ .sub_opcode = SUB_OPCODE_ALU_IMM, \ .opcode = OPCODE_ALU } }
Logical OR register and an immediate value: dest = src | imm

**I_MOVI** (reg_dest, imm_) { .alu_imm = { \ .dreg = reg_dest, \ .sreg = 0, \ .imm = imm_, \ .unused = 0, \ .sel = ALU_SEL_MOV, \ .sub_opcode = SUB_OPCODE_ALU_IMM, \ .opcode = OPCODE_ALU } }
Copy an immediate value into register: dest = imm

**I_LSHI** (reg_dest, reg_src, imm_) { .alu_imm = { \ .dreg = reg_dest, \ .sreg = reg_src, \ .imm = imm_, \ .unused = 0, \ .sel = ALU_SEL_LSH, \ .sub_opcode = SUB_OPCODE_ALU_IMM, \ .opcode = OPCODE_ALU } }
Logical shift left register value by an immediate: dest = src << imm

**I_RSHI** (reg_dest, reg_src, imm_) { .alu_imm = { \ .dreg = reg_dest, \ .sreg = reg_src, \ .imm = imm_, \ .unused = 0, \ .sel = ALU_SEL_RSH, \ .sub_opcode = SUB_OPCODE_ALU_IMM, \ .opcode = OPCODE_ALU } }
Logical shift right register value by an immediate: dest = val >> imm

**M_LABEL** (label_num) { .macro = { \ .label = label_num, \ .unused = 0, \ .sub_opcode = SUB_OPCODE_MACRO_LABEL, \ .opcode = OPCODE_MACRO } }
Define a label with number label_num.

This is a macro which doesn't generate a real instruction. The token generated by this macro is removed by ulp_process_macros_and_load function. Label defined using this macro can be used in branch macros defined below.

**M_BL** (label_num, imm_value) M_BRANCH(label_num), \ I_BL(0, imm_value)
Macro: branch to label label_num if R0 is less than immediate value.

This macro generates two ulp_insn_t values separated by a comma, and should be used when defining contents of ulp_insn_t arrays. First value is not a real instruction; it is a token which is removed by ulp_process_macros_and_load function.

**M_BGE** (label_num, imm_value) M_BRANCH(label_num), \ I_BGE(0, imm_value)
Macro: branch to label label_num if R0 is greater or equal than immediate value

This macro generates two ulp_insn_t values separated by a comma, and should be used when defining contents of ulp_insn_t arrays. First value is not a real instruction; it is a token which is removed by ulp_process_macros_and_load function.

**M_BX** (label_num) M_BRANCH(label_num), \ I_BXI(0)
Macro: unconditional branch to label

This macro generates two ulp_insn_t values separated by a comma, and should be used when defining contents of ulp_insn_t arrays. First value is not a real instruction; it is a token which is removed by ulp_process_macros_and_load function.

**M_BXZ** (label_num) M_BRANCH(label_num), \ I_BXZI(0)
Macro: branch to label if ALU result is zero

This macro generates two ulp_insn_t values separated by a comma, and should be used when defining contents of ulp_insn_t arrays. First value is not a real instruction; it is a token which is removed by ulp_process_macros_and_load function.

**M_BXF** (label_num) M_BRANCH(label_num), \ I_BXFI(0)
Macro: branch to label if ALU overflow

This macro generates two ulp_insn_t values separated by a comma, and should be used when defining contents of ulp_insn_t arrays. First value is not a real instruction; it is a token which is removed by ulp_process_macros_and_load function.

### Defines

**RTC_SLOW_MEM** ((uint32_t*) 0x50000000)
RTC slow memory, 8k size

ULP (Ultra Low Power) coprocessor is a simple FSM which is designed to perform measurements using ADC, temperature sensor, and external I2C sensors, while main processors are in deep sleep mode. ULP coprocessor can access RTC_SLOW_MEM memory region, and registers in RTC_CNTL, RTC_IO, and SARADC peripherals. ULP coprocessor uses fixed-width 32-bit instructions, 32-bit memory addressing, and has 4 general purpose 16-bit registers.

## Installing the toolchain

ULP coprocessor code is written in assembly and compiled using the binutils-esp32ulp toolchain.

1. Download the toolchain using the links listed on this page: https://github.com/espressif/binutils-esp32ulp/wiki#downloads

2. Extract the toolchain into a directory, and add the path to the `bin/` directory of the toolchain to the `PATH` environment variable.

## Compiling ULP code

To compile ULP code as part of a component, the following steps must be taken:

1. ULP code, written in assembly, must be added to one or more files with *.S* extension. These files must be placed into a separate directory inside component directory, for instance *ulp/*.

2. Modify the component makefile, adding the following:

```
ULP_APP_NAME ?= ulp_$(COMPONENT_NAME)
ULP_S_SOURCES = $(COMPONENT_PATH)/ulp/ulp_source_file.S
ULP_EXP_DEP_OBJECTS := main.o
include $(IDF_PATH)/components/ulp/component_ulp_common.mk
```

   Here is each line explained:

   **ULP_APP_NAME** Name of the generated ULP application, without an extension. This name is used for build products of the ULP application: ELF file, map file, binary file, generated header file, and generated linker export file.

   **ULP_S_SOURCES** List of assembly files to be passed to the ULP assembler. These must be absolute paths, i.e. start with `$(COMPONENT_PATH)`. Consider using `$(addprefix)` function if more than one file needs to be listed. Paths are relative to component build directory, so prefixing them is not necessary.

   **ULP_EXP_DEP_OBJECTS** List of object files names within the component which include the generated header file. This list is needed to build the dependencies correctly and ensure that the generated header file is created before any of these files are compiled. See section below explaining the concept of generated header files for ULP applications.

   **include $(IDF_PATH)/components/ulp/component_ulp_common.mk** Includes common definitions of ULP build steps. Defines build targets for ULP object files, ELF file, binary file, etc.

3. Build the application as usual (e.g. *make app*)

   Inside, the build system will take the following steps to build ULP program:

   (a) **Run each assembly file (foo.S) through C preprocessor.** This step generates the preprocessed assembly files (foo.ulp.pS) in the component build directory. This step also generates dependency files (foo.ulp.d).

   (b) **Run preprocessed assembly sources through assembler.** This produces objects (foo.ulp.o) and listing (foo.ulp.lst) files. Listing files are generated for debugging purposes and are not used at later stages of build process.

   (c) **Run linker script template through C preprocessor.** The template is located in components/ulp/ld directory.

   (d) **Link object files into an output ELF file** (ulp_app_name.elf). Map file (ulp_app_name.map) generated at this stage may be useful for debugging purposes.

   (e) **Dump contents of the ELF file into binary** (ulp_app_name.bin) for embedding into the application.

   (f) **Generate list of global symbols** (ulp_app_name.sym) in the ELF file using esp32ulp-elf-nm.

   (g) **Create LD export script and header file** (ulp_app_name.ld and ulp_app_name.h) containing the symbols from ulp_app_name.sym. This is done using esp32ulp_mapgen.py utility.

(h) **Add the generated binary to the list of binary files** to be emedded into the application.

## Accessing ULP program variables

Global symbols defined in the ULP program may be used inside the main program.

For example, ULP program may define a variable `measurement_count` which will define the number of ADC measurements the program needs to make before waking up the chip from deep sleep:

```
                        .global measurement_count
measurement_count:      .long 0

                        /* later, use measurement_count */
                        move r3, measurement_count
                        ld r3, r3, 0
```

Main program needs to initialize this variable before ULP program is started. Build system makes this possible by generating a `$(ULP_APP_NAME).h` and `$(ULP_APP_NAME).ld` files which define global symbols present in the ULP program. This files include each global symbol defined in the ULP program, prefixed with `ulp_`.

The header file contains declaration of the symbol:

```
extern uint32_t ulp_measurement_count;
```

Note that all symbols (variables, arrays, functions) are declared as `uint32_t`. For functions and arrays, take address of the symbol and cast to the appropriate type.

The generated linker script file defines locations of symbols in RTC_SLOW_MEM:

```
PROVIDE ( ulp_measurement_count = 0x50000060 );
```

To access ULP program variables from the main program, include the generated header file and use variables as one normally would:

```
#include "ulp_app_name.h"

// later
void init_ulp_vars() {
    ulp_measurement_count = 64;
}
```

Note that ULP program can only use lower 16 bits of each 32-bit word in RTC memory, because the registers are 16-bit, and there is no instruction to load from high part of the word.

Likewise, ULP store instruction writes register value into the lower 16 bit part of the 32-bit word. Upper 16 bits are written with a value which depends on the address of the store instruction, so when reading variables written by the ULP, main application needs to mask upper 16 bits, e.g.:

```
printf("Last measurement value: %d\n", ulp_last_measurement & UINT16_MAX);
```

## Starting the ULP program

To run a ULP program, main application needs to load the ULP program into RTC memory using `ulp_load_binary` function, and then start it using `ulp_run` function.

Note that "Enable Ultra Low Power (ULP) Coprocessor" option must be enabled in menuconfig in order to reserve memory for the ULP. "RTC slow memory reserved for coprocessor" option must be set to a value sufficient to store ULP code and data. If the application components contain multiple ULP programs, then the size of the RTC memory must be sufficient to hold the largest one.

Each ULP program is embedded into the ESP-IDF application as a binary blob. Application can reference this blob and load it in the following way (suppose ULP_APP_NAME was defined to `ulp_app_name`:

```
extern const uint8_t bin_start[] asm("_binary_ulp_app_name_bin_start");
extern const uint8_t bin_end[]   asm("_binary_ulp_app_name_bin_end");

void start_ulp_program() {
    ESP_ERROR_CHECK( ulp_load_binary(
        0 /* load address, set to 0 when using default linker scripts */,
        bin_start,
        (bin_end - bin_start) / sizeof(uint32_t)) );
}
```

esp_err_t **`ulp_load_binary`** (uint32_t *load_addr*, **const** uint8_t **program_binary*, size_t *program_size*)

Load ULP program binary into RTC memory.

ULP program binary should have the following format (all values little-endian):

1. MAGIC, (value 0x00706c75, 4 bytes)
2. TEXT_OFFSET, offset of .text section from binary start (2 bytes)
3. TEXT_SIZE, size of .text section (2 bytes)
4. DATA_SIZE, size of .data section (2 bytes)
5. BSS_SIZE, size of .bss section (2 bytes)
6. (TEXT_OFFSET - 16) bytes of arbitrary data (will not be loaded into RTC memory)
7. .text section
8. .data section

Linker script in components/ulp/ld/esp32.ulp.ld produces ELF files which correspond to this format. This linker script produces binaries with load_addr == 0.

**Return**

- ESP_OK on success
- ESP_ERR_INVALID_ARG if load_addr is out of range
- ESP_ERR_INVALID_SIZE if program_size doesn't match (TEXT_OFFSET + TEXT_SIZE + DATA_SIZE)
- ESP_ERR_NOT_SUPPORTED if the magic number is incorrect

**Parameters**

- `load_addr`: address where the program should be loaded, expressed in 32-bit words
- `program_binary`: pointer to program binary
- `program_size`: size of the program binary

Once the program is loaded into RTC memory, application can start it, passing the address of the entry point to `ulp_run` function:

```
ESP_ERROR_CHECK( ulp_run((&ulp_entry - RTC_SLOW_MEM) / sizeof(uint32_t)) );
```

esp_err_t **ulp_run** (uint32_t *entry_point*)
Run the program loaded into RTC memory.

**Return** ESP_OK on success

**Parameters**

- `entry_point`: entry point, expressed in 32-bit words

Declaration of the entry point symbol comes from the above mentioned generated header file, `$(ULP_APP_NAME).h`. In assembly source of the ULP application, this symbol must be marked as `.global`:

```
        .global entry
entry:
        /* code starts here */
```

## ULP program flow

ULP coprocessor is started by a timer. The timer is started once `ulp_run` is called. The timer counts a number of RTC_SLOW_CLK ticks (by default, produced by an internal 150kHz RC oscillator). The number of ticks is set using `SENS_ULP_CP_SLEEP_CYCx_REG` registers (x = 0..4). When starting the ULP for the first time, `SENS_ULP_CP_SLEEP_CYC0_REG` will be used to obtain the number of timer ticks. Later the ULP program can select another `SENS_ULP_CP_SLEEP_CYCx_REG` register using `sleep` instruction.

Once the timer counts the number of ticks set by the selected `SENS_ULP_CP_SLEEP_CYCx_REG` register, ULP coprocessor powers up and starts running the program from the entry point set in the call to `ulp_run`.

The program runs until it encounters a `halt` instruction or an illegal instruction. Once the program halts, ULP coprocessor powers down, and the timer is started again.

To disable the timer (effectively preventing the ULP program from running again), clear the `RTC_CNTL_ULP_CP_SLP_TIMER_EN` bit in the `RTC_CNTL_STATE0_REG` register. This can be done both from ULP code and from the main program.

# CHAPTER 16

## Unit Testing in ESP32

ESP-IDF comes with a unit test app based on Unity - unit test framework. Unit tests are integrated in the ESP-IDF repository and are placed in `test` subdirectory of each component respectively.

### Adding unit tests

Unit tests are added in the `test` subdirectory of the respective component. Tests are added in C files, a single C file can include multiple test cases. Test files start with the word "test".

The test file should include unity.h and the header for the C module to be tested.

Tests are added in a function in the C file as follows:

```
TEST_CASE("test name", "[module name]"
{
        // Add test here
}
```

First argument is a descriptive name for the test, second argument is an identifier in square brackets. Identifiers are used to group related test, or tests with specific properties.

There is no need to add a main function with `UNITY_BEGIN()` and `UNITY_END()` in each test case. `unity_platform.c` will run `UNITY_BEGIN()`, run the tests cases, and then call `UNITY_END()`.

Each *test* subdirectory needs to include component.mk file with at least the following line of code:

```
COMPONENT_ADD_LDFLAGS = -Wl,--whole-archive -l$(COMPONENT_NAME) -Wl,--no-whole-archive
```

See http://www.throwtheswitch.org/unity for more information about writing tests in Unity.

## Building unit test app

Follow the setup instructions in the top-level esp-idf README. Make sure that IDF_PATH environment variable is set to point to the path of esp-idf top-level directory.

Change into tools/unit-test-app directory to configure and build it:

- *make menuconfig* - configure unit test app.
- *make TESTS_ALL=1* - build unit test app with tests for each component having tests in the `test` subdirectory.
- *make TEST_COMPONENTS='xxx'* - build unit test app with tests for specific components.

When the build finishes, it will print instructions for flashing the chip. You can simply run `make flash` to flash all build output.

You can also run `make flash TESTS_ALL=1` or `make TEST_COMPONENTS='xxx'` to build and flash. Everything needed will be rebuilt automatically before flashing.

Use menuconfig to set the serial port for flashing.

## Running unit tests

After flashing reset the ESP32 and it will boot the unit test app.

Unit test app prints a test menu with all available tests.

Test cases can be run by inputting one of the following:

- Test case name in quotation marks to run a single test case
- Test case index to run a single test case
- Module name in square brackets to run all test cases for a specific module
- An asterisk to run all test cases

CHAPTER 17

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# Wi-Fi API

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## Wi-Fi

### Overview

Instructions

### Application Example

Simple code showing how to connect ESP32 module to an Access Point: esp-idf-template.

### API Reference

#### Header Files

- esp32/include/esp_wifi.h

### Macros

**WIFI_INIT_CONFIG_DEFAULT** {0}; _Static_assert(0, "please enable wifi in menuconfig to use esp_wifi.h");

### Type Definitions

**typedef** void (***wifi_promiscuous_cb_t**) (void *buf, wifi_promiscuous_pkt_type_t type)

The RX callback function in the promiscuous mode. Each time a packet is received, the callback function will be called.

**Parameters**

- `buf`: Data received. Type of data in buffer (wifi_promiscuous_pkt_t or wifi_pkt_rx_ctrl_t) indicated by 'type' parameter.
- `type`: promiscuous packet type.

**typedef** void (***esp_vendor_ie_cb_t**)(void *ctx, wifi_vendor_ie_type_t type, **const** uint8_t sa[6], **const** uint8_t *vnd_ie, int rssi)

Define function pointer for vendor specific element callback.

**Parameters**

- `ctx`: reserved
- `type`: information element type
- `sa`: source address
- `vnd_ie`: pointer to a vendor specific element
- `rssi`: received signal strength indication

## Functions

esp_err_t **esp_wifi_init**(wifi_init_config_t **config*)

Init WiFi Alloc resource for WiFi driver, such as WiFi control structure, RX/TX buffer, WiFi NVS structure etc, this WiFi also start WiFi task.

**Attention** 1. This API must be called before all other WiFi API can be called

**Attention** 2. Always use WIFI_INIT_CONFIG_DEFAULT macro to init the config to default values, this can guarantee all the fields got correct value when more fields are added into wifi_init_config_t in future release. If you want to set your owner initial values, overwrite the default values which are set by WIFI_INIT_CONFIG_DEFAULT, please be notified that the field 'magic' of wifi_init_config_t should always be WIFI_INIT_CONFIG_MAGIC!

**Return**

- ESP_OK: succeed
- ESP_ERR_WIFI_NO_MEM: out of memory
- others: refer to error code esp_err.h

**Parameters**

- `config`: provide WiFi init configuration

esp_err_t **esp_wifi_deinit**(void)

Deinit WiFi Free all resource allocated in esp_wifi_init and stop WiFi task.

**Attention** 1. This API should be called if you want to remove WiFi driver from the system

**Return** ESP_OK: succeed

esp_err_t **esp_wifi_set_mode**(wifi_mode_t *mode*)

Set the WiFi operating mode.

Set the WiFi operating mode as station, soft-AP or station+soft-AP, The default mode is soft-AP mode.

**Return**

- ESP_OK: succeed
- ESP_ERR_WIFI_NOT_INIT: WiFi is not initialized by eps_wifi_init
- ESP_ERR_WIFI_ARG: invalid argument
- others: refer to error code in esp_err.h

**Parameters**

- `mode`: WiFi operating mode

esp_err_t **esp_wifi_get_mode**(wifi_mode_t **mode*)

Get current operating mode of WiFi.

**Return**

- ESP_OK: succeed
- ESP_ERR_WIFI_NOT_INIT: WiFi is not initialized by eps_wifi_init
- ESP_ERR_WIFI_ARG: invalid argument

**Parameters**

- `mode`: store current WiFi mode

esp_err_t **esp_wifi_start**(void)

Start WiFi according to current configuration If mode is WIFI_MODE_STA, it create station control block and start station If mode is WIFI_MODE_AP, it create soft-AP control block and start soft-AP If mode is WIFI_MODE_APSTA, it create soft-AP and station control block and start soft-AP and station.

**Return**

- ESP_OK: succeed
- ESP_ERR_WIFI_NOT_INIT: WiFi is not initialized by eps_wifi_init
- ESP_ERR_WIFI_ARG: invalid argument
- ESP_ERR_WIFI_NO_MEM: out of memory
- ESP_ERR_WIFI_CONN: WiFi internal error, station or soft-AP control block wrong
- ESP_ERR_WIFI_FAIL: other WiFi internal errors

esp_err_t **esp_wifi_stop**(void)

Stop WiFi If mode is WIFI_MODE_STA, it stop station and free station control block If mode is WIFI_MODE_AP, it stop soft-AP and free soft-AP control block If mode is WIFI_MODE_APSTA, it stop station/soft-AP and free station/soft-AP control block.

**Return**

- ESP_OK: succeed
- ESP_ERR_WIFI_NOT_INIT: WiFi is not initialized by eps_wifi_init

esp_err_t **esp_wifi_connect**(void)

Connect the ESP32 WiFi station to the AP.

**Attention** 1. This API only impact WIFI_MODE_STA or WIFI_MODE_APSTA mode

**Attention** 2. If the ESP32 is connected to an AP, call esp_wifi_disconnect to disconnect.

**Return**

- ESP_OK: succeed
- ESP_ERR_WIFI_NOT_INIT: WiFi is not initialized by eps_wifi_init
- ESP_ERR_WIFI_NOT_START: WiFi is not started by esp_wifi_start
- ESP_ERR_WIFI_CONN: WiFi internal error, station or soft-AP control block wrong
- ESP_ERR_WIFI_SSID: SSID of AP which station connects is invalid

esp_err_t **esp_wifi_disconnect**(void)
Disconnect the ESP32 WiFi station from the AP.

**Return**

- ESP_OK: succeed
- ESP_ERR_WIFI_NOT_INIT: WiFi was not initialized by eps_wifi_init
- ESP_ERR_WIFI_NOT_STARTED: WiFi was not started by esp_wifi_start
- ESP_ERR_WIFI_FAIL: other WiFi internal errors

esp_err_t **esp_wifi_clear_fast_connect**(void)
Currently this API is just an stub API.

**Return**

- ESP_OK: succeed
- others: fail

esp_err_t **esp_wifi_deauth_sta**(uint16_t *aid*)
deauthenticate all stations or associated id equals to aid

**Return**

- ESP_OK: succeed
- ESP_ERR_WIFI_NOT_INIT: WiFi is not initialized by eps_wifi_init
- ESP_ERR_WIFI_NOT_STARTED: WiFi was not started by esp_wifi_start
- ESP_ERR_WIFI_ARG: invalid argument
- ESP_ERR_WIFI_MODE: WiFi mode is wrong

**Parameters**

- `aid`: when aid is 0, deauthenticate all stations, otherwise deauthenticate station whose associated id is aid

esp_err_t **esp_wifi_scan_start**(wifi_scan_config_t **config*, bool *block*)
Scan all available APs.

**Attention** If this API is called, the found APs are stored in WiFi driver dynamic allocated memory and the will be freed in esp_wifi_get_ap_list, so generally, call esp_wifi_get_ap_list to cause the memory to be freed once the scan is done

**Attention** The values of maximum active scan time and passive scan time per channel are limited to 1500 milliseconds. Values above 1500ms may cause station to disconnect from AP and are not recommended.

**Return**

- ESP_OK: succeed
- ESP_ERR_WIFI_NOT_INIT: WiFi is not initialized by eps_wifi_init
- ESP_ERR_WIFI_NOT_STARTED: WiFi was not started by esp_wifi_start
- ESP_ERR_WIFI_TIMEOUT: blocking scan is timeout
- others: refer to error code in esp_err.h

**Parameters**

- `config`: configuration of scanning
- `block`: if block is true, this API will block the caller until the scan is done, otherwise it will return immediately

esp_err_t **esp_wifi_scan_stop**(void)
Stop the scan in process.

**Return**

- ESP_OK: succeed
- ESP_ERR_WIFI_NOT_INIT: WiFi is not initialized by eps_wifi_init
- ESP_ERR_WIFI_NOT_STARTED: WiFi is not started by esp_wifi_start

esp_err_t **esp_wifi_scan_get_ap_num**(uint16_t **number*)
Get number of APs found in last scan.

**Attention** This API can only be called when the scan is completed, otherwise it may get wrong value.

**Return**

- ESP_OK: succeed
- ESP_ERR_WIFI_NOT_INIT: WiFi is not initialized by eps_wifi_init
- ESP_ERR_WIFI_NOT_STARTED: WiFi is not started by esp_wifi_start
- ESP_ERR_WIFI_ARG: invalid argument

**Parameters**

- `number`: store number of APIs found in last scan

esp_err_t **esp_wifi_scan_get_ap_records**(uint16_t **number*, wifi_ap_record_t **ap_records*)
Get AP list found in last scan.

**Return**

- ESP_OK: succeed
- ESP_ERR_WIFI_NOT_INIT: WiFi is not initialized by eps_wifi_init
- ESP_ERR_WIFI_NOT_STARTED: WiFi is not started by esp_wifi_start
- ESP_ERR_WIFI_ARG: invalid argument
- ESP_ERR_WIFI_NO_MEM: out of memory

**Parameters**

- `number`: As input param, it stores max AP number ap_records can hold. As output param, it receives the actual AP number this API returns.
- `ap_records`: wifi_ap_record_t array to hold the found APs

esp_err_t **esp_wifi_sta_get_ap_info**(wifi_ap_record_t **ap_info*)

Get information of AP which the ESP32 station is associated with.

**Return**

- ESP_OK: succeed
- others: fail

**Parameters**

- `ap_info`: the wifi_ap_record_t to hold AP information

esp_err_t **esp_wifi_set_ps**(wifi_ps_type_t *type*)

Set current power save type.

**Attention** Default power save type is WIFI_PS_NONE.

**Return** ESP_ERR_WIFI_NOT_SUPPORT: not supported yet

**Parameters**

- `type`: power save type

esp_err_t **esp_wifi_get_ps**(wifi_ps_type_t **type*)

Get current power save type.

**Attention** Default power save type is WIFI_PS_NONE.

**Return** ESP_ERR_WIFI_NOT_SUPPORT: not supported yet

**Parameters**

- `type`: store current power save type

esp_err_t **esp_wifi_set_protocol**(wifi_interface_t *ifx*, uint8_t *protocol_bitmap*)

Set protocol type of specified interface The default protocol is (WIFI_PROTOCOL_11B|WIFI_PROTOCOL_11G|WIFI_PROTOC

**Attention** Currently we only support 802.11b or 802.11bg or 802.11bgn mode

**Return**

- ESP_OK: succeed
- ESP_ERR_WIFI_NOT_INIT: WiFi is not initialized by eps_wifi_init
- ESP_ERR_WIFI_IF: invalid interface
- others: refer to error codes in esp_err.h

**Parameters**

- `ifx`: interfaces
- `protocol_bitmap`: WiFi protocol bitmap

esp_err_t **esp_wifi_get_protocol**(wifi_interface_t *ifx*, uint8_t **protocol_bitmap*)

Get the current protocol bitmap of the specified interface.

**Return**

- ESP_OK: succeed
- ESP_ERR_WIFI_NOT_INIT: WiFi is not initialized by eps_wifi_init
- ESP_ERR_WIFI_IF: invalid interface
- ESP_ERR_WIFI_ARG: invalid argument
- others: refer to error codes in esp_err.h

**Parameters**

- `ifx`: interface
- `protocol_bitmap`: store current WiFi protocol bitmap of interface ifx

esp_err_t **esp_wifi_set_bandwidth**(wifi_interface_t *ifx*, wifi_bandwidth_t *bw*)
Set the bandwidth of ESP32 specified interface.

**Attention** 1. API return false if try to configure an interface that is not enabled

**Attention** 2. WIFI_BW_HT40 is supported only when the interface support 11N

**Return**

- ESP_OK: succeed
- ESP_ERR_WIFI_NOT_INIT: WiFi is not initialized by eps_wifi_init
- ESP_ERR_WIFI_IF: invalid interface
- ESP_ERR_WIFI_ARG: invalid argument
- others: refer to error codes in esp_err.h

**Parameters**

- `ifx`: interface to be configured
- `bw`: bandwidth

esp_err_t **esp_wifi_get_bandwidth**(wifi_interface_t *ifx*, wifi_bandwidth_t **bw*)
Get the bandwidth of ESP32 specified interface.

**Attention** 1. API return false if try to get a interface that is not enable

**Return**

- ESP_OK: succeed
- ESP_ERR_WIFI_NOT_INIT: WiFi is not initialized by eps_wifi_init
- ESP_ERR_WIFI_IF: invalid interface
- ESP_ERR_WIFI_ARG: invalid argument

**Parameters**

- `ifx`: interface to be configured
- `bw`: store bandwidth of interface ifx

esp_err_t **esp_wifi_set_channel**(uint8_t *primary*, wifi_second_chan_t *second*)
Set primary/secondary channel of ESP32.

**Attention** 1. This is a special API for sniffer

**Attention** 2. This API should be called after esp_wifi_start() or esp_wifi_set_promiscuous()

**Return**

- ESP_OK: succeed
- ESP_ERR_WIFI_NOT_INIT: WiFi is not initialized by eps_wifi_init
- ESP_ERR_WIFI_IF: invalid interface
- ESP_ERR_WIFI_ARG: invalid argument

**Parameters**

- `primary`: for HT20, primary is the channel number, for HT40, primary is the primary channel
- `second`: for HT20, second is ignored, for HT40, second is the second channel

esp_err_t **esp_wifi_get_channel**(uint8_t **primary*, wifi_second_chan_t **second*)

Get the primary/secondary channel of ESP32.

**Attention** 1. API return false if try to get a interface that is not enable

**Return**

- ESP_OK: succeed
- ESP_ERR_WIFI_NOT_INIT: WiFi is not initialized by eps_wifi_init
- ESP_ERR_WIFI_ARG: invalid argument

**Parameters**

- `primary`: store current primary channel
- `second`: store current second channel

esp_err_t **esp_wifi_set_country**(wifi_country_t *country*)

Set country code The default value is WIFI_COUNTRY_CN.

**Return**

- ESP_OK: succeed
- ESP_ERR_WIFI_NOT_INIT: WiFi is not initialized by eps_wifi_init
- ESP_ERR_WIFI_ARG: invalid argument
- others: refer to error code in esp_err.h

**Parameters**

- `country`: country type

esp_err_t **esp_wifi_get_country**(wifi_country_t **country*)

Get country code.

**Return**

- ESP_OK: succeed
- ESP_ERR_WIFI_NOT_INIT: WiFi is not initialized by eps_wifi_init
- ESP_ERR_WIFI_ARG: invalid argument

**Parameters**

- `country`: store current country

esp_err_t **esp_wifi_set_mac** (wifi_interface_t *ifx*, uint8_t *mac*[6])

Set MAC address of the ESP32 WiFi station or the soft-AP interface.

**Attention** 1. This API can only be called when the interface is disabled

**Attention** 2. ESP32 soft-AP and station have different MAC addresses, do not set them to be the same.

**Attention** 3. The bit 0 of the first byte of ESP32 MAC address can not be 1. For example, the MAC address can set to be "1a:XX:XX:XX:XX:XX", but can not be "15:XX:XX:XX:XX:XX".

**Return**

- ESP_OK: succeed
- ESP_ERR_WIFI_NOT_INIT: WiFi is not initialized by eps_wifi_init
- ESP_ERR_WIFI_ARG: invalid argument
- ESP_ERR_WIFI_IF: invalid interface
- ESP_ERR_WIFI_MAC: invalid mac address
- ESP_ERR_WIFI_MODE: WiFi mode is wrong
- others: refer to error codes in esp_err.h

**Parameters**

- `ifx`: interface
- `mac`: the MAC address

esp_err_t **esp_wifi_get_mac** (wifi_interface_t *ifx*, uint8_t *mac*[6])

Get mac of specified interface.

**Return**

- ESP_OK: succeed
- ESP_ERR_WIFI_NOT_INIT: WiFi is not initialized by eps_wifi_init
- ESP_ERR_WIFI_ARG: invalid argument
- ESP_ERR_WIFI_IF: invalid interface

**Parameters**

- `ifx`: interface
- `mac`: store mac of the interface ifx

esp_err_t **esp_wifi_set_promiscuous_rx_cb** (*wifi_promiscuous_cb_t cb*)

Register the RX callback function in the promiscuous mode.

Each time a packet is received, the registered callback function will be called.

**Return**

- ESP_OK: succeed
- ESP_ERR_WIFI_NOT_INIT: WiFi is not initialized by eps_wifi_init

**Parameters**

- `cb`: callback

esp_err_t **`esp_wifi_set_promiscuous`** (bool *en*)
Enable the promiscuous mode.

**Return**

- ESP_OK: succeed
- ESP_ERR_WIFI_NOT_INIT: WiFi is not initialized by eps_wifi_init

**Parameters**

- `en`: false - disable, true - enable

esp_err_t **`esp_wifi_get_promiscuous`** (bool **en*)
Get the promiscuous mode.

**Return**

- ESP_OK: succeed
- ESP_ERR_WIFI_NOT_INIT: WiFi is not initialized by eps_wifi_init
- ESP_ERR_WIFI_ARG: invalid argument

**Parameters**

- `en`: store the current status of promiscuous mode

esp_err_t **`esp_wifi_set_config`** (wifi_interface_t *ifx*, wifi_config_t **conf*)
Set the configuration of the ESP32 STA or AP.

**Attention** 1. This API can be called only when specified interface is enabled, otherwise, API fail

**Attention** 2. For station configuration, bssid_set needs to be 0; and it needs to be 1 only when users need to check the MAC address of the AP.

**Attention** 3. ESP32 is limited to only one channel, so when in the soft-AP+station mode, the soft-AP will adjust its channel automatically to be the same as the channel of the ESP32 station.

**Return**

- ESP_OK: succeed
- ESP_ERR_WIFI_NOT_INIT: WiFi is not initialized by eps_wifi_init
- ESP_ERR_WIFI_ARG: invalid argument
- ESP_ERR_WIFI_IF: invalid interface
- ESP_ERR_WIFI_MODE: invalid mode
- ESP_ERR_WIFI_PASSWORD: invalid password
- ESP_ERR_WIFI_NVS: WiFi internal NVS error
- others: refer to the erro code in esp_err.h

**Parameters**

- `ifx`: interface
- `conf`: station or soft-AP configuration

esp_err_t **esp_wifi_get_config** (wifi_interface_t *ifx*, wifi_config_t **conf*)
Get configuration of specified interface.

**Return**

- ESP_OK: succeed
- ESP_ERR_WIFI_NOT_INIT: WiFi is not initialized by eps_wifi_init
- ESP_ERR_WIFI_ARG: invalid argument
- ESP_ERR_WIFI_IF: invalid interface

**Parameters**

- `ifx`: interface
- `conf`: station or soft-AP configuration

esp_err_t **esp_wifi_ap_get_sta_list** (wifi_sta_list_t **sta*)
Get STAs associated with soft-AP.

**Attention** SSC only API

**Return**

- ESP_OK: succeed
- ESP_ERR_WIFI_NOT_INIT: WiFi is not initialized by eps_wifi_init
- ESP_ERR_WIFI_ARG: invalid argument
- ESP_ERR_WIFI_MODE: WiFi mode is wrong
- ESP_ERR_WIFI_CONN: WiFi internal error, the station/soft-AP control block is invalid

**Parameters**

- `sta`: station list

esp_err_t **esp_wifi_set_storage** (wifi_storage_t *storage*)
Set the WiFi API configuration storage type.

**Attention** 1. The default value is WIFI_STORAGE_FLASH

**Return**

- ESP_OK: succeed
- ESP_ERR_WIFI_NOT_INIT: WiFi is not initialized by eps_wifi_init
- ESP_ERR_WIFI_ARG: invalid argument

**Parameters**

- `storage`: : storage type

esp_err_t **esp_wifi_set_auto_connect** (bool *en*)
Set auto connect The default value is true.

**Return**

- ESP_OK: succeed
- ESP_ERR_WIFI_NOT_INIT: WiFi is not initialized by eps_wifi_init

- ESP_ERR_WIFI_MODE: WiFi internal error, the station/soft-AP control block is invalid
- others: refer to error code in esp_err.h

**Parameters**

- `en`: : true - enable auto connect / false - disable auto connect

esp_err_t **`esp_wifi_get_auto_connect`** (bool **en*)

Get the auto connect flag.

**Return**

- ESP_OK: succeed
- ESP_ERR_WIFI_NOT_INIT: WiFi is not initialized by eps_wifi_init
- ESP_ERR_WIFI_ARG: invalid argument

**Parameters**

- `en`: store current auto connect configuration

esp_err_t **`esp_wifi_set_vendor_ie`** (bool *enable*, wifi_vendor_ie_type_t *type*, wifi_vendor_ie_id_t *idx*, uint8_t **vnd_ie*)

Set vendor specific element.

**Return**

- ESP_OK: succeed
- ESP_ERR_WIFI_NOT_INIT: WiFi is not initialized by eps_wifi_init
- ESP_ERR_WIFI_ARG: invalid argument
- ESP_ERR_WIFI_NO_MEM: out of memory

**Parameters**

- `enable`: enable or not
- `type`: information element type
- `idx`: information element index
- `vnd_ie`: pointer to a vendor specific element

esp_err_t **`esp_wifi_set_vendor_ie_cb`** (*esp_vendor_ie_cb_t* *cb*, void **ctx*)

Set vendor specific element callback.

**Return**

- ESP_OK: succeed
- ESP_ERR_WIFI_NOT_INIT: WiFi is not initialized by eps_wifi_init

**Parameters**

- `cb`: callback function
- `ctx`: reserved

# Smart Config

## API Reference

### Header Files

- esp32/include/esp_smartconfig.h

### Type Definitions

**typedef** void (***sc_callback_t**) (smartconfig_status_t status, void *pdata)
The callback of SmartConfig, executed when smart-config status changed.

**Parameters**

- `status`: Status of SmartConfig:
  - SC_STATUS_GETTING_SSID_PSWD : pdata is a pointer of smartconfig_type_t, means config type.
  - SC_STATUS_LINK : pdata is a pointer of struct station_config.
  - SC_STATUS_LINK_OVER : pdata is a pointer of phone's IP address(4 bytes) if pdata unequal NULL.
  - otherwise : parameter void *pdata is NULL.
- `pdata`: According to the different status have different values.

### Functions

**const** char ***esp_smartconfig_get_version** (void)
Get the version of SmartConfig.

**Return**

- SmartConfig version const char.

esp_err_t **esp_smartconfig_start** (*sc_callback_t cb*, ...)
Start SmartConfig, config ESP device to connect AP. You need to broadcast information by phone APP. Device sniffer special packets from the air that containing SSID and password of target AP.

**Attention** 1. This API can be called in station or softAP-station mode.

**Attention** 2. Can not call esp_smartconfig_start twice before it finish, please call esp_smartconfig_stop first.

**Return**

- ESP_OK: succeed
- others: fail

**Parameters**

- `cb`: SmartConfig callback function.
- `...`: log 1: UART output logs; 0: UART only outputs the result.

esp_err_t **esp_smartconfig_stop**(void)
Stop SmartConfig, free the buffer taken by esp_smartconfig_start.

**Attention** Whether connect to AP succeed or not, this API should be called to free memory taken by smartconfig_start.

**Return**

- ESP_OK: succeed
- others: fail

esp_err_t **esp_esptouch_set_timeout**(uint8_t *time_s*)
Set timeout of SmartConfig process.

**Attention** Timing starts from SC_STATUS_FIND_CHANNEL status. SmartConfig will restart if timeout.

**Return**

- ESP_OK: succeed
- others: fail

**Parameters**

- `time_s`: range 15s~255s, offset:45s.

esp_err_t **esp_smartconfig_set_type**(smartconfig_type_t *type*)
Set protocol type of SmartConfig.

**Attention** If users need to set the SmartConfig type, please set it before calling esp_smartconfig_start.

**Return**

- ESP_OK: succeed
- others: fail

**Parameters**

- `type`: Choose from the smartconfig_type_t.

esp_err_t **esp_smartconfig_fast_mode**(bool *enable*)
Set mode of SmartConfig. default normal mode.

**Attention** 1. Please call it before API esp_smartconfig_start.

**Attention** 2. Fast mode have corresponding APP(phone).

**Attention** 3. Two mode is compatible.

**Return**

- ESP_OK: succeed
- others: fail

**Parameters**

- `enable`: false-disable(default); true-enable;

Example code for this API section is provided in wifi directory of ESP-IDF examples.

CHAPTER 18

# Bluetooth API

## Controller && VHCI

### Overview

Instructions

### Application Example

Check bluetooth folder in ESP-IDF examples, which contains the following example:

bluetooth/ble_adv

This is a BLE advertising demo with virtual HCI interface. Send Reset/ADV_PARAM/ADV_DATA/ADV_ENABLE HCI command for BLE advertising.

### API Reference

#### Header Files

- bt/include/bt.h

#### Type Definitions

**typedef struct** *esp_vhci_host_callback* **`esp_vhci_host_callback_t`**

*esp_vhci_host_callback* used for vhci call host function to notify what host need to do

### Enumerations

**enum esp_bt_mode_t**
Bluetooth mode for controller enable/disable.

*Values:*

**ESP_BT_MODE_IDLE** = 0x00
Bluetooth is not running

**ESP_BT_MODE_BLE** = 0x01
Run BLE mode

**ESP_BT_MODE_CLASSIC_BT** = 0x02
Run Classic BT mode

**ESP_BT_MODE_BTDM** = 0x03
Run dual mode

### Structures

**struct esp_vhci_host_callback**
*esp_vhci_host_callback* used for vhci call host function to notify what host need to do

#### Public Members

void (***notify_host_send_available**) (void)
callback used to notify that the host can send packet to controller

int (***notify_host_recv**) (uint8_t *data, uint16_t len)
callback used to notify that the controller has a packet to send to the host

### Functions

void **esp_bt_controller_init** (void)
Initialize BT controller to allocate task and other resource.

This function should be called only once, before any other BT functions are called.

void **esp_bt_controller_deinit** (void)
De-initialize BT controller to free resource and delete task.

This function should be called only once, after any other BT functions are called. This function is not whole completed, esp_bt_controller_init cannot called after this function.

esp_err_t **esp_bt_controller_enable** (*esp_bt_mode_t mode*)
Enable BT controller.

**Return** ESP_OK - success, other - failed

**Parameters**

- `mode`: : the mode(BLE/BT/BTDM) to enable. Now only support BTDM.

esp_err_t **esp_bt_controller_disable** (*esp_bt_mode_t mode*)
Disable BT controller.

**Return** ESP_OK - success, other - failed

**Parameters**

- `mode`: : the mode(BLE/BT/BTDM) to disable. Now only support BTDM.

esp_bt_controller_status_t **esp_bt_controller_get_status**(void)
Get BT controller is initialised/de-initialised/enabled/disabled.

**Return** status value

bool **esp_vhci_host_check_send_available**(void)
esp_vhci_host_check_send_available used for check actively if the host can send packet to controller or not.

**Return** true for ready to send, false means cannot send packet

void **esp_vhci_host_send_packet**(uint8_t **data*, uint16_t *len*)
esp_vhci_host_send_packet host send packet to controller

**Parameters**

- `data`: the packet point ,
- `len`: the packet length

void **esp_vhci_host_register_callback**(**const** *esp_vhci_host_callback_t* **callback*)
esp_vhci_host_register_callback register the vhci referece callback, the call back struct defined by vhci_host_callback structure.

**Parameters**

- `callback`: *esp_vhci_host_callback* type variable

# BT COMMON

## BT GENERIC DEFINES

### Overview

Instructions

### Application Example

Instructions

### API Reference

### Header Files

- bt/bluedroid/api/include/esp_bt_defs.h

### Macros

**ESP_DEFAULT_GATT_IF** 0xff
Default GATT interface id.

**ESP_BLE_CONN_PARAM_UNDEF** 0xffff /* use this value when a specific value not to be overwritten */
Default BLE connection param, if the value doesn't be overwritten.

**ESP_BLE_IS_VALID_PARAM**(x, min, max) (((x) >= (min) && (x) <= (max)) || ((x) == ESP_BLE_CONN_PARAM_UNDEF))
Check the param is valid or not.

**ESP_UUID_LEN_16** 2

**ESP_UUID_LEN_32** 4

**ESP_UUID_LEN_128** 16

**ESP_BD_ADDR_LEN** 6
Bluetooth address length.

**ESP_APP_ID_MIN** 0x0000
Minimum of the application id.

**ESP_APP_ID_MAX** 0x7fff
Maximum of the application id.

### Type Definitions

**typedef** uint8_t **esp_bd_addr_t**[ESP_BD_ADDR_LEN]
Bluetooth device address.

### Enumerations

**enum esp_bt_status_t**
Status Return Value.

*Values:*

**ESP_BT_STATUS_SUCCESS** = 0

**ESP_BT_STATUS_FAILURE** = 1

**ESP_BT_STATUS_PENDING** = 2

**ESP_BT_STATUS_BUSY** = 3

**ESP_BT_STATUS_NO_RESOURCES** = 4

**ESP_BT_STATUS_WRONG_MODE** = 5

**enum esp_bt_dev_type_t**
Bluetooth device type.

*Values:*

**ESP_BT_DEVICE_TYPE_BREDR** = 0x01

**ESP_BT_DEVICE_TYPE_BLE** = 0x02

**ESP_BT_DEVICE_TYPE_DUMO** = 0x03

**enum esp_bd_addr_type_t**
Own BD address source of the device.

*Values:*

**BD_ADDR_PUBLIC**
Public Address.

**BD_ADDR_PROVIDED_RND**
Provided random address.

**BD_ADDR_GEN_STATIC_RND**
Provided static random address.

**BD_ADDR_GEN_RSLV**
Generated resolvable private random address.

**BD_ADDR_GEN_NON_RSLV**
Generated non-resolvable private random address.

**BD_ADDR_PROVIDED_RECON**
Provided Reconnection address.

**enum esp_ble_addr_type_t**
BLE device address type.

*Values:*

**BLE_ADDR_TYPE_PUBLIC** = 0x00

**BLE_ADDR_TYPE_RANDOM** = 0x01

**BLE_ADDR_TYPE_RPA_PUBLIC** = 0x02

**BLE_ADDR_TYPE_RPA_RANDOM** = 0x03

### Structures

### Functions

## BT MAIN API

### Overview

Instructions

### Application Example

Instructions

### API Reference

### Header Files

- bt/bluedroid/api/include/esp_bt_main.h

### Macros

### Type Definitions

### Enumerations

**enum esp_bluedroid_status_t**
Bluetooth stack status type, to indicate whether the bluetooth stack is ready.

*Values:*

**ESP_BLUEDROID_STATUS_UNINITIALIZED** = 0
Bluetooth not initialized

**ESP_BLUEDROID_STATUS_INITIALIZED**
Bluetooth initialized but not enabled

**ESP_BLUEDROID_STATUS_ENABLED**
Bluetooth initialized and enabled

### Structures

### Functions

*esp_bluedroid_status_t* **esp_bluedroid_get_status** (void)
Get bluetooth stack status.

**Return** Bluetooth stack status

esp_err_t **esp_bluedroid_enable** (void)
Enable bluetooth, must after esp_bluedroid_init()

**Return**

- ESP_OK : Succeed
- Other : Failed

esp_err_t **esp_bluedroid_disable** (void)
Disable bluetooth, must prior to esp_bluedroid_deinit()

**Return**

- ESP_OK : Succeed
- Other : Failed

esp_err_t **esp_bluedroid_init** (void)
Init and alloc the resource for bluetooth, must be prior to every bluetooth stuff.

**Return**

- ESP_OK : Succeed
- Other : Failed

esp_err_t **esp_bluedroid_deinit** (void)
Deinit and free the resource for bluetooth, must be after every bluetooth stuff.

**Return**

- ESP_OK : Succeed
- Other : Failed

## BT DEVICE APIs

### Overview

Bluetooth device reference APIs.

Instructions

### Application Example

Instructions

### API Reference

### Header Files

- bt/bluedroid/api/include/esp_bt_device.h

### Macros

### Type Definitions

### Enumerations

### Structures

### Functions

**const** uint8_t ***esp_bt_dev_get_address** (void)
Get bluetooth device address. Must use after "esp_bluedroid_enable".

**Return** bluetooth device address (six bytes), or NULL if bluetooth stack is not enabled

# BT COMMON

## GAP API

### Overview

Instructions

### Application Example

Check bluetooth folder in ESP-IDF examples, which contains the following examples:

bluetooth/gatt_server, bluetooth/gatt_client

The two demos use different GAP APIs, such like advertising, scan, set device name and others.

### API Reference

### Header Files

- bt/bluedroid/api/include/esp_gap_ble_api.h

### Macros

**ESP_BLE_ADV_FLAG_LIMIT_DISC** (0x01 << 0)
BLE_ADV_DATA_FLAG data flag bit definition used for advertising data flag

**ESP_BLE_ADV_FLAG_GEN_DISC** (0x01 << 1)

**ESP_BLE_ADV_FLAG_BREDR_NOT_SPT** (0x01 << 2)

**ESP_BLE_ADV_FLAG_DMT_CONTROLLER_SPT** (0x01 << 3)

**ESP_BLE_ADV_FLAG_DMT_HOST_SPT** (0x01 << 4)

**ESP_BLE_ADV_FLAG_NON_LIMIT_DISC** (0x00 )

**ESP_BLE_ADV_DATA_LEN_MAX** 31
Advertising data maximum length.

**ESP_BLE_SCAN_RSP_DATA_LEN_MAX** 31
Scan response data maximum length.

### Type Definitions

**typedef** void (***esp_gap_ble_cb_t**)(*esp_gap_ble_cb_event_t* event, esp_ble_gap_cb_param_t *param)
GAP callback function type.

**Parameters**

- `event`: : Event type
- `param`: : Point to callback parameter, currently is union type

### Enumerations

**enum esp_gap_ble_cb_event_t**
GAP BLE callback event type.

*Values:*

**ESP_GAP_BLE_ADV_DATA_SET_COMPLETE_EVT** = 0
When advertising data set complete, the event comes

**ESP_GAP_BLE_SCAN_RSP_DATA_SET_COMPLETE_EVT**
When scan response data set complete, the event comes

**ESP_GAP_BLE_SCAN_PARAM_SET_COMPLETE_EVT**
When scan parameters set complete, the event comes

**ESP_GAP_BLE_SCAN_RESULT_EVT**
When one scan result ready, the event comes each time

**ESP_GAP_BLE_ADV_DATA_RAW_SET_COMPLETE_EVT**
When raw advertising data set complete, the event comes

**ESP_GAP_BLE_SCAN_RSP_DATA_RAW_SET_COMPLETE_EVT**
When raw advertising data set complete, the event comes

**ESP_GAP_BLE_ADV_START_COMPLETE_EVT**
When start advertising complete, the event comes

**ESP_GAP_BLE_SCAN_START_COMPLETE_EVT**
When start scan complete, the event comes

**enum esp_ble_adv_data_type**
The type of advertising data(not adv_type)

*Values:*

**ESP_BLE_AD_TYPE_FLAG** = 0x01

**ESP_BLE_AD_TYPE_16SRV_PART** = 0x02

**ESP_BLE_AD_TYPE_16SRV_CMPL** = 0x03

**ESP_BLE_AD_TYPE_32SRV_PART** = 0x04

**ESP_BLE_AD_TYPE_32SRV_CMPL** = 0x05

**ESP_BLE_AD_TYPE_128SRV_PART** = 0x06

**ESP_BLE_AD_TYPE_128SRV_CMPL** = 0x07

**ESP_BLE_AD_TYPE_NAME_SHORT** = 0x08

**ESP_BLE_AD_TYPE_NAME_CMPL** = 0x09

**ESP_BLE_AD_TYPE_TX_PWR** = 0x0A

**ESP_BLE_AD_TYPE_DEV_CLASS** = 0x0D

**ESP_BLE_AD_TYPE_SM_TK** = 0x10

**ESP_BLE_AD_TYPE_SM_OOB_FLAG** = 0x11

**ESP_BLE_AD_TYPE_INT_RANGE** = 0x12

**ESP_BLE_AD_TYPE_SOL_SRV_UUID** = 0x14

**ESP_BLE_AD_TYPE_128SOL_SRV_UUID** = 0x15

**ESP_BLE_AD_TYPE_SERVICE_DATA** = 0x16

**ESP_BLE_AD_TYPE_PUBLIC_TARGET** = 0x17

**ESP_BLE_AD_TYPE_RANDOM_TARGET** = 0x18

**ESP_BLE_AD_TYPE_APPEARANCE** = 0x19

**ESP_BLE_AD_TYPE_ADV_INT** = 0x1A

**ESP_BLE_AD_TYPE_32SOL_SRV_UUID** = 0x1B

**ESP_BLE_AD_TYPE_32SERVICE_DATA** = 0x1C

**ESP_BLE_AD_TYPE_128SERVICE_DATA** = 0x1D

**ESP_BLE_AD_MANUFACTURER_SPECIFIC_TYPE** = 0xFF

**enum esp_ble_adv_type_t**
Advertising mode.

*Values:*

**ADV_TYPE_IND** = 0x00

**ADV_TYPE_DIRECT_IND_HIGH** = 0x01

**ADV_TYPE_SCAN_IND** = 0x02

**ADV_TYPE_NONCONN_IND** = 0x03

**ADV_TYPE_DIRECT_IND_LOW** = 0x04

**enum esp_ble_adv_channel_t**
Advertising channel mask.

*Values:*

**ADV_CHNL_37** = 0x01

**ADV_CHNL_38** = 0x02

**ADV_CHNL_39** = 0x04

**ADV_CHNL_ALL** = 0x07

**enum esp_ble_adv_filter_t**
*Values:*

**ADV_FILTER_ALLOW_SCAN_ANY_CON_ANY** = 0x00
Allow both scan and connection requests from anyone.

**ADV_FILTER_ALLOW_SCAN_WLST_CON_ANY**
Allow both scan req from White List devices only and connection req from anyone.

**ADV_FILTER_ALLOW_SCAN_ANY_CON_WLST**
Allow both scan req from anyone and connection req from White List devices only.

**ADV_FILTER_ALLOW_SCAN_WLST_CON_WLST**
Allow scan and connection requests from White List devices only.

**enum esp_ble_own_addr_src_t**
Own BD address source of the device.

*Values:*

**ESP_PUBLIC_ADDR**
Public Address.

**ESP_PROVIDED_RND_ADDR**
Provided random address.

**ESP_GEN_STATIC_RND_ADDR**
Provided static random address.

**ESP_GEN_RSLV_ADDR**
Generated resolvable private random address.

**ESP_GEN_NON_RSLV_ADDR**
Generated non-resolvable private random address.

**ESP_PROVIDED_RECON_ADDR**
Provided Reconnection address.

**enum esp_ble_scan_type_t**
Ble scan type.

*Values:*

**BLE_SCAN_TYPE_PASSIVE** = 0x0
Passive scan

**BLE_SCAN_TYPE_ACTIVE** = 0x1
Active scan

**enum esp_ble_scan_filter_t**
Ble scan filter type.

*Values:*

**BLE_SCAN_FILTER_ALLOW_ALL** = 0x0
Accept all :

1.advertisement packets except directed advertising packets not addressed to this device (default).

**BLE_SCAN_FILTER_ALLOW_ONLY_WLST** = 0x1
Accept only :

1.advertisement packets from devices where the advertiser's address is in the White list.

2.Directed advertising packets which are not addressed for this device shall be ignored.

**BLE_SCAN_FILTER_ALLOW_UND_RPA_DIR** = 0x2
Accept all :

1.undirected advertisement packets, and

2.directed advertising packets where the initiator address is a resolvable private address, and

3.directed advertising packets addressed to this device.

**BLE_SCAN_FILTER_ALLOW_WLIST_PRA_DIR** = 0x3
Accept all :

1.advertisement packets from devices where the advertiser's address is in the White list, and

2.directed advertising packets where the initiator address is a resolvable private address, and

3.directed advertising packets addressed to this device.

**enum esp_gap_search_evt_t**
Sub Event of ESP_GAP_BLE_SCAN_RESULT_EVT.

*Values:*

**ESP_GAP_SEARCH_INQ_RES_EVT** = 0
Inquiry result for a peer device.

**ESP_GAP_SEARCH_INQ_CMPL_EVT** = 1
Inquiry complete.

**ESP_GAP_SEARCH_DISC_RES_EVT** = 2
Discovery result for a peer device.

**ESP_GAP_SEARCH_DISC_BLE_RES_EVT** = 3
Discovery result for BLE GATT based service on a peer device.

**ESP_GAP_SEARCH_DISC_CMPL_EVT** = 4
Discovery complete.

**ESP_GAP_SEARCH_DI_DISC_CMPL_EVT** = 5
Discovery complete.

**ESP_GAP_SEARCH_SEARCH_CANCEL_CMPL_EVT** = 6
Search cancelled

**enum esp_ble_evt_type_t**
Ble scan result event type, to indicate the result is scan response or advertising data or other.

*Values:*

**ESP_BLE_EVT_CONN_ADV** = 0x00
Connectable undirected advertising (ADV_IND)

**ESP_BLE_EVT_CONN_DIR_ADV** = 0x01
Connectable directed advertising (ADV_DIRECT_IND)

**ESP_BLE_EVT_DISC_ADV** = 0x02
Scannable undirected advertising (ADV_SCAN_IND)

**ESP_BLE_EVT_NON_CONN_ADV** = 0x03
Non connectable undirected advertising (ADV_NONCONN_IND)

**ESP_BLE_EVT_SCAN_RSP** = 0x04
Scan Response (SCAN_RSP)

## Structures

**struct esp_ble_adv_params_t**
Advertising parameters.

### Public Members

uint16_t **adv_int_min**
Minimum advertising interval for undirected and low duty cycle directed advertising. Range: 0x0020 to 0x4000 Default: N = 0x0800 (1.28 second) Time = N * 0.625 msec Time Range: 20 ms to 10.24 sec

uint16_t **adv_int_max**
Maximum advertising interval for undirected and low duty cycle directed advertising. Range: 0x0020 to 0x4000 Default: N = 0x0800 (1.28 second) Time = N * 0.625 msec Time Range: 20 ms to 10.24 sec Advertising max interval

*esp_ble_adv_type_t* **adv_type**
Advertising type

*esp_ble_addr_type_t* **own_addr_type**
Owner bluetooth device address type

*esp_bd_addr_t* **peer_addr**
Peer device bluetooth device address

*esp_ble_addr_type_t* **peer_addr_type**
Peer device bluetooth device address type

*esp_ble_adv_channel_t* **channel_map**
Advertising channel map

*esp_ble_adv_filter_t* **adv_filter_policy**
Advertising filter policy

**struct esp_ble_adv_data_t**
Advertising data content, according to "Supplement to the Bluetooth Core Specification".

### Public Members

bool **set_scan_rsp**
Set this advertising data as scan response or not

bool **include_name**
Advertising data include device name or not

bool **include_txpower**
Advertising data include TX power

int **min_interval**
Advertising data show advertising min interval

int **max_interval**
Advertising data show advertising max interval

int **appearance**
External appearance of device

uint16_t **manufacturer_len**
Manufacturer data length

uint8_t ***p_manufacturer_data**
Manufacturer data point

uint16_t **service_data_len**
Service data length

uint8_t ***p_service_data**
Service data point

uint16_t **service_uuid_len**
Service uuid length

uint8_t ***p_service_uuid**
Service uuid array point

uint8_t **flag**
Advertising flag of discovery mode, see BLE_ADV_DATA_FLAG detail

**struct esp_ble_scan_params_t**
Ble scan parameters.

### Public Members

*esp_ble_scan_type_t* **scan_type**
Scan type

*esp_ble_addr_type_t* **own_addr_type**
Owner address type

*esp_ble_scan_filter_t* **scan_filter_policy**
Scan filter policy

uint16_t **scan_interval**
Scan interval. This is defined as the time interval from when the Controller started its last LE scan until it begins the subsequent LE scan. Range: 0x0004 to 0x4000 Default: 0x0010 (10 ms) Time = N * 0.625 msec Time Range: 2.5 msec to 10.24 seconds

uint16_t **scan_window**
Scan window. The duration of the LE scan. LE_Scan_Window shall be less than or equal to LE_Scan_Interval Range: 0x0004 to 0x4000 Default: 0x0010 (10 ms) Time = N * 0.625 msec Time Range: 2.5 msec to 10240 msec

**struct esp_ble_conn_update_params_t**
Connection update parameters.

### Public Members

*esp_bd_addr_t* **bda**
Bluetooth device address

uint16_t **min_int**
Min connection interval

uint16_t **max_int**
Max connection interval

uint16_t **latency**
Slave latency for the connection in number of connection events. Range: 0x0000 to 0x01F3

uint16_t **timeout**
Supervision timeout for the LE Link. Range: 0x000A to 0x0C80. Mandatory Range: 0x000A to 0x0C80 Time = N * 10 msec Time Range: 100 msec to 32 seconds

> **Warning:** doxygenstruct: Cannot find class "esp_ble_gap_cb_param_t" in doxygen xml output for project "esp32-idf" from directory: xml/

**struct** esp_ble_gap_cb_param_t::**ble_adv_data_cmpl_evt_param**
ESP_GAP_BLE_ADV_DATA_SET_COMPLETE_EVT.

### Public Members

*esp_bt_status_t* **status**
Indicate the set advertising data operation success status

**struct** esp_ble_gap_cb_param_t::**ble_scan_rsp_data_cmpl_evt_param**
ESP_GAP_BLE_SCAN_RSP_DATA_SET_COMPLETE_EVT.

### Public Members

*esp_bt_status_t* **status**
Indicate the set scan response data operation success status

**struct** esp_ble_gap_cb_param_t::**ble_scan_param_cmpl_evt_param**
ESP_GAP_BLE_SCAN_PARAM_SET_COMPLETE_EVT.

### Public Members

*esp_bt_status_t* **status**
Indicate the set scan param operation success status

**struct** esp_ble_gap_cb_param_t::**ble_scan_result_evt_param**
ESP_GAP_BLE_SCAN_RESULT_EVT.

### Public Members

*esp_gap_search_evt_t* **search_evt**
Search event type

*esp_bd_addr_t* **bda**
Bluetooth device address which has been searched

*esp_bt_dev_type_t* **dev_type**
Device type

*esp_ble_addr_type_t* **ble_addr_type**
Ble device address type

*esp_ble_evt_type_t* **ble_evt_type**
Ble scan result event type

int **rssi**
Searched device's RSSI

uint8_t **ble_adv**[ESP_BLE_ADV_DATA_LEN_MAX+ESP_BLE_SCAN_RSP_DATA_LEN_MAX]
Received EIR

int **flag**
Advertising data flag bit

int **num_resps**
Scan result number

**struct** esp_ble_gap_cb_param_t::**ble_adv_data_raw_cmpl_evt_param**
ESP_GAP_BLE_ADV_DATA_RAW_SET_COMPLETE_EVT.

### Public Members

*esp_bt_status_t* **status**
Indicate the set raw advertising data operation success status

**struct** esp_ble_gap_cb_param_t::**ble_scan_rsp_data_raw_cmpl_evt_param**
ESP_GAP_BLE_SCAN_RSP_DATA_RAW_SET_COMPLETE_EVT.

#### Public Members

*esp_bt_status_t* **status**
Indicate the set raw advertising data operation success status

**struct** esp_ble_gap_cb_param_t::**ble_adv_start_cmpl_evt_param**
ESP_GAP_BLE_ADV_START_COMPLETE_EVT.

#### Public Members

*esp_bt_status_t* **status**
Indicate advertising start operation success status

**struct** esp_ble_gap_cb_param_t::**ble_scan_start_cmpl_evt_param**
ESP_GAP_BLE_SCAN_START_COMPLETE_EVT.

#### Public Members

*esp_bt_status_t* **status**
Indicate scan start operation success status

### Functions

esp_err_t **esp_ble_gap_register_callback**(*esp_gap_ble_cb_t callback*)
This function is called to occur gap event, such as scan result.

**Return**

- ESP_OK : success
- other : failed

**Parameters**

- `callback`: callback function

esp_err_t **esp_ble_gap_config_adv_data**(*esp_ble_adv_data_t *adv_data*)
This function is called to override the BTA default ADV parameters.

**Return**

- ESP_OK : success
- other : failed

**Parameters**

- `adv_data`: Pointer to User defined ADV data structure. This memory space can not be freed until callback of config_adv_data is received.

esp_err_t **esp_ble_gap_set_scan_params**(*esp_ble_scan_params_t *scan_params*)
This function is called to set scan parameters.

**Return**

- ESP_OK : success

- other : failed

**Parameters**

- `scan_params`: Pointer to User defined scan_params data structure. This memory space can not be freed until callback of set_scan_params

esp_err_t **esp_ble_gap_start_scanning**(uint32_t *duration*)

This procedure keep the device scanning the peer device which advertising on the air.

**Return**

- ESP_OK : success
- other : failed

**Parameters**

- `duration`: Keeping the scanning time, the unit is second.

esp_err_t **esp_ble_gap_stop_scanning**(void)

This function call to stop the device scanning the peer device which advertising on the air.

**Return**

- ESP_OK : success
  - other : failed

esp_err_t **esp_ble_gap_start_advertising**(*esp_ble_adv_params_t* **adv_params*)

This function is called to start advertising.

**Return**

- ESP_OK : success
- other : failed

**Parameters**

- `adv_params`: pointer to User defined adv_params data structure.

esp_err_t **esp_ble_gap_stop_advertising**(void)

This function is called to stop advertising.

**Return**

- ESP_OK : success
- other : failed

esp_err_t **esp_ble_gap_update_conn_params**(*esp_ble_conn_update_params_t* **params*)

Update connection parameters, can only be used when connection is up.

**Return**

- ESP_OK : success
- other : failed

**Parameters**

- `params`: - connection update parameters

esp_err_t **esp_ble_gap_set_pkt_data_len** (*esp_bd_addr_t remote_device*, uint16_t *tx_data_length*)
This function is to set maximum LE data packet size.

**Return**

- ESP_OK : success
- other : failed

esp_err_t **esp_ble_gap_set_rand_addr** (*esp_bd_addr_t rand_addr*)
This function set the random address for the application.

**Return**

- ESP_OK : success
- other : failed

**Parameters**

- `rand_addr`: the random address which should be setting

esp_err_t **esp_ble_gap_config_local_privacy** (bool *privacy_enable*)
Enable/disable privacy on the local device.

**Return**

- ESP_OK : success
- other : failed

**Parameters**

- `privacy_enable`: - enable/disable privacy on remote device.

esp_err_t **esp_ble_gap_set_device_name** (**const** char **name*)
Set device name to the local device.

**Return**

- ESP_OK : success
- other : failed

**Parameters**

- `name`: - device name.

uint8_t ***esp_ble_resolve_adv_data** (uint8_t **adv_data*, uint8_t *type*, uint8_t **length*)
This function is called to get ADV data for a specific type.

**Return** - ESP_OK : success

- other : failed

**Parameters**

- `adv_data`: - pointer of ADV data which to be resolved
- `type`: - finding ADV data type
- `length`: - return the length of ADV data not including type

esp_err_t **esp_ble_gap_config_adv_data_raw**(uint8_t **raw_data*, uint32_t *raw_data_len*)
This function is called to set raw advertising data. User need to fill ADV data by self.

**Return**

- ESP_OK : success
- other : failed

**Parameters**

- `raw_data`: : raw advertising data
- `raw_data_len`: : raw advertising data length , less than 31 bytes

esp_err_t **esp_ble_gap_config_scan_rsp_data_raw**(uint8_t **raw_data*, uint32_t *raw_data_len*)
This function is called to set raw scan response data. User need to fill scan response data by self.

**Return**

- ESP_OK : success
- other : failed

**Parameters**

- `raw_data`: : raw scan response data
- `raw_data_len`: : raw scan response data length , less than 31 bytes

## GATT DEFINES

### Overview

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### Application Example

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### API Reference

### Header Files

- bt/bluedroid/api/include/esp_gatt_defs.h

### Macros

**ESP_GATT_UUID_IMMEDIATE_ALERT_SVC** 0x1802 /* Immediate alert Service*/
All "ESP_GATT_UUID_xxx" is attribute types

**ESP_GATT_UUID_LINK_LOSS_SVC** 0x1803 /* Link Loss Service*/

**ESP_GATT_UUID_TX_POWER_SVC** 0x1804 /* TX Power Service*/

**ESP_GATT_UUID_CURRENT_TIME_SVC** 0x1805 /* Current Time Service Service*/

**ESP_GATT_UUID_REF_TIME_UPDATE_SVC** 0x1806 /* Reference Time Update Service*/

**ESP_GATT_UUID_NEXT_DST_CHANGE_SVC** 0x1807 /* Next DST Change Service*/

**ESP_GATT_UUID_GLUCOSE_SVC** 0x1808 /* Glucose Service*/

**ESP_GATT_UUID_HEALTH_THERMOM_SVC** 0x1809 /* Health Thermometer Service*/

**ESP_GATT_UUID_DEVICE_INFO_SVC** 0x180A /* Device Information Service*/

**ESP_GATT_UUID_HEART_RATE_SVC** 0x180D /* Heart Rate Service*/

**ESP_GATT_UUID_PHONE_ALERT_STATUS_SVC** 0x180E /* Phone Alert Status Service*/

**ESP_GATT_UUID_BATTERY_SERVICE_SVC** 0x180F /* Battery Service*/

**ESP_GATT_UUID_BLOOD_PRESSURE_SVC** 0x1810 /* Blood Pressure Service*/

**ESP_GATT_UUID_ALERT_NTF_SVC** 0x1811 /* Alert Notification Service*/

**ESP_GATT_UUID_HID_SVC** 0x1812 /* HID Service*/

**ESP_GATT_UUID_SCAN_PARAMETERS_SVC** 0x1813 /* Scan Parameters Service*/

**ESP_GATT_UUID_RUNNING_SPEED_CADENCE_SVC** 0x1814 /* Running Speed and Cadence Service*/

**ESP_GATT_UUID_CYCLING_SPEED_CADENCE_SVC** 0x1816 /* Cycling Speed and Cadence Service*/

**ESP_GATT_UUID_CYCLING_POWER_SVC** 0x1818 /* Cycling Power Service*/

**ESP_GATT_UUID_LOCATION_AND_NAVIGATION_SVC** 0x1819 /* Location and Navigation Service*/

**ESP_GATT_UUID_USER_DATA_SVC** 0x181C /* User Data Service*/

**ESP_GATT_UUID_WEIGHT_SCALE_SVC** 0x181D /* Weight Scale Service*/

**ESP_GATT_UUID_PRI_SERVICE** 0x2800

**ESP_GATT_UUID_SEC_SERVICE** 0x2801

**ESP_GATT_UUID_INCLUDE_SERVICE** 0x2802

**ESP_GATT_UUID_CHAR_DECLARE** 0x2803 /* Characteristic Declaration*/

**ESP_GATT_UUID_CHAR_EXT_PROP** 0x2900 /* Characteristic Extended Properties */

**ESP_GATT_UUID_CHAR_DESCRIPTION** 0x2901 /* Characteristic User Description*/

**ESP_GATT_UUID_CHAR_CLIENT_CONFIG** 0x2902 /* Client Characteristic Configuration */

**ESP_GATT_UUID_CHAR_SRVR_CONFIG** 0x2903 /* Server Characteristic Configuration */

**ESP_GATT_UUID_CHAR_PRESENT_FORMAT** 0x2904 /* Characteristic Presentation Format*/

**ESP_GATT_UUID_CHAR_AGG_FORMAT** 0x2905 /* Characteristic Aggregate Format*/

**ESP_GATT_UUID_CHAR_VALID_RANGE** 0x2906 /* Characteristic Valid Range */

**ESP_GATT_UUID_EXT_RPT_REF_DESCR** 0x2907

**ESP_GATT_UUID_RPT_REF_DESCR** 0x2908

**ESP_GATT_UUID_GAP_DEVICE_NAME** 0x2A00

**ESP_GATT_UUID_GAP_ICON** 0x2A01

**ESP_GATT_UUID_GAP_PREF_CONN_PARAM** 0x2A04

**ESP_GATT_UUID_GAP_CENTRAL_ADDR_RESOL** 0x2AA6

**ESP_GATT_UUID_GATT_SRV_CHGD** 0x2A05

**ESP_GATT_UUID_ALERT_LEVEL** 0x2A06 /* Alert Level */

**ESP_GATT_UUID_TX_POWER_LEVEL** 0x2A07 /* TX power level */

**ESP_GATT_UUID_CURRENT_TIME** 0x2A2B /* Current Time */

**ESP_GATT_UUID_LOCAL_TIME_INFO** 0x2A0F /* Local time info */

**ESP_GATT_UUID_REF_TIME_INFO** 0x2A14 /* reference time information */

**ESP_GATT_UUID_NW_STATUS** 0x2A18 /* network availability status */

**ESP_GATT_UUID_NW_TRIGGER** 0x2A1A /* Network availability trigger */

**ESP_GATT_UUID_ALERT_STATUS** 0x2A3F /* alert status */

**ESP_GATT_UUID_RINGER_CP** 0x2A40 /* ringer control point */

**ESP_GATT_UUID_RINGER_SETTING** 0x2A41 /* ringer setting */

**ESP_GATT_UUID_GM_MEASUREMENT** 0x2A18

**ESP_GATT_UUID_GM_CONTEXT** 0x2A34

**ESP_GATT_UUID_GM_CONTROL_POINT** 0x2A52

**ESP_GATT_UUID_GM_FEATURE** 0x2A51

**ESP_GATT_UUID_SYSTEM_ID** 0x2A23

**ESP_GATT_UUID_MODEL_NUMBER_STR** 0x2A24

**ESP_GATT_UUID_SERIAL_NUMBER_STR** 0x2A25

**ESP_GATT_UUID_FW_VERSION_STR** 0x2A26

**ESP_GATT_UUID_HW_VERSION_STR** 0x2A27

**ESP_GATT_UUID_SW_VERSION_STR** 0x2A28

**ESP_GATT_UUID_MANU_NAME** 0x2A29

**ESP_GATT_UUID_IEEE_DATA** 0x2A2A

**ESP_GATT_UUID_PNP_ID** 0x2A50

**ESP_GATT_UUID_HID_INFORMATION** 0x2A4A

**ESP_GATT_UUID_HID_REPORT_MAP** 0x2A4B

**ESP_GATT_UUID_HID_CONTROL_POINT** 0x2A4C

**ESP_GATT_UUID_HID_REPORT** 0x2A4D

**ESP_GATT_UUID_HID_PROTO_MODE** 0x2A4E

**ESP_GATT_UUID_HID_BT_KB_INPUT** 0x2A22

**ESP_GATT_UUID_HID_BT_KB_OUTPUT** 0x2A32

**ESP_GATT_UUID_HID_BT_MOUSE_INPUT** 0x2A33

**ESP_GATT_HEART_RATE_MEAS** 0x2A37
Heart Rate Measurement.

**ESP_GATT_BODY_SENSOR_LOCATION** 0x2A38
Body Sensor Location.

**ESP_GATT_HEART_RATE_CNTL_POINT** 0x2A39
Heart Rate Control Point.

**ESP_GATT_UUID_BATTERY_LEVEL** 0x2A19

**ESP_GATT_UUID_SC_CONTROL_POINT** 0x2A55

**ESP_GATT_UUID_SENSOR_LOCATION** 0x2A5D

**ESP_GATT_UUID_RSC_MEASUREMENT** 0x2A53

**ESP_GATT_UUID_RSC_FEATURE** 0x2A54

**ESP_GATT_UUID_CSC_MEASUREMENT** 0x2A5B

**ESP_GATT_UUID_CSC_FEATURE** 0x2A5C

**ESP_GATT_UUID_SCAN_INT_WINDOW** 0x2A4F

**ESP_GATT_UUID_SCAN_REFRESH** 0x2A31

**ESP_GATT_ILLEGAL_UUID** 0
GATT INVALID UUID.

**ESP_GATT_ILLEGAL_HANDLE** 0
GATT INVALID HANDLE.

**ESP_GATT_ATTR_HANDLE_MAX** 100
GATT attribute max handle.

**ESP_GATT_MAX_ATTR_LEN** 600
GATT maximum attribute length.

**ESP_GATT_RSP_BY_APP** 0

**ESP_GATT_AUTO_RSP** 1

**ESP_GATT_IF_NONE** 0xff
If callback report gattc_if/gatts_if as this macro, means this event is not correspond to any app

### Type Definitions

**typedef** uint8_t **esp_gatt_if_t**
Gatt interface type, different application on GATT client use different gatt_if

### Enumerations

**enum esp_gatt_prep_write_type**
Attribute write data type from the client.

*Values:*

**ESP_GATT_PREP_WRITE_CANCEL** = 0x00
Prepare write cancel

**ESP_GATT_PREP_WRITE_EXEC** = 0x01
Prepare write execute

**enum esp_gatt_status_t**
GATT success code and error codes.

*Values:*

**ESP_GATT_OK** = 0x0

**ESP_GATT_INVALID_HANDLE** = 0x01

**ESP_GATT_READ_NOT_PERMIT** = 0x02

**ESP_GATT_WRITE_NOT_PERMIT** = 0x03

**ESP_GATT_INVALID_PDU** = 0x04

**ESP_GATT_INSUF_AUTHENTICATION** = 0x05

**ESP_GATT_REQ_NOT_SUPPORTED** = 0x06

**ESP_GATT_INVALID_OFFSET** = 0x07

**ESP_GATT_INSUF_AUTHORIZATION** = 0x08

**ESP_GATT_PREPARE_Q_FULL** = 0x09

**ESP_GATT_NOT_FOUND** = 0x0a

**ESP_GATT_NOT_LONG** = 0x0b

**ESP_GATT_INSUF_KEY_SIZE** = 0x0c

**ESP_GATT_INVALID_ATTR_LEN** = 0x0d

**ESP_GATT_ERR_UNLIKELY** = 0x0e

**ESP_GATT_INSUF_ENCRYPTION** = 0x0f

**ESP_GATT_UNSUPPORT_GRP_TYPE** = 0x10

**ESP_GATT_INSUF_RESOURCE** = 0x11

**ESP_GATT_NO_RESOURCES** = 0x80

**ESP_GATT_INTERNAL_ERROR** = 0x81

**ESP_GATT_WRONG_STATE** = 0x82

**ESP_GATT_DB_FULL** = 0x83

**ESP_GATT_BUSY** = 0x84

**ESP_GATT_ERROR** = 0x85

**ESP_GATT_CMD_STARTED** = 0x86

**ESP_GATT_ILLEGAL_PARAMETER** = 0x87

**ESP_GATT_PENDING** = 0x88

**ESP_GATT_AUTH_FAIL** = 0x89

**ESP_GATT_MORE** = 0x8a

**ESP_GATT_INVALID_CFG** = 0x8b

**ESP_GATT_SERVICE_STARTED** = 0x8c

**ESP_GATT_ENCRYPED_MITM** = ESP_GATT_OK

**ESP_GATT_ENCRYPED_NO_MITM** = 0x8d

**ESP_GATT_NOT_ENCRYPTED** = 0x8e

**ESP_GATT_CONGESTED** = 0x8f

**ESP_GATT_DUP_REG** = 0x90

**ESP_GATT_ALREADY_OPEN** = 0x91

**ESP_GATT_CANCEL** = 0x92

**ESP_GATT_CCC_CFG_ERR** = 0xfd

**ESP_GATT_PRC_IN_PROGRESS** = 0xfe

**ESP_GATT_OUT_OF_RANGE** = 0xff

**enum esp_gatt_conn_reason_t**
Gatt Connection reason enum.

*Values:*

**ESP_GATT_CONN_UNKNOWN** = 0
Gatt connection unknown

**ESP_GATT_CONN_L2C_FAILURE** = 1
General L2cap failure

**ESP_GATT_CONN_TIMEOUT** = 0x08
Connection timeout

**ESP_GATT_CONN_TERMINATE_PEER_USER** = 0x13
Connection terminate by peer user

**ESP_GATT_CONN_TERMINATE_LOCAL_HOST** = 0x16
Connectionterminated by local host

**ESP_GATT_CONN_FAIL_ESTABLISH** = 0x3e
Connection fail to establish

**ESP_GATT_CONN_LMP_TIMEOUT** = 0x22
Connection fail for LMP response tout

**ESP_GATT_CONN_CONN_CANCEL** = 0x0100
L2CAP connection cancelled

**ESP_GATT_CONN_NONE** = 0x0101
No connection to cancel

**enum esp_gatt_auth_req_t**
Gatt authentication request type.

*Values:*

**ESP_GATT_AUTH_REQ_NONE** = 0

**ESP_GATT_AUTH_REQ_NO_MITM** = 1

**ESP_GATT_AUTH_REQ_MITM** = 2

**ESP_GATT_AUTH_REQ_SIGNED_NO_MITM** = 3

**ESP_GATT_AUTH_REQ_SIGNED_MITM** = 4

**enum esp_gatt_perm_t**
Attribute permissions.

*Values:*

**ESP_GATT_PERM_READ** = (1 << 0)

**ESP_GATT_PERM_READ_ENCRYPTED** = (1 << 1)

**ESP_GATT_PERM_READ_ENC_MITM** = (1 << 2)

**ESP_GATT_PERM_WRITE** = (1 << 4)

**ESP_GATT_PERM_WRITE_ENCRYPTED** = (1 << 5)

**ESP_GATT_PERM_WRITE_ENC_MITM** = (1 << 6)

**ESP_GATT_PERM_WRITE_SIGNED** = (1 << 7)

**ESP_GATT_PERM_WRITE_SIGNED_MITM** = (1 << 8)

enum **esp_gatt_char_prop_t**

*Values:*

**ESP_GATT_CHAR_PROP_BIT_BROADCAST** = (1 << 0)

**ESP_GATT_CHAR_PROP_BIT_READ** = (1 << 1)

**ESP_GATT_CHAR_PROP_BIT_WRITE_NR** = (1 << 2)

**ESP_GATT_CHAR_PROP_BIT_WRITE** = (1 << 3)

**ESP_GATT_CHAR_PROP_BIT_NOTIFY** = (1 << 4)

**ESP_GATT_CHAR_PROP_BIT_INDICATE** = (1 << 5)

**ESP_GATT_CHAR_PROP_BIT_AUTH** = (1 << 6)

**ESP_GATT_CHAR_PROP_BIT_EXT_PROP** = (1 << 7)

enum **esp_gatt_write_type_t**

Gatt write type.

*Values:*

**ESP_GATT_WRITE_TYPE_NO_RSP** = 1

Gatt write attribute need no response

**ESP_GATT_WRITE_TYPE_RSP**

Gatt write attribute need remote response

### Structures

struct **esp_attr_desc_t**

Attribute description (used to create database)

#### Public Members

uint16_t **uuid_length**

UUID length

uint8_t ***uuid_p**

UUID value

uint16_t **perm**

Attribute permission

uint16_t **max_length**

Maximum length of the element

uint16_t **length**

Current length of the element

uint8_t ***value**

Element value array

struct **esp_attr_control_t**

attribute auto respose flag

### Public Members

uint8_t **auto_rsp**
need the app response to the client if need_rsp set to 1

**struct esp_gatts_attr_db_t**
attribute type added to the gatt server database

### Public Members

*esp_attr_control_t* **attr_control**
The attribue control type

*esp_attr_desc_t* **att_desc**
The attribue type

**struct esp_attr_value_t**
set the attribute value type

### Public Members

uint16_t **attr_max_len**
attribute max value length

uint16_t **attr_len**
attribute current value length

uint8_t ***attr_value**
the pointer to attribute value

**struct esp_gatts_incl_svc_desc_t**
Gatt include service entry element.

### Public Members

uint16_t **start_hdl**
Gatt start handle value of included service

uint16_t **end_hdl**
Gatt end handle value of included service

uint16_t **uuid**
Gatt attribute value UUID of included service

**struct esp_gatts_incl128_svc_desc_t**
Gatt include 128 bit service entry element.

### Public Members

uint16_t **start_hdl**
Gatt start handle value of included 128 bit service

uint16_t **end_hdl**
Gatt end handle value of included 128 bit service

struct **esp_gatt_value_t**
Gatt attribute value.

#### Public Members

uint8_t **value**[ESP_GATT_MAX_ATTR_LEN]
Gatt attribute value

uint16_t **handle**
Gatt attribute handle

uint16_t **offset**
Gatt attribute value offset

uint16_t **len**
Gatt attribute value length

uint8_t **auth_req**
Gatt authentication request

> **Warning:** doxygenstruct: Cannot find class "esp_gatt_rsp_t" in doxygen xml output for project "esp32-idf" from directory: xml/

### Functions

## GATT SERVER API

### Overview

Instructions

### Application Example

Check bluetooth folder in ESP-IDF examples, which contains the following example:

bluetooth/gatt_server

This is a GATT server demo. Use GATT API to create a GATT server with send advertising. This GATT server can be connected and the service can be discovery.

### API Reference

### Header Files

- bt/bluedroid/api/include/esp_gatts_api.h

### Macros

**ESP_GATT_PREP_WRITE_CANCEL** 0x00
Prepare write flag to indicate cancel prepare write

**ESP_GATT_PREP_WRITE_EXEC** 0x01
Prepare write flag to indicate execute prepare write

### Type Definitions

**typedef** void (***esp_gatts_cb_t**) (*esp_gatts_cb_event_t* event, *esp_gatt_if_t* gatts_if, esp_ble_gatts_cb_param_t *param)
GATT Server callback function type.

**Parameters**

- `event`: : Event type
- `gatts_if`: : GATT server access interface, normally different gatts_if correspond to different profile
- `param`: : Point to callback parameter, currently is union type

### Enumerations

**enum esp_gatts_cb_event_t**
GATT Server callback function events.

*Values:*

**ESP_GATTS_REG_EVT** = 0
When register application id, the event comes

**ESP_GATTS_READ_EVT** = 1
When gatt client request read operation, the event comes

**ESP_GATTS_WRITE_EVT** = 2
When gatt client request write operation, the event comes

**ESP_GATTS_EXEC_WRITE_EVT** = 3
When gatt client request execute write, the event comes

**ESP_GATTS_MTU_EVT** = 4
When set mtu complete, the event comes

**ESP_GATTS_CONF_EVT** = 5
When receive confirm, the event comes

**ESP_GATTS_UNREG_EVT** = 6
When unregister application id, the event comes

**ESP_GATTS_CREATE_EVT** = 7
When create service complete, the event comes

**ESP_GATTS_ADD_INCL_SRVC_EVT** = 8
When add included service complete, the event comes

**ESP_GATTS_ADD_CHAR_EVT** = 9
When add characteristic complete, the event comes

**ESP_GATTS_ADD_CHAR_DESCR_EVT** = 10
When add descriptor complete, the event comes

**ESP_GATTS_DELETE_EVT** = 11
When delete service complete, the event comes

**ESP_GATTS_START_EVT** = 12
When start service complete, the event comes

**ESP_GATTS_STOP_EVT** = 13
When stop service complete, the event comes

**ESP_GATTS_CONNECT_EVT** = 14
When gatt client connect, the event comes

**ESP_GATTS_DISCONNECT_EVT** = 15
When gatt client disconnect, the event comes

**ESP_GATTS_OPEN_EVT** = 16
When connect to peer, the event comes

**ESP_GATTS_CANCEL_OPEN_EVT** = 17
When disconnect from peer, the event comes

**ESP_GATTS_CLOSE_EVT** = 18
When gatt server close, the event comes

**ESP_GATTS_LISTEN_EVT** = 19
When gatt listen to be connected the event comes

**ESP_GATTS_CONGEST_EVT** = 20
When congest happen, the event comes

**ESP_GATTS_RESPONSE_EVT** = 21
When gatt send response complete, the event comes

**ESP_GATTS_CREAT_ATTR_TAB_EVT** = 22

**ESP_GATTS_SET_ATTR_VAL_EVT** = 23

### Structures

> **Warning:** doxygenstruct: Cannot find class "esp_ble_gatts_cb_param_t" in doxygen xml output for project "esp32-idf" from directory: xml/

**struct** esp_ble_gatts_cb_param_t::**gatts_reg_evt_param**
ESP_GATTS_REG_EVT.

#### Public Members

*esp_gatt_status_t* **status**
Operation status

uint16_t **app_id**
Application id which input in register API

**struct** esp_ble_gatts_cb_param_t::**gatts_read_evt_param**
ESP_GATTS_READ_EVT.

### Public Members

uint16_t **conn_id**
Connection id

uint32_t **trans_id**
Transfer id

*esp_bd_addr_t* **bda**
The bluetooth device address which been read

uint16_t **handle**
The attribute handle

uint16_t **offset**
Offset of the value, if the value is too long

bool **is_long**
The value is too long or not

bool **need_rsp**
The read operation need to do response

**struct** esp_ble_gatts_cb_param_t::**gatts_write_evt_param**
ESP_GATTS_WRITE_EVT.

### Public Members

uint16_t **conn_id**
Connection id

uint32_t **trans_id**
Transfer id

*esp_bd_addr_t* **bda**
The bluetooth device address which been written

uint16_t **handle**
The attribute handle

uint16_t **offset**
Offset of the value, if the value is too long

bool **need_rsp**
The write operation need to do response

bool **is_prep**
This write operation is prepare write

uint16_t **len**
The write attribute value length

uint8_t ***value**
The write attribute value

**struct** esp_ble_gatts_cb_param_t::**gatts_exec_write_evt_param**
ESP_GATTS_EXEC_WRITE_EVT.

### Public Members

uint16_t **conn_id**
Connection id

uint32_t **trans_id**
Transfer id

*esp_bd_addr_t* **bda**
The bluetooth device address which been written

uint8_t **exec_write_flag**
Execute write flag

**struct** esp_ble_gatts_cb_param_t::**gatts_mtu_evt_param**
ESP_GATTS_MTU_EVT.

### Public Members

uint16_t **conn_id**
Connection id

uint16_t **mtu**
MTU size

**struct** esp_ble_gatts_cb_param_t::**gatts_conf_evt_param**
ESP_GATTS_CONF_EVT.

### Public Members

*esp_gatt_status_t* **status**
Operation status

uint16_t **conn_id**
Connection id

**struct** esp_ble_gatts_cb_param_t::**gatts_create_evt_param**
ESP_GATTS_UNREG_EVT.

ESP_GATTS_CREATE_EVT

### Public Members

*esp_gatt_status_t* **status**
Operation status

uint16_t **service_handle**
Service attribute handle

esp_gatt_srvc_id_t **service_id**
Service id, include service uuid and other information

**struct** esp_ble_gatts_cb_param_t::**gatts_add_incl_srvc_evt_param**
ESP_GATTS_ADD_INCL_SRVC_EVT.

#### Public Members

*esp_gatt_status_t* **status**
Operation status

uint16_t **attr_handle**
Included service attribute handle

uint16_t **service_handle**
Service attribute handle

**struct** `esp_ble_gatts_cb_param_t::`**gatts_add_char_evt_param**
ESP_GATTS_ADD_CHAR_EVT.

#### Public Members

*esp_gatt_status_t* **status**
Operation status

uint16_t **attr_handle**
Characteristic attribute handle

uint16_t **service_handle**
Service attribute handle

esp_bt_uuid_t **char_uuid**
Characteristic uuid

**struct** `esp_ble_gatts_cb_param_t::`**gatts_add_char_descr_evt_param**
ESP_GATTS_ADD_CHAR_DESCR_EVT.

#### Public Members

*esp_gatt_status_t* **status**
Operation status

uint16_t **attr_handle**
Descriptor attribute handle

uint16_t **service_handle**
Service attribute handle

esp_bt_uuid_t **char_uuid**
Characteristic uuid

**struct** `esp_ble_gatts_cb_param_t::`**gatts_delete_evt_param**
ESP_GATTS_DELETE_EVT.

#### Public Members

*esp_gatt_status_t* **status**
Operation status

uint16_t **service_handle**
Service attribute handle

**struct** `esp_ble_gatts_cb_param_t::`**`gatts_start_evt_param`**
ESP_GATTS_START_EVT.

### Public Members

*esp_gatt_status_t* **`status`**
Operation status

uint16_t **`service_handle`**
Service attribute handle

**struct** `esp_ble_gatts_cb_param_t::`**`gatts_stop_evt_param`**
ESP_GATTS_STOP_EVT.

### Public Members

*esp_gatt_status_t* **`status`**
Operation status

uint16_t **`service_handle`**
Service attribute handle

**struct** `esp_ble_gatts_cb_param_t::`**`gatts_connect_evt_param`**
ESP_GATTS_CONNECT_EVT.

### Public Members

uint16_t **`conn_id`**
Connection id

*esp_bd_addr_t* **`remote_bda`**
Remote bluetooth device address

bool **`is_connected`**
Indicate it is connected or not

**struct** `esp_ble_gatts_cb_param_t::`**`gatts_disconnect_evt_param`**
ESP_GATTS_DISCONNECT_EVT.

### Public Members

uint16_t **`conn_id`**
Connection id

*esp_bd_addr_t* **`remote_bda`**
Remote bluetooth device address

bool **`is_connected`**
Indicate it is connected or not

**struct** `esp_ble_gatts_cb_param_t::`**`gatts_congest_evt_param`**
ESP_GATTS_OPEN_EVT.

ESP_GATTS_CANCEL_OPEN_EVT ESP_GATTS_CLOSE_EVT ESP_GATTS_LISTEN_EVT ESP_GATTS_CONGEST_EVT

#### Public Members

uint16_t **conn_id**
Connection id

bool **congested**
Congested or not

**struct** esp_ble_gatts_cb_param_t::**gatts_rsp_evt_param**
ESP_GATTS_RESPONSE_EVT.

#### Public Members

*esp_gatt_status_t* **status**
Operation status

uint16_t **handle**
Attribute handle which send response

**struct** esp_ble_gatts_cb_param_t::**gatts_add_attr_tab_evt_param**
ESP_GATTS_CREAT_ATTR_TAB_EVT.

#### Public Members

*esp_gatt_status_t* **status**
Operation status

esp_bt_uuid_t **svc_uuid**
Service uuid type

uint16_t **num_handle**
The number of the attribute handle to be added to the gatts database

uint16_t ***handles**
The number to the handles

**struct** esp_ble_gatts_cb_param_t::**gatts_set_attr_val_evt_param**
ESP_GATTS_SET_ATTR_VAL_EVT.

#### Public Members

uint16_t **srvc_handle**
The service handle

uint16_t **attr_handle**
The attribute handle

*esp_gatt_status_t* **status**
Operation status

### Functions

esp_err_t **esp_ble_gatts_register_callback** (*esp_gatts_cb_t callback*)
This function is called to register application callbacks with BTA GATTS module.

**Return**

- ESP_OK : success
- other : failed

esp_err_t **esp_ble_gatts_app_register**(uint16_t *app_id*)
This function is called to register application identifier.

**Return**

- ESP_OK : success
- other : failed

esp_err_t **esp_ble_gatts_app_unregister**(*esp_gatt_if_t* *gatts_if*)
unregister with GATT Server.

**Return**

- ESP_OK : success
- other : failed

**Parameters**

- `gatts_if`: GATT server access interface

esp_err_t **esp_ble_gatts_create_service**(*esp_gatt_if_t* *gatts_if*, esp_gatt_srvc_id_t **service_id*, uint16_t *num_handle*)
Create a service. When service creation is done, a callback event BTA_GATTS_CREATE_SRVC_EVT is called to report status and service ID to the profile. The service ID obtained in the callback function needs to be used when adding included service and characteristics/descriptors into the service.

**Return**

- ESP_OK : success
- other : failed

**Parameters**

- `gatts_if`: GATT server access interface
- `service_id`: service ID.
- `num_handle`: number of handle requested for this service.

esp_err_t **esp_ble_gatts_create_attr_tab**(**const** *esp_gatts_attr_db_t* **gatts_attr_db*, *esp_gatt_if_t* *gatts_if*, uint8_t *max_nb_attr*, uint8_t *srvc_inst_id*)
Create a service attribute tab.

**Return**

- ESP_OK : success
- other : failed

**Parameters**

- `gatts_attr_db`: the pointer to the service attr tab
- `gatts_if`: GATT server access interface

- `max_nb_attr`: the number of attribute to be added to the service database.
- `srvc_inst_id`: the instance id of the service

esp_err_t **esp_ble_gatts_add_included_service** (uint16_t *service_handle*, uint16_t *included_service_handle*)

This function is called to add an included service. After included service is included, a callback event BTA_GATTS_ADD_INCL_SRVC_EVT is reported the included service ID.

**Return**

- ESP_OK : success
- other : failed

**Parameters**

- `service_handle`: service handle to which this included service is to be added.
- `included_service_handle`: the service ID to be included.

esp_err_t **esp_ble_gatts_add_char** (uint16_t *service_handle*, esp_bt_uuid_t **char_uuid*, *esp_gatt_perm_t* *perm*, *esp_gatt_char_prop_t* *property*, *esp_attr_value_t* **char_val*, *esp_attr_control_t* **control*)

This function is called to add a characteristic into a service.

**Return**

- ESP_OK : success
- other : failed

**Parameters**

- `service_handle`: service handle to which this included service is to be added.
- `char_uuid`: : Characteristic UUID.
- `perm`: : Characteristic value declaration attribute permission.
- `property`: : Characteristic Properties
- `char_val`: : Characteristic value
- `control`: : attribute response control byte

esp_err_t **esp_ble_gatts_add_char_descr** (uint16_t *service_handle*, esp_bt_uuid_t **descr_uuid*, *esp_gatt_perm_t* *perm*, *esp_attr_value_t* **char_descr_val*, *esp_attr_control_t* **control*)

This function is called to add characteristic descriptor. When it's done, a callback event BTA_GATTS_ADD_DESCR_EVT is called to report the status and an ID number for this descriptor.

**Return**

- ESP_OK : success
- other : failed

**Parameters**

- `service_handle`: service handle to which this characteristic descriptor is to be added.
- `perm`: descriptor access permission.
- `descr_uuid`: descriptor UUID.

- `char_descr_val`: : Characteristic descriptor value
- `control`: : attribute response control byte

esp_err_t **esp_ble_gatts_delete_service** (uint16_t *service_handle*)

This function is called to delete a service. When this is done, a callback event BTA_GATTS_DELETE_EVT is report with the status.

**Return**

- ESP_OK : success
- other : failed

**Parameters**

- `service_handle`: service_handle to be deleted.

esp_err_t **esp_ble_gatts_start_service** (uint16_t *service_handle*)

This function is called to start a service.

**Return**

- ESP_OK : success
- other : failed

**Parameters**

- `service_handle`: the service handle to be started.

esp_err_t **esp_ble_gatts_stop_service** (uint16_t *service_handle*)

This function is called to stop a service.

**Return**

- ESP_OK : success
- other : failed

**Parameters**

- `service_handle`: - service to be topped.

esp_err_t **esp_ble_gatts_send_indicate** (*esp_gatt_if_t gatts_if*, uint16_t *conn_id*, uint16_t *attr_handle*, uint16_t *value_len*, uint8_t **value*, bool *need_confirm*)

Send indicate or notify to GATT client. Set param need_confirm as false will send notification, otherwise indication.

**Return**

- ESP_OK : success
- other : failed

**Parameters**

- `gatts_if`: GATT server access interface
- `conn_id`: - connection id to indicate.
- `attr_handle`: - attribute handle to indicate.

- `value_len`: - indicate value length.
- `value`: value to indicate.
- `need_confirm`: - Whether a confirmation is required. false sends a GATT notification, true sends a GATT indication.

esp_err_t **esp_ble_gatts_send_response**(*esp_gatt_if_t* *gatts_if*, uint16_t *conn_id*, uint32_t *trans_id*, *esp_gatt_status_t* *status*, esp_gatt_rsp_t **rsp*)

This function is called to send a response to a request.

**Return**

- ESP_OK : success
- other : failed

**Parameters**

- `gatts_if`: GATT server access interface
- `conn_id`: - connection identifier.
- `trans_id`: - transfer id
- `status`: - response status
- `rsp`: - response data.

esp_err_t **esp_ble_gatts_set_attr_value**(uint16_t *attr_handle*, uint16_t *length*, **const** uint8_t **value*)

This function is called to set the attribute value by the application.

**Return**

- ESP_OK : success
- other : failed

**Parameters**

- `attr_handle`: the attribute handle which to be set
- `length`: the value length
- `value`: the pointer to the attribute value

esp_err_t **esp_ble_gatts_get_attr_value**(uint16_t *attr_handle*, uint16_t **length*, **const** uint8_t ***value*)

Retrieve attribute value.

**Return**

- ESP_OK : success
- other : failed

**Parameters**

- `attr_handle`: Attribute handle.
- `length`: pointer to the attribute value length
- `value`: Pointer to attribute value payload, the value cannot be modified by user

esp_err_t **esp_ble_gatts_open** (*esp_gatt_if_t gatts_if*, *esp_bd_addr_t remote_bda*, bool *is_direct*)

Open a direct open connection or add a background auto connection.

**Return**

- ESP_OK : success
- other : failed

**Parameters**

- `gatts_if`: GATT server access interface
- `remote_bda`: remote device bluetooth device address.
- `is_direct`: direct connection or background auto connection

esp_err_t **esp_ble_gatts_close** (*esp_gatt_if_t gatts_if*, uint16_t *conn_id*)

Close a connection a remote device.

**Return**

- ESP_OK : success
- other : failed

**Parameters**

- `gatts_if`: GATT server access interface
- `conn_id`: connection ID to be closed.

## GATT CLIENT API

### Overview

Instructions

### Application Example

Check bluetooth folder in ESP-IDF examples, which contains the following examples:

bluetooth/gatt_client

This is a GATT client demo. This demo can scan devices, connect to the GATT server and discover the service.

### API Reference

### Header Files

- bt/bluedroid/api/include/esp_gattc_api.h

### Macros

**ESP_GATT_DEF_BLE_MTU_SIZE** 23
Maximum Transmission Unit used in GATT.

**ESP_GATT_MAX_MTU_SIZE** 517
Maximum Transmission Unit allowed in GATT.

### Type Definitions

**typedef** void (***esp_gattc_cb_t**)(*esp_gattc_cb_event_t* event, *esp_gatt_if_t* gattc_if, esp_ble_gattc_cb_param_t *param)
GATT Client callback function type.

**Parameters**

- `event`: : Event type
- `gatts_if`: : GATT client access interface, normally different gattc_if correspond to different profile
- `param`: : Point to callback parameter, currently is union type

### Enumerations

**enum esp_gattc_cb_event_t**
GATT Client callback function events.

*Values:*

**ESP_GATTC_REG_EVT** = 0
When GATT client is registered, the event comes

**ESP_GATTC_UNREG_EVT** = 1
When GATT client is unregistered, the event comes

**ESP_GATTC_OPEN_EVT** = 2
When GATT connection is set up, the event comes

**ESP_GATTC_READ_CHAR_EVT** = 3
When GATT characteristic is read, the event comes

**ESP_GATTC_WRITE_CHAR_EVT** = 4
When GATT characteristic write operation completes, the event comes

**ESP_GATTC_CLOSE_EVT** = 5
When GATT connection is closed, the event comes

**ESP_GATTC_SEARCH_CMPL_EVT** = 6
When GATT service discovery is completed, the event comes

**ESP_GATTC_SEARCH_RES_EVT** = 7
When GATT service discovery result is got, the event comes

**ESP_GATTC_READ_DESCR_EVT** = 8
When GATT characteristic descriptor read completes, the event comes

**ESP_GATTC_WRITE_DESCR_EVT** = 9
When GATT characteristic descriptor write completes, the event comes

**ESP_GATTC_NOTIFY_EVT** = 10
When GATT notification or indication arrives, the event comes

**ESP_GATTC_PREP_WRITE_EVT** = 11
When GATT prepare-write operation completes, the event comes

**ESP_GATTC_EXEC_EVT** = 12
When write execution completes, the event comes

**ESP_GATTC_ACL_EVT** = 13
When ACL connection is up, the event comes

**ESP_GATTC_CANCEL_OPEN_EVT** = 14
When GATT client ongoing connection is cancelled, the event comes

**ESP_GATTC_SRVC_CHG_EVT** = 15
When "service changed" occurs, the event comes

**ESP_GATTC_ENC_CMPL_CB_EVT** = 17
When encryption procedure completes, the event comes

**ESP_GATTC_CFG_MTU_EVT** = 18
When configuration of MTU completes, the event comes

**ESP_GATTC_ADV_DATA_EVT** = 19
When advertising of data, the event comes

**ESP_GATTC_MULT_ADV_ENB_EVT** = 20
When multi-advertising is enabled, the event comes

**ESP_GATTC_MULT_ADV_UPD_EVT** = 21
When multi-advertising parameters are updated, the event comes

**ESP_GATTC_MULT_ADV_DATA_EVT** = 22
When multi-advertising data arrives, the event comes

**ESP_GATTC_MULT_ADV_DIS_EVT** = 23
When multi-advertising is disabled, the event comes

**ESP_GATTC_CONGEST_EVT** = 24
When GATT connection congestion comes, the event comes

**ESP_GATTC_BTH_SCAN_ENB_EVT** = 25
When batch scan is enabled, the event comes

**ESP_GATTC_BTH_SCAN_CFG_EVT** = 26
When batch scan storage is configured, the event comes

**ESP_GATTC_BTH_SCAN_RD_EVT** = 27
When Batch scan read event is reported, the event comes

**ESP_GATTC_BTH_SCAN_THR_EVT** = 28
When Batch scan threshold is set, the event comes

**ESP_GATTC_BTH_SCAN_PARAM_EVT** = 29
When Batch scan parameters are set, the event comes

**ESP_GATTC_BTH_SCAN_DIS_EVT** = 30
When Batch scan is disabled, the event comes

**ESP_GATTC_SCAN_FLT_CFG_EVT** = 31
When Scan filter configuration completes, the event comes

**ESP_GATTC_SCAN_FLT_PARAM_EVT** = 32
When Scan filter parameters are set, the event comes

**ESP_GATTC_SCAN_FLT_STATUS_EVT** = 33
When Scan filter status is reported, the event comes

**ESP_GATTC_ADV_VSC_EVT** = 34
When advertising vendor spec content event is reported, the event comes

**ESP_GATTC_GET_CHAR_EVT** = 35
When characteristic is got from GATT server, the event comes

**ESP_GATTC_GET_DESCR_EVT** = 36
When characteristic descriptor is got from GATT server, the event comes

**ESP_GATTC_GET_INCL_SRVC_EVT** = 37
When included service is got from GATT server, the event comes

**ESP_GATTC_REG_FOR_NOTIFY_EVT** = 38
When register for notification of a service completes, the event comes

**ESP_GATTC_UNREG_FOR_NOTIFY_EVT** = 39
When unregister for notification of a service completes, the event comes

### Structures

> **Warning:** doxygenstruct: Cannot find class "esp_ble_gattc_cb_param_t" in doxygen xml output for project "esp32-idf" from directory: xml/

**struct** esp_ble_gattc_cb_param_t::**gattc_reg_evt_param**
ESP_GATTC_REG_EVT.

#### Public Members

*esp_gatt_status_t* **status**
Operation status

uint16_t **app_id**
Application id which input in register API

**struct** esp_ble_gattc_cb_param_t::**gattc_open_evt_param**
ESP_GATTC_OPEN_EVT.

#### Public Members

*esp_gatt_status_t* **status**
Operation status

uint16_t **conn_id**
Connection id

*esp_bd_addr_t* **remote_bda**
Remote bluetooth device address

uint16_t **mtu**
MTU size

**struct** esp_ble_gattc_cb_param_t::**gattc_close_evt_param**
ESP_GATTC_CLOSE_EVT.

### Public Members

*esp_gatt_status_t* **status**
Operation status

uint16_t **conn_id**
Connection id

*esp_bd_addr_t* **remote_bda**
Remote bluetooth device address

*esp_gatt_conn_reason_t* **reason**
The reason of gatt connection close

**struct** esp_ble_gattc_cb_param_t::**gattc_cfg_mtu_evt_param**
ESP_GATTC_CFG_MTU_EVT.

### Public Members

*esp_gatt_status_t* **status**
Operation status

uint16_t **conn_id**
Connection id

uint16_t **mtu**
MTU size

**struct** esp_ble_gattc_cb_param_t::**gattc_search_cmpl_evt_param**
ESP_GATTC_SEARCH_CMPL_EVT.

### Public Members

*esp_gatt_status_t* **status**
Operation status

uint16_t **conn_id**
Connection id

**struct** esp_ble_gattc_cb_param_t::**gattc_search_res_evt_param**
ESP_GATTC_SEARCH_RES_EVT.

### Public Members

uint16_t **conn_id**
Connection id

esp_gatt_srvc_id_t **srvc_id**
Service id, include service uuid and other information

**struct** `esp_ble_gattc_cb_param_t::`**`gattc_read_char_evt_param`**
ESP_GATTC_READ_CHAR_EVT, ESP_GATTC_READ_DESCR_EVT.

### Public Members

*esp_gatt_status_t* **`status`**
Operation status

uint16_t **`conn_id`**
Connection id

esp_gatt_srvc_id_t **`srvc_id`**
Service id, include service uuid and other information

esp_gatt_id_t **`char_id`**
Characteristic id, include characteristic uuid and other information

esp_gatt_id_t **`descr_id`**
Descriptor id, include descriptor uuid and other information

uint8_t ***`value`**
Characteristic value

uint16_t **`value_type`**
Characteristic value type

uint16_t **`value_len`**
Characteristic value length

**struct** `esp_ble_gattc_cb_param_t::`**`gattc_write_evt_param`**
ESP_GATTC_WRITE_CHAR_EVT, ESP_GATTC_PREP_WRITE_EVT, ESP_GATTC_WRITE_DESCR_EVT.

### Public Members

*esp_gatt_status_t* **`status`**
Operation status

uint16_t **`conn_id`**
Connection id

esp_gatt_srvc_id_t **`srvc_id`**
Service id, include service uuid and other information

esp_gatt_id_t **`char_id`**
Characteristic id, include characteristic uuid and other information

esp_gatt_id_t **`descr_id`**
Descriptor id, include descriptor uuid and other information

**struct** `esp_ble_gattc_cb_param_t::`**`gattc_exec_cmpl_evt_param`**
ESP_GATTC_EXEC_EVT.

### Public Members

*esp_gatt_status_t* **`status`**
Operation status

uint16_t **conn_id**
Connection id

**struct** esp_ble_gattc_cb_param_t::**gattc_notify_evt_param**
ESP_GATTC_NOTIFY_EVT.

### Public Members

uint16_t **conn_id**
Connection id

*esp_bd_addr_t* **remote_bda**
Remote bluetooth device address

esp_gatt_srvc_id_t **srvc_id**
Service id, include service uuid and other information

esp_gatt_id_t **char_id**
Characteristic id, include characteristic uuid and other information

esp_gatt_id_t **descr_id**
Descriptor id, include descriptor uuid and other information

uint16_t **value_len**
Notify attribute value

uint8_t ***value**
Notify attribute value

bool **is_notify**
True means notify, false means indicate

**struct** esp_ble_gattc_cb_param_t::**gattc_srvc_chg_evt_param**
ESP_GATTC_SRVC_CHG_EVT.

### Public Members

*esp_bd_addr_t* **remote_bda**
Remote bluetooth device address

**struct** esp_ble_gattc_cb_param_t::**gattc_congest_evt_param**
ESP_GATTC_CONGEST_EVT.

### Public Members

uint16_t **conn_id**
Connection id

bool **congested**
Congested or not

**struct** esp_ble_gattc_cb_param_t::**gattc_get_char_evt_param**
ESP_GATTC_GET_CHAR_EVT.

### Public Members

*esp_gatt_status_t* **status**
Operation status

uint16_t **conn_id**
Connection id

esp_gatt_srvc_id_t **srvc_id**
Service id, include service uuid and other information

esp_gatt_id_t **char_id**
Characteristic id, include characteristic uuid and other information

*esp_gatt_char_prop_t* **char_prop**
Characteristic property

**struct** esp_ble_gattc_cb_param_t::**gattc_get_descr_evt_param**
ESP_GATTC_GET_DESCR_EVT.

### Public Members

*esp_gatt_status_t* **status**
Operation status

uint16_t **conn_id**
Connection id

esp_gatt_srvc_id_t **srvc_id**
Service id, include service uuid and other information

esp_gatt_id_t **char_id**
Characteristic id, include characteristic uuid and other information

esp_gatt_id_t **descr_id**
Descriptor id, include descriptor uuid and other information

**struct** esp_ble_gattc_cb_param_t::**gattc_get_incl_srvc_evt_param**
ESP_GATTC_GET_INCL_SRVC_EVT.

### Public Members

*esp_gatt_status_t* **status**
Operation status

uint16_t **conn_id**
Connection id

esp_gatt_srvc_id_t **srvc_id**
Service id, include service uuid and other information

esp_gatt_srvc_id_t **incl_srvc_id**
Included service id, include service uuid and other information

**struct** esp_ble_gattc_cb_param_t::**gattc_reg_for_notify_evt_param**
ESP_GATTC_REG_FOR_NOTIFY_EVT.

### Public Members

*esp_gatt_status_t* **status**
Operation status

esp_gatt_srvc_id_t **srvc_id**
Service id, include service uuid and other information

esp_gatt_id_t **char_id**
Characteristic id, include characteristic uuid and other information

**struct** esp_ble_gattc_cb_param_t::**gattc_unreg_for_notify_evt_param**
ESP_GATTC_UNREG_FOR_NOTIFY_EVT.

### Public Members

*esp_gatt_status_t* **status**
Operation status

esp_gatt_srvc_id_t **srvc_id**
Service id, include service uuid and other information

esp_gatt_id_t **char_id**
Characteristic id, include characteristic uuid and other information

## Functions

esp_err_t **esp_ble_gattc_register_callback**(*esp_gattc_cb_t callback*)
This function is called to register application callbacks with GATTC module.

**Return**

- ESP_OK: success
- other: failed

**Parameters**

- `callback`: : pointer to the application callback function.

esp_err_t **esp_ble_gattc_app_register**(uint16_t *app_id*)
This function is called to register application callbacks with GATTC module.

**Return**

- ESP_OK: success
- other: failed

**Parameters**

- `app_id`: : Application Identify (UUID), for different application

esp_err_t **esp_ble_gattc_app_unregister**(*esp_gatt_if_t gattc_if*)
This function is called to unregister an application from GATTC module.

**Return**

- ESP_OK: success

- other: failed

**Parameters**

- `gattc_if`: Gatt client access interface.

esp_err_t **esp_ble_gattc_open** (*esp_gatt_if_t gattc_if*, *esp_bd_addr_t remote_bda*, bool *is_direct*)

Open a direct connection or add a background auto connection.

**Return**

- ESP_OK: success
- other: failed

**Parameters**

- `gattc_if`: Gatt client access interface.
- `remote_bda`: remote device bluetooth device address.
- `is_direct`: direct connection or background auto connection

esp_err_t **esp_ble_gattc_close** (*esp_gatt_if_t gattc_if*, uint16_t *conn_id*)

Close a connection to a GATT server.

**Return**

- ESP_OK: success
- other: failed

**Parameters**

- `gattc_if`: Gatt client access interface.
- `conn_id`: connection ID to be closed.

esp_err_t **esp_ble_gattc_config_mtu** (*esp_gatt_if_t gattc_if*, uint16_t *conn_id*, uint16_t *mtu*)

Configure the MTU size in the GATT channel. This can be done only once per connection.

**Return**

- ESP_OK: success
- other: failed

**Parameters**

- `gattc_if`: Gatt client access interface.
- `conn_id`: connection ID.
- `mtu`: desired MTU size to use.

esp_err_t **esp_ble_gattc_search_service** (*esp_gatt_if_t gattc_if*, uint16_t *conn_id*, esp_bt_uuid_t **filter_uuid*)

This function is called to request a GATT service discovery on a GATT server. This function report service search result by a callback event, and followed by a service search complete event.

**Return**

- ESP_OK: success
- other: failed

**Parameters**

- `gattc_if`: Gatt client access interface.
- `conn_id`: connection ID.
- `filter_uuid`: a UUID of the service application is interested in. If Null, discover for all services.

esp_err_t **esp_ble_gattc_get_characteristic**(*esp_gatt_if_t gattc_if*, uint16_t *conn_id*, esp_gatt_srvc_id_t **srvc_id*, esp_gatt_id_t **start_char_id*)

This function is called to find the first characteristic of the service on the given server.

**Return**

- ESP_OK: success
- other: failed

**Parameters**

- `gattc_if`: Gatt client access interface.
- `conn_id`: connection ID which identify the server.
- `srvc_id`: service ID
- `start_char_id`: the start characteristic ID

esp_err_t **esp_ble_gattc_get_descriptor**(*esp_gatt_if_t gattc_if*, uint16_t *conn_id*, esp_gatt_srvc_id_t **srvc_id*, esp_gatt_id_t **char_id*, esp_gatt_id_t **start_descr_id*)

This function is called to find the descriptor of the service on the given server.

**Return**

- ESP_OK: success
- other: failed

**Parameters**

- `gattc_if`: Gatt client access interface.
- `conn_id`: connection ID which identify the server.
- `srvc_id`: the service ID of which the characteristic is belonged to.
- `char_id`: Characteristic ID, if NULL find the first available characteristic.
- `start_descr_id`: the start descriptor id

esp_err_t **esp_ble_gattc_get_included_service**(*esp_gatt_if_t gattc_if*, uint16_t *conn_id*, esp_gatt_srvc_id_t **srvc_id*, esp_gatt_srvc_id_t **start_incl_srvc_id*)

This function is called to find the first characteristic of the service on the given server.

**Return**

- ESP_OK: success
- other: failed

**Parameters**

- `gattc_if`: Gatt client access interface.

- `conn_id`: connection ID which identify the server.
- `srvc_id`: the service ID of which the characteristic is belonged to.
- `start_incl_srvc_id`: the start include service id

esp_err_t **esp_ble_gattc_read_char**(*esp_gatt_if_t gattc_if*, uint16_t *conn_id*, esp_gatt_srvc_id_t **srvc_id*, esp_gatt_id_t **char_id*, *esp_gatt_auth_req_t auth_req*)

This function is called to read a service's characteristics of the given characteristic ID.

**Return**

- ESP_OK: success
- other: failed

**Parameters**

- `gattc_if`: Gatt client access interface.
- `conn_id`: : connection ID.
- `srvc_id`: : service ID.
- `char_id`: : characteristic ID to read.
- `auth_req`: : authenticate request type

esp_err_t **esp_ble_gattc_read_char_descr**(*esp_gatt_if_t gattc_if*, uint16_t *conn_id*, esp_gatt_srvc_id_t **srvc_id*, esp_gatt_id_t **char_id*, esp_gatt_id_t **descr_id*, *esp_gatt_auth_req_t auth_req*)

This function is called to read a characteristics descriptor.

**Return**

- ESP_OK: success
- other: failed

**Parameters**

- `gattc_if`: Gatt client access interface.
- `conn_id`: : connection ID.
- `srvc_id`: : service ID.
- `char_id`: : characteristic ID to read.
- `descr_id`: : characteristic descriptor ID to read.
- `auth_req`: : authenticate request type

esp_err_t **esp_ble_gattc_write_char**(*esp_gatt_if_t gattc_if*, uint16_t *conn_id*, esp_gatt_srvc_id_t **srvc_id*, esp_gatt_id_t **char_id*, uint16_t *value_len*, uint8_t **value*, *esp_gatt_write_type_t write_type*, *esp_gatt_auth_req_t auth_req*)

This function is called to write characteristic value.

**Return**

- ESP_OK: success

- other: failed

**Parameters**

- `gattc_if`: Gatt client access interface.
- `conn_id`: : connection ID.
- `srvc_id`: : service ID.
- `char_id`: : characteristic ID to write.
- `value_len`: length of the value to be written.
- `value`: : the value to be written.
- `write_type`: : the type of attribute write operation.
- `auth_req`: : authentication request.

esp_err_t **esp_ble_gattc_write_char_descr** (*esp_gatt_if_t gattc_if*, uint16_t *conn_id*, esp_gatt_srvc_id_t **srvc_id*, esp_gatt_id_t **char_id*, esp_gatt_id_t **descr_id*, uint16_t *value_len*, uint8_t **value*, *esp_gatt_write_type_t write_type*, *esp_gatt_auth_req_t auth_req*)

This function is called to write characteristic descriptor value.

**Return**

- ESP_OK: success
- other: failed

**Parameters**

- `gattc_if`: Gatt client access interface.
- `conn_id`: : connection ID
- `srvc_id`: : service ID.
- `char_id`: : characteristic ID.
- `descr_id`: : characteristic descriptor ID to write.
- `value_len`: length of the value to be written.
- `value`: : the value to be written.
- `write_type`: : the type of attribute write operation.
- `auth_req`: : authentication request.

esp_err_t **esp_ble_gattc_prepare_write** (*esp_gatt_if_t gattc_if*, uint16_t *conn_id*, esp_gatt_srvc_id_t **srvc_id*, esp_gatt_id_t **char_id*, uint16_t *offset*, uint16_t *value_len*, uint8_t **value*, *esp_gatt_auth_req_t auth_req*)

This function is called to prepare write a characteristic value.

**Return**

- ESP_OK: success
- other: failed

**Parameters**

- `gattc_if`: Gatt client access interface.

- `conn_id`: : connection ID.
- `srvc_id`: : service ID.
- `char_id`: : GATT characteristic ID of the service.
- `offset`: : offset of the write value.
- `value_len`: length of the value to be written.
- `value`: : the value to be written.
- `auth_req`: : authentication request.

esp_err_t **esp_ble_gattc_execute_write**(*esp_gatt_if_t* *gattc_if*, uint16_t *conn_id*, bool *is_execute*)
This function is called to execute write a prepare write sequence.

**Return**

- ESP_OK: success
- other: failed

**Parameters**

- `gattc_if`: Gatt client access interface.
- `conn_id`: : connection ID.
- `is_execute`: : execute or cancel.

*esp_gatt_status_t* **esp_ble_gattc_register_for_notify**(*esp_gatt_if_t* *gattc_if*, *esp_bd_addr_t* *server_bda*, esp_gatt_srvc_id_t **srvc_id*, esp_gatt_id_t **char_id*)
This function is called to register for notification of a service.

**Return**

- ESP_OK: registration succeeds
- other: failed

**Parameters**

- `gattc_if`: Gatt client access interface.
- `server_bda`: : target GATT server.
- `srvc_id`: : pointer to GATT service ID.
- `char_id`: : pointer to GATT characteristic ID.

*esp_gatt_status_t* **esp_ble_gattc_unregister_for_notify**(*esp_gatt_if_t* *gattc_if*, *esp_bd_addr_t* *server_bda*, esp_gatt_srvc_id_t **srvc_id*, esp_gatt_id_t **char_id*)
This function is called to de-register for notification of a service.

**Return**

- ESP_OK: unregister succeeds
- other: failed

**Parameters**

- `gattc_if`: Gatt client access interface.

- `server_bda`: : target GATT server.
- `srvc_id`: : pointer to GATT service ID.
- `char_id`: : pointer to GATT characteristic ID.

## BLUFI API

### Overview

BLUFI is a profile based GATT to config ESP32 WIFI to connect/disconnect AP or setup a softap and etc. Use should concern these things: 1. The event sent from profile. Then you need to do something as the event indicate. 2. Security reference. You can write your own Security functions such as symmetrical encryption/decryption and checksum functions. Even you can define the "Key Exchange/Negotiation" procedure.

### Application Example

Check bluetooth folder in ESP-IDF examples, which contains the following example:

bluetooth/blufi

This is a BLUFI demo. This demo can set ESP32's wifi to softap/station/softap&station mode and config wifi connections.

### API Reference

### Header Files

- bt/bluedroid/api/include/esp_blufi_api.h

### Macros

### Type Definitions

**typedef** void (***`esp_blufi_event_cb_t`**)(*esp_blufi_cb_event_t* event, esp_blufi_cb_param_t *param)

BLUFI event callback function type.

**Parameters**

- `event`: : Event type
- `param`: : Point to callback parameter, currently is union type

**typedef** void (***`esp_blufi_negotiate_data_handler_t`**)(uint8_t *data, int len, uint8_t **output_data, int *output_len, bool *need_free)

BLUFI negotiate data handler.

**Parameters**

- `data`: : data from phone
- `len`: : length of data from phone
- `output_data`: : data want to send to phone

- `output_len`: : length of data want to send to phone

**typedef** int (***`esp_blufi_encrypt_func_t`**)(uint8_t iv8, uint8_t *crypt_data, int cyprt_len)
BLUFI encrypt the data after negotiate a share key.

**Return** Nonnegative number is encrypted length, if error, return negative number;

**Parameters**

- `iv8`: : initial vector(8bit), normally, blufi core will input packet sequence number
- `crypt_data`: : plain text and encrypted data, the encrypt function must support autochthonous encrypt
- `crypt_len`: : length of plain text

**typedef** int (***`esp_blufi_decrypt_func_t`**)(uint8_t iv8, uint8_t *crypt_data, int crypt_len)
BLUFI decrypt the data after negotiate a share key.

**Return** Nonnegative number is decrypted length, if error, return negative number;

**Parameters**

- `iv8`: : initial vector(8bit), normally, blufi core will input packet sequence number
- `crypt_data`: : encrypted data and plain text, the encrypt function must support autochthonous decrypt
- `crypt_len`: : length of encrypted text

**typedef** uint16_t (***`esp_blufi_checksum_func_t`**)(uint8_t iv8, uint8_t *data, int len)
BLUFI checksum.

**Parameters**

- `iv8`: : initial vector(8bit), normally, blufi core will input packet sequence number
- `data`: : data need to checksum
- `len`: : length of data

### Enumerations

**enum `esp_blufi_cb_event_t`**
*Values:*

**`ESP_BLUFI_EVENT_INIT_FINISH`** = 0

**`ESP_BLUFI_EVENT_DEINIT_FINISH`**

**`ESP_BLUFI_EVENT_SET_WIFI_OPMODE`**

**`ESP_BLUFI_EVENT_BLE_CONNECT`**

**`ESP_BLUFI_EVENT_BLE_DISCONNECT`**

**`ESP_BLUFI_EVENT_REQ_CONNECT_TO_AP`**

**`ESP_BLUFI_EVENT_REQ_DISCONNECT_FROM_AP`**

**`ESP_BLUFI_EVENT_GET_WIFI_STATUS`**

**`ESP_BLUFI_EVENT_DEAUTHENTICATE_STA`**

**ESP_BLUFI_EVENT_RECV_STA_BSSID**

**ESP_BLUFI_EVENT_RECV_STA_SSID**

**ESP_BLUFI_EVENT_RECV_STA_PASSWD**

**ESP_BLUFI_EVENT_RECV_SOFTAP_SSID**

**ESP_BLUFI_EVENT_RECV_SOFTAP_PASSWD**

**ESP_BLUFI_EVENT_RECV_SOFTAP_MAX_CONN_NUM**

**ESP_BLUFI_EVENT_RECV_SOFTAP_AUTH_MODE**

**ESP_BLUFI_EVENT_RECV_SOFTAP_CHANNEL**

**ESP_BLUFI_EVENT_RECV_USERNAME**

**ESP_BLUFI_EVENT_RECV_CA_CERT**

**ESP_BLUFI_EVENT_RECV_CLIENT_CERT**

**ESP_BLUFI_EVENT_RECV_SERVER_CERT**

**ESP_BLUFI_EVENT_RECV_CLIENT_PRIV_KEY**

**ESP_BLUFI_EVENT_RECV_SERVER_PRIV_KEY**

**enum esp_blufi_sta_conn_state_t**

BLUFI config status.

*Values:*

**ESP_BLUFI_STA_CONN_SUCCESS** = 0x00

**ESP_BLUFI_STA_CONN_FAIL** = 0x01

**enum esp_blufi_init_state_t**

BLUFI init status.

*Values:*

**ESP_BLUFI_INIT_OK** = 0

**ESP_BLUFI_INIT_FAILED** = 0

**enum esp_blufi_deinit_state_t**

BLUFI deinit status.

*Values:*

**ESP_BLUFI_DEINIT_OK** = 0

**ESP_BLUFI_DEINIT_FAILED** = 0

### Structures

**struct esp_blufi_extra_info_t**

BLUFI extra information structure.

#### Public Members

uint8_t **sta_bssid**[6]

BSSID of station interface

bool **sta_bssid_set**
is BSSID of station interface set

uint8_t ***sta_ssid**
SSID of station interface

int **sta_ssid_len**
length of SSID of station interface

uint8_t ***sta_passwd**
password of station interface

int **sta_passwd_len**
length of password of station interface

uint8_t ***softap_ssid**
SSID of softap interface

int **softap_ssid_len**
length of SSID of softap interface

uint8_t ***softap_passwd**
password of station interface

int **softap_passwd_len**
length of password of station interface

uint8_t **softap_authmode**
authentication mode of softap interface

bool **softap_authmode_set**
is authentication mode of softap interface set

uint8_t **softap_max_conn_num**
max connection number of softap interface

bool **softap_max_conn_num_set**
is max connection number of softap interface set

uint8_t **softap_channel**
channel of softap interface

bool **softap_channel_set**
is channel of softap interface set

> **Warning:** doxygenstruct: Cannot find class "esp_blufi_cb_param_t" in doxygen xml output for project "esp32-idf" from directory: xml/

**struct** esp_blufi_cb_param_t::**blufi_init_finish_evt_param**
ESP_BLUFI_EVENT_INIT_FINISH.

### Public Members

*esp_blufi_init_state_t* **state**
Initial status

**struct** esp_blufi_cb_param_t::**blufi_deinit_finish_evt_param**
ESP_BLUFI_EVENT_DEINIT_FINISH.

### Public Members

*esp_blufi_deinit_state_t* **state**
De-initial status

**struct** esp_blufi_cb_param_t::**blufi_set_wifi_mode_evt_param**
ESP_BLUFI_EVENT_SET_WIFI_MODE.

### Public Members

wifi_mode_t **op_mode**
Wifi operation mode

**struct** esp_blufi_cb_param_t::**blufi_connect_evt_param**
ESP_BLUFI_EVENT_CONNECT.

### Public Members

*esp_bd_addr_t* **remote_bda**
Blufi Remote bluetooth device address

**struct** esp_blufi_cb_param_t::**blufi_disconnect_evt_param**
ESP_BLUFI_EVENT_DISCONNECT.

### Public Members

*esp_bd_addr_t* **remote_bda**
Blufi Remote bluetooth device address

**struct** esp_blufi_cb_param_t::**blufi_recv_sta_bssid_evt_param**
ESP_BLUFI_EVENT_RECV_STA_BSSID.

### Public Members

uint8_t **bssid**[6]
BSSID

**struct** esp_blufi_cb_param_t::**blufi_recv_sta_ssid_evt_param**
ESP_BLUFI_EVENT_RECV_STA_SSID.

### Public Members

uint8_t ***ssid**
SSID

int **ssid_len**
SSID length

**struct** esp_blufi_cb_param_t::**blufi_recv_sta_passwd_evt_param**
ESP_BLUFI_EVENT_RECV_STA_PASSWD.

### Public Members

uint8_t ***passwd**
Password

int **passwd_len**
Password Length

**struct** esp_blufi_cb_param_t::**blufi_recv_softap_ssid_evt_param**
ESP_BLUFI_EVENT_RECV_SOFTAP_SSID.

### Public Members

uint8_t ***ssid**
SSID

int **ssid_len**
SSID length

**struct** esp_blufi_cb_param_t::**blufi_recv_softap_passwd_evt_param**
ESP_BLUFI_EVENT_RECV_SOFTAP_PASSWD.

### Public Members

uint8_t ***passwd**
Password

int **passwd_len**
Password Length

**struct** esp_blufi_cb_param_t::**blufi_recv_softap_max_conn_num_evt_param**
ESP_BLUFI_EVENT_RECV_SOFTAP_MAX_CONN_NUM.

### Public Members

int **max_conn_num**
SSID

**struct** esp_blufi_cb_param_t::**blufi_recv_softap_auth_mode_evt_param**
ESP_BLUFI_EVENT_RECV_SOFTAP_AUTH_MODE.

### Public Members

wifi_auth_mode_t **auth_mode**
Authentication mode

**struct** esp_blufi_cb_param_t::**blufi_recv_softap_channel_evt_param**
ESP_BLUFI_EVENT_RECV_SOFTAP_CHANNEL.

### Public Members

uint8_t **channel**
Authentication mode

**struct** esp_blufi_cb_param_t::**blufi_recv_username_evt_param**
ESP_BLUFI_EVENT_RECV_USERNAME.

### Public Members

uint8_t ***name**
Username point

int **name_len**
Username length

**struct** esp_blufi_cb_param_t::**blufi_recv_ca_evt_param**
ESP_BLUFI_EVENT_RECV_CA_CERT.

### Public Members

uint8_t ***cert**
CA certificate point

int **cert_len**
CA certificate length

**struct** esp_blufi_cb_param_t::**blufi_recv_client_cert_evt_param**
ESP_BLUFI_EVENT_RECV_CLIENT_CERT

### Public Members

uint8_t ***cert**
Client certificate point

int **cert_len**
Client certificate length

**struct** esp_blufi_cb_param_t::**blufi_recv_server_cert_evt_param**
ESP_BLUFI_EVENT_RECV_SERVER_CERT

### Public Members

uint8_t ***cert**
Client certificate point

int **cert_len**
Client certificate length

**struct** esp_blufi_cb_param_t::**blufi_recv_client_pkey_evt_param**
ESP_BLUFI_EVENT_RECV_CLIENT_PRIV_KEY

### Public Members

uint8_t ***pkey**
Client Private Key point, if Client certificate not contain Key

int **pkey_len**
Client Private key length

**struct** esp_blufi_cb_param_t::**blufi_recv_server_pkey_evt_param**
ESP_BLUFI_EVENT_RECV_SERVER_PRIV_KEY

### Public Members

uint8_t ***pkey**
Client Private Key point, if Client certificate not contain Key

int **pkey_len**
Client Private key length

**struct esp_blufi_callbacks_t**
BLUFI callback functions type.

### Public Members

*esp_blufi_event_cb_t* **event_cb**
BLUFI event callback

*esp_blufi_negotiate_data_handler_t* **negotiate_data_handler**
BLUFI negotiate data function for negotiate share key

*esp_blufi_encrypt_func_t* **encrypt_func**
BLUFI encrypt data function with share key generated by negotiate_data_handler

*esp_blufi_decrypt_func_t* **decrypt_func**
BLUFI decrypt data function with share key generated by negotiate_data_handler

*esp_blufi_checksum_func_t* **checksum_func**
BLUFI check sum function (FCS)

## Functions

esp_err_t **esp_blufi_register_callbacks**(*esp_blufi_callbacks_t* **callbacks*)
This function is called to receive blufi callback event.

**Return** ESP_OK - success, other - failed

**Parameters**

- `callbacks`: callback functions

esp_err_t **esp_blufi_profile_init**(void)
This function is called to initialize blufi_profile.

**Return** ESP_OK - success, other - failed

esp_err_t **esp_blufi_profile_deinit**(void)
This function is called to de-initialize blufi_profile.

**Return** ESP_OK - success, other - failed esp_err_t **esp_blufi_send_wifi_conn_report** (wifi_mode_t *opmode*, *esp_blufi_sta_conn_state_t sta_conn_state*, uint8_t *softap_conn_num*, *esp_blufi_extra_info_t* **extra_info*)

This function is called to send wifi connection report.

**Return** ESP_OK - success, other - failed

**Parameters**

- `opmode`: : wifi opmode
- `sta_conn_state`: : station is already in connection or not
- `softap_conn_num`: : softap connection number
- `extra_info`: : extra information, such as sta_ssid, softap_ssid and etc.

uint16_t **esp_blufi_get_version** (void)

Get BLUFI profile version.

**Return** Most 8bit significant is Great version, Least 8bit is Sub version

Example code for this API section is provided in bluetooth directory of ESP-IDF examples.

CHAPTER 19

# Ethernet API

## ETHERNET

### Application Example

Ethernet example: ethernet/ethernet.

### API Reference

#### Header Files

- ethernet/include/esp_eth.h

#### Macros

#### Type Definitions

**typedef** bool (***eth_phy_check_link_func**) (void)

**typedef** void (***eth_phy_check_init_func**) (void)

**typedef** *eth_speed_mode_t* (***eth_phy_get_speed_mode_func**) (void)

**typedef** *eth_duplex_mode_t* (***eth_phy_get_duplex_mode_func**) (void)

**typedef** void (***eth_phy_func**) (void)

**typedef** esp_err_t (***eth_tcpip_input_func**) (void *buffer, uint16_t len, void *eb)

**typedef** void (***eth_gpio_config_func**) (void)

**typedef** bool (***eth_phy_get_partner_pause_enable_func**) (void)

### Enumerations

enum **eth_mode_t**

*Values:*

**ETH_MODE_RMII** = 0

**ETH_MDOE_MII**

enum **eth_speed_mode_t**

*Values:*

**ETH_SPEED_MODE_10M** = 0

**ETH_SPEED_MODE_100M**

enum **eth_duplex_mode_t**

*Values:*

**ETH_MODE_HALFDUPLEX** = 0

**ETH_MDOE_FULLDUPLEX**

enum **eth_phy_base_t**

*Values:*

**PHY0** = 0

**PHY1**

**PHY2**

**PHY3**

**PHY4**

**PHY5**

**PHY6**

**PHY7**

**PHY8**

**PHY9**

**PHY10**

**PHY11**

**PHY12**

**PHY13**

**PHY14**

**PHY15**

**PHY16**

**PHY17**

**PHY18**

**PHY19**

**PHY20**

**PHY21**

**PHY22**

**PHY23**

**PHY24**

**PHY25**

**PHY26**

**PHY27**

**PHY28**

**PHY29**

**PHY30**

**PHY31**

## Structures

**struct eth_config_t**
ethernet configuration

### Public Members

*eth_phy_base_t* **phy_addr**
phy base addr (0~31)

*eth_mode_t* **mac_mode**
mac mode only support RMII now

*eth_tcpip_input_func* **tcpip_input**
tcpip input func

*eth_phy_func* **phy_init**
phy init func

*eth_phy_check_link_func* **phy_check_link**
phy check link func

*eth_phy_check_init_func* **phy_check_init**
phy check init func

*eth_phy_get_speed_mode_func* **phy_get_speed_mode**
phy check init func

*eth_phy_get_duplex_mode_func* **phy_get_duplex_mode**
phy check init func

*eth_gpio_config_func* **gpio_config**
gpio config func

bool **flow_ctrl_enable**
flag of flow ctrl enable

*eth_phy_get_partner_pause_enable_func* **phy_get_partner_pause_enable**
get partner pause enable

eth_phy_power_enable_func **phy_power_enable**
enable or disable phy power

### Functions

esp_err_t **esp_eth_init** (*eth_config_t *config*)
Init ethernet mac.

**Note** config can not be NULL,and phy chip must be suitable to phy init func.

**Return**

- ESP_OK
- ESP_FAIL

**Parameters**

- `config`: mac init data.

esp_err_t **esp_eth_tx** (uint8_t **buf*, uint16_t *size*)
Send packet from tcp/ip to mac.

**Note** buf can not be NULL,size must be less than 1580

**Return**

- ESP_OK
- ESP_FAIL

**Parameters**

- `buf`: start address of packet data.
- `size`: size (byte) of packet data.

esp_err_t **esp_eth_enable** (void)
Enable ethernet interface.

**Note** Shout be called after esp_eth_init

**Return**

- ESP_OK
- ESP_FAIL

esp_err_t **esp_eth_disable** (void)
Disable ethernet interface.

**Note** Shout be called after esp_eth_init

**Return**

- ESP_OK
- ESP_FAIL

void **esp_eth_get_mac** (uint8_t *mac*[6])
Get mac addr.

**Note** mac addr must be a valid unicast address

**Parameters**

- `mac`: start address of mac address.

void **esp_eth_smi_write**(uint32_t *reg_num*, uint16_t *value*)
Read phy reg with smi interface.

**Note** phy base addr must be right.

**Parameters**

- `reg_num`: phy reg num.
- `value`: value which write to phy reg.

uint16_t **esp_eth_smi_read**(uint32_t *reg_num*)
Write phy reg with smi interface.

**Note** phy base addr must be right.

**Return** value what read from phy reg

**Parameters**

- `reg_num`: phy reg num.

void **esp_eth_free_rx_buf**(void **buf*)
Free emac rx buf.

**Note** buf can not be null,and it is tcpip input buf.

**Parameters**

- `buf`: start address of recevie packet data.

Example code for this API section is provided in ethernet directory of ESP-IDF examples.

# CHAPTER 20

## Peripherals API

### Analog to Digital Converter

#### Overview

ESP32 integrates two 12-bit SAR ("Successive Approximation Register") ADCs (Analog to Digital Converters) and supports measurements on 18 channels (analog enabled pins). Some of these pins can be used to build a programmable gain amplifier which is used for the measurement of small analog signals.

The ADC driver API currently only supports ADC1 (9 channels, attached to GPIOs 32-39).

Taking an ADC reading involves configuring the ADC with the desired precision and attentuation settings, and then calling adc1_get_voltage() to read the channel.

It is also possible to read the internal hall effect sensor via ADC1.

#### Application Example

Reading voltage on ADC1 channel 0 (GPIO 36):

```
#include <driver/adc.h>

...

    adc1_config_width(ADC_WIDTH_12Bit);
    adc1_config_channel_atten(ADC1_CHANNEL_0,ADC_ATTEN_0db);
    int val = adc1_get_voltage(ADC1_CHANNEL_0);
```

Reading the internal hall effect sensor:

```
#include <driver/adc.h>

...
```

```
adc1_config_width(ADC_WIDTH_12Bit);
int val = hall_sensor_read();
```

The value read in both these examples is 12 bits wide (range 0-4095).

## API Reference

### Header Files

- *components/driver/include/driver/adc.h*

### Enumerations

**enum adc1_channel_t**
*Values:*

**ADC1_CHANNEL_0** = 0
ADC1 channel 0 is GPIO36

**ADC1_CHANNEL_1**
ADC1 channel 1 is GPIO37

**ADC1_CHANNEL_2**
ADC1 channel 2 is GPIO38

**ADC1_CHANNEL_3**
ADC1 channel 3 is GPIO39

**ADC1_CHANNEL_4**
ADC1 channel 4 is GPIO32

**ADC1_CHANNEL_5**
ADC1 channel 5 is GPIO33

**ADC1_CHANNEL_6**
ADC1 channel 6 is GPIO34

**ADC1_CHANNEL_7**
ADC1 channel 7 is GPIO35

**ADC1_CHANNEL_MAX**

**enum adc_atten_t**
*Values:*

**ADC_ATTEN_0db** = 0
The input voltage of ADC will be reduced to about 1/1

**ADC_ATTEN_2_5db** = 1
The input voltage of ADC will be reduced to about 1/1.34

**ADC_ATTEN_6db** = 2
The input voltage of ADC will be reduced to about 1/2

**ADC_ATTEN_11db** = 3
The input voltage of ADC will be reduced to about 1/3.6

**enum adc_bits_width_t**
*Values:*

**ADC_WIDTH_9Bit** = 0
ADC capture width is 9Bit

**ADC_WIDTH_10Bit** = 1
ADC capture width is 10Bit

**ADC_WIDTH_11Bit** = 2
ADC capture width is 11Bit

**ADC_WIDTH_12Bit** = 3
ADC capture width is 12Bit

### Functions

esp_err_t **adc1_config_width** (*adc_bits_width_t width_bit*)
Configure ADC1 capture width.

The configuration is for all channels of ADC1

**Return**

- ESP_OK success
- ESP_ERR_INVALID_ARG Parameter error

**Parameters**

- `width_bit`: Bit capture width for ADC1

esp_err_t **adc1_config_channel_atten** (*adc1_channel_t channel*, *adc_atten_t atten*)
Configure the ADC1 channel, including setting attenuation.

The default ADC full-scale voltage is 1.1V. To read higher voltages (up to the pin maximum voltage, usually 3.3V) requires setting >0dB signal attenuation for that ADC channel.

**Note** This function also configures the input GPIO pin mux to connect it to the ADC1 channel. It must be called before calling adc1_get_voltage() for this channel.

When VDD_A is 3.3V:

- 0dB attenuaton (ADC_ATTEN_0db) gives full-scale voltage 1.1V
- 2.5dB attenuation (ADC_ATTEN_2_5db) gives full-scale voltage 1.5V
- 6dB attenuation (ADC_ATTEN_6db) gives full-scale voltage 2.2V
- 11dB attenuation (ADC_ATTEN_11db) gives full-scale voltage 3.9V (see note below)

**Note** The full-scale voltage is the voltage corresponding to a maximum reading (depending on ADC1 configured bit width, this value is: 4095 for 12-bits, 2047 for 11-bits, 1023 for 10-bits, 511 for 9 bits.)

**Note** At 11dB attenuation the maximum voltage is limited by VDD_A, not the full scale voltage.

**Return**

- ESP_OK success
- ESP_ERR_INVALID_ARG Parameter error

**Parameters**

- `channel`: ADC1 channel to configure

- `atten`: Attenuation level

int **adc1_get_voltage** (*adc1_channel_t channel*)

Take an ADC1 reading on a single channel.

**Note** Call adc1_config_width() before the first time this function is called.

**Note** For a given channel, adc1_config_channel_atten(channel) must be called before the first time this function is called.

**Return**

- -1: Parameter error
- Other: ADC1 channel reading.

**Parameters**

- `channel`: ADC1 channel to read

int **hall_sensor_read** ()

Read Hall Sensor.

**Note** The Hall Sensor uses channels 0 and 3 of ADC1. Do not configure these channels for use as ADC channels.

**Note** The ADC1 module must be enabled by calling adc1_config_width() before calling hall_sensor_read(). ADC1 should be configured for 12 bit readings, as the hall sensor readings are low values and do not cover the full range of the ADC.

**Return** The hall sensor reading.

## Digital To Analog Converter

### Overview

ESP32 has two 8-bit DAC (digital to analog converter) channels, connected to GPIO25 (Channel 1) and GPIO26 (Channel 2).

The DAC driver allows these channels to be set to arbitrary voltages.

The DAC channels can also be driven with DMA-style written sample data, via the *I2S driver* when using the "built-in DAC mode".

For other analog output options, see the *Sigma-delta Modulation module* and the *LED Control module*. Both these modules produce high frequency PWM output, which can be hardware low-pass filtered in order to generate a lower frequency analog output.

### Application Example

Setting DAC channel 1 (GPIO 25) voltage to approx 0.78 of VDD_A voltage (VDD * 200 / 255). For VDD_A 3.3V, this is 2.59V:

```
#include <driver/dac.h>

...
```

```
dac_out_voltage(DAC_CHANNEL_1, 200);
```

### API Reference

#### Header Files

- *components/driver/include/driver/dac.h*

#### Enumerations

**enum dac_channel_t**
*Values:*

**DAC_CHANNEL_1** = 1
DAC channel 1 is GPIO25

**DAC_CHANNEL_2**
DAC channel 2 is GPIO26

**DAC_CHANNEL_MAX**

#### Functions

esp_err_t **dac_out_voltage**(*dac_channel_t channel*, uint8_t *dac_value*)
Set DAC output voltage.

DAC output is 8-bit. Maximum (255) corresponds to VDD.

**Note** When this function is called, function for the DAC channel's GPIO pin is reconfigured for RTC DAC function.

**Return**

- ESP_OK success
- ESP_ERR_INVALID_ARG Parameter error

**Parameters**

- `channel`: DAC channel
- `dac_value`: DAC output value

## GPIO & RTC GPIO

### Overview

The ESP32 chip features 40 physical GPIO pads. Some GPIO pads cannot be used or do not have the corresponding pin on the chip package(refer to technical reference manual ). Each pad can be used as a general purpose I/O or can be connected to an internal peripheral signal.

- Note that GPIO6-11 are usually used for SPI flash.
- GPIO34-39 can only be set as input mode and do not have software pullup or pulldown functions.

There is also separate "RTC GPIO" support, which functions when GPIOs are routed to the "RTC" low-power and analog subsystem. These pin functions can be used when in deep sleep, when the *Ultra Low Power co-processor* is running, or when analog functions such as ADC/DAC/etc are in use.

## Application Example

GPIO output and input interrupt example: peripherals/gpio.

## API Reference

### Header Files

- driver/include/driver/gpio.h
- driver/include/driver/rtc_io.h

### Macros

### Normal GPIO

**GPIO_SEL_0** (BIT(0))
Pin 0 selected

**GPIO_SEL_1** (BIT(1))
Pin 1 selected

**GPIO_SEL_2** (BIT(2))
Pin 2 selected

**GPIO_SEL_3** (BIT(3))
Pin 3 selected

**GPIO_SEL_4** (BIT(4))
Pin 4 selected

**GPIO_SEL_5** (BIT(5))
Pin 5 selected

**GPIO_SEL_6** (BIT(6))
Pin 6 selected

**GPIO_SEL_7** (BIT(7))
Pin 7 selected

**GPIO_SEL_8** (BIT(8))
Pin 8 selected

**GPIO_SEL_9** (BIT(9))
Pin 9 selected

**GPIO_SEL_10** (BIT(10))
Pin 10 selected

**GPIO_SEL_11** (BIT(11))
Pin 11 selected

**GPIO_SEL_12** (BIT(12))
Pin 12 selected

**GPIO_SEL_13** (BIT(13))
Pin 13 selected

**GPIO_SEL_14** (BIT(14))
Pin 14 selected

**GPIO_SEL_15** (BIT(15))
Pin 15 selected

**GPIO_SEL_16** (BIT(16))
Pin 16 selected

**GPIO_SEL_17** (BIT(17))
Pin 17 selected

**GPIO_SEL_18** (BIT(18))
Pin 18 selected

**GPIO_SEL_19** (BIT(19))
Pin 19 selected

**GPIO_SEL_21** (BIT(21))
Pin 21 selected

**GPIO_SEL_22** (BIT(22))
Pin 22 selected

**GPIO_SEL_23** (BIT(23))
Pin 23 selected

**GPIO_SEL_25** (BIT(25))
Pin 25 selected

**GPIO_SEL_26** (BIT(26))
Pin 26 selected

**GPIO_SEL_27** (BIT(27))
Pin 27 selected

**GPIO_SEL_32** ((uint64_t)(((uint64_t)1)<<32))
Pin 32 selected

**GPIO_SEL_33** ((uint64_t)(((uint64_t)1)<<33))
Pin 33 selected

**GPIO_SEL_34** ((uint64_t)(((uint64_t)1)<<34))
Pin 34 selected

**GPIO_SEL_35** ((uint64_t)(((uint64_t)1)<<35))
Pin 35 selected

**GPIO_SEL_36** ((uint64_t)(((uint64_t)1)<<36))
Pin 36 selected

**GPIO_SEL_37** ((uint64_t)(((uint64_t)1)<<37))
Pin 37 selected

**GPIO_SEL_38** ((uint64_t)(((uint64_t)1)<<38))
Pin 38 selected

**GPIO_SEL_39** ((uint64_t)(((uint64_t)1)<<39))
Pin 39 selected

**GPIO_PIN_REG_0** PERIPHS_IO_MUX_GPIO0_U

**GPIO_PIN_REG_1** PERIPHS_IO_MUX_U0TXD_U

**GPIO_PIN_REG_2** PERIPHS_IO_MUX_GPIO2_U

**GPIO_PIN_REG_3** PERIPHS_IO_MUX_U0RXD_U

**GPIO_PIN_REG_4** PERIPHS_IO_MUX_GPIO4_U

**GPIO_PIN_REG_5** PERIPHS_IO_MUX_GPIO5_U

**GPIO_PIN_REG_6** PERIPHS_IO_MUX_SD_CLK_U

**GPIO_PIN_REG_7** PERIPHS_IO_MUX_SD_DATA0_U

**GPIO_PIN_REG_8** PERIPHS_IO_MUX_SD_DATA1_U

**GPIO_PIN_REG_9** PERIPHS_IO_MUX_SD_DATA2_U

**GPIO_PIN_REG_10** PERIPHS_IO_MUX_SD_DATA3_U

**GPIO_PIN_REG_11** PERIPHS_IO_MUX_SD_CMD_U

**GPIO_PIN_REG_12** PERIPHS_IO_MUX_MTDI_U

**GPIO_PIN_REG_13** PERIPHS_IO_MUX_MTCK_U

**GPIO_PIN_REG_14** PERIPHS_IO_MUX_MTMS_U

**GPIO_PIN_REG_15** PERIPHS_IO_MUX_MTDO_U

**GPIO_PIN_REG_16** PERIPHS_IO_MUX_GPIO16_U

**GPIO_PIN_REG_17** PERIPHS_IO_MUX_GPIO17_U

**GPIO_PIN_REG_18** PERIPHS_IO_MUX_GPIO18_U

**GPIO_PIN_REG_19** PERIPHS_IO_MUX_GPIO19_U

**GPIO_PIN_REG_20** PERIPHS_IO_MUX_GPIO20_U

**GPIO_PIN_REG_21** PERIPHS_IO_MUX_GPIO21_U

**GPIO_PIN_REG_22** PERIPHS_IO_MUX_GPIO22_U

**GPIO_PIN_REG_23** PERIPHS_IO_MUX_GPIO23_U

**GPIO_PIN_REG_25** PERIPHS_IO_MUX_GPIO25_U

**GPIO_PIN_REG_26** PERIPHS_IO_MUX_GPIO26_U

**GPIO_PIN_REG_27** PERIPHS_IO_MUX_GPIO27_U

**GPIO_PIN_REG_32** PERIPHS_IO_MUX_GPIO32_U

**GPIO_PIN_REG_33** PERIPHS_IO_MUX_GPIO33_U

**GPIO_PIN_REG_34** PERIPHS_IO_MUX_GPIO34_U

**GPIO_PIN_REG_35** PERIPHS_IO_MUX_GPIO35_U

**GPIO_PIN_REG_36** PERIPHS_IO_MUX_GPIO36_U

**GPIO_PIN_REG_37** PERIPHS_IO_MUX_GPIO37_U

**GPIO_PIN_REG_38** PERIPHS_IO_MUX_GPIO38_U

**GPIO_PIN_REG_39** PERIPHS_IO_MUX_GPIO39_U

**GPIO_APP_CPU_INTR_ENA** (BIT(0))

**GPIO_APP_CPU_NMI_INTR_ENA** (BIT(1))

**GPIO_PRO_CPU_INTR_ENA** (BIT(2))

**GPIO_PRO_CPU_NMI_INTR_ENA** (BIT(3))

**GPIO_SDIO_EXT_INTR_ENA** (BIT(4))

**GPIO_MODE_DEF_INPUT** (BIT0)

**GPIO_MODE_DEF_OUTPUT** (BIT1)

**GPIO_MODE_DEF_OD** (BIT2)

**GPIO_PIN_COUNT** 40

**GPIO_IS_VALID_GPIO** (gpio_num) ((gpio_num < GPIO_PIN_COUNT && GPIO_PIN_MUX_REG[gpio_num] != 0))

**GPIO_IS_VALID_OUTPUT_GPIO** (gpio_num) ((GPIO_IS_VALID_GPIO(gpio_num)) && (gpio_num < 34))

### Type Definitions

### Normal GPIO

**typedef** void (***gpio_isr_t**) (void *)

**typedef** intr_handle_t **gpio_isr_handle_t**

### Enumerations

### Normal GPIO

**enum gpio_num_t**

*Values:*

**GPIO_NUM_0** = 0
GPIO0, input and output

**GPIO_NUM_1** = 1
GPIO1, input and output

**GPIO_NUM_2** = 2
GPIO2, input and output

**GPIO_NUM_3** = 3
GPIO3, input and output

**GPIO_NUM_4** = 4
GPIO4, input and output

**GPIO_NUM_5** = 5
GPIO5, input and output

**GPIO_NUM_6** = 6
GPIO6, input and output

**GPIO_NUM_7** = 7
GPIO7, input and output

**GPIO_NUM_8** = 8
GPIO8, input and output

**GPIO_NUM_9** = 9
GPIO9, input and output

**GPIO_NUM_10** = 10
GPIO10, input and output

**GPIO_NUM_11** = 11
GPIO11, input and output

**GPIO_NUM_12** = 12
GPIO12, input and output

**GPIO_NUM_13** = 13
GPIO13, input and output

**GPIO_NUM_14** = 14
GPIO14, input and output

**GPIO_NUM_15** = 15
GPIO15, input and output

**GPIO_NUM_16** = 16
GPIO16, input and output

**GPIO_NUM_17** = 17
GPIO17, input and output

**GPIO_NUM_18** = 18
GPIO18, input and output

**GPIO_NUM_19** = 19
GPIO19, input and output

**GPIO_NUM_21** = 21
GPIO21, input and output

**GPIO_NUM_22** = 22
GPIO22, input and output

**GPIO_NUM_23** = 23
GPIO23, input and output

**GPIO_NUM_25** = 25
GPIO25, input and output

**GPIO_NUM_26** = 26
GPIO26, input and output

**GPIO_NUM_27** = 27
GPIO27, input and output

**GPIO_NUM_32** = 32
GPIO32, input and output

**GPIO_NUM_33** = 33
GPIO32, input and output

**GPIO_NUM_34** = 34
GPIO34, input mode only

**GPIO_NUM_35** = 35
GPIO35, input mode only

**GPIO_NUM_36** = 36
GPIO36, input mode only

**GPIO_NUM_37** = 37
GPIO37, input mode only

**GPIO_NUM_38** = 38
GPIO38, input mode only

**GPIO_NUM_39** = 39
GPIO39, input mode only

**GPIO_NUM_MAX** = 40

**enum gpio_int_type_t**
*Values:*

**GPIO_INTR_DISABLE** = 0
Disable GPIO interrupt

**GPIO_INTR_POSEDGE** = 1
GPIO interrupt type : rising edge

**GPIO_INTR_NEGEDGE** = 2
GPIO interrupt type : falling edge

**GPIO_INTR_ANYEDGE** = 3
GPIO interrupt type : both rising and falling edge

**GPIO_INTR_LOW_LEVEL** = 4
GPIO interrupt type : input low level trigger

**GPIO_INTR_HIGH_LEVEL** = 5
GPIO interrupt type : input high level trigger

**GPIO_INTR_MAX**

**enum gpio_mode_t**
*Values:*

**GPIO_MODE_INPUT** = GPIO_MODE_DEF_INPUT
GPIO mode : input only

**GPIO_MODE_OUTPUT** = GPIO_MODE_DEF_OUTPUT
GPIO mode : output only mode

**GPIO_MODE_OUTPUT_OD** = ((GPIO_MODE_DEF_OUTPUT)|(GPIO_MODE_DEF_OD))
GPIO mode : output only with open-drain mode

**GPIO_MODE_INPUT_OUTPUT_OD** = ((GPIO_MODE_DEF_INPUT)|(GPIO_MODE_DEF_OUTPUT)|(GPIO_MODE_DEF_C
GPIO mode : output and input with open-drain mode

**GPIO_MODE_INPUT_OUTPUT** = ((GPIO_MODE_DEF_INPUT)|(GPIO_MODE_DEF_OUTPUT))
GPIO mode : output and input mode

**enum gpio_pullup_t**
*Values:*

**GPIO_PULLUP_DISABLE** = 0x0
Disable GPIO pull-up resistor

**GPIO_PULLUP_ENABLE** = 0x1
Enable GPIO pull-up resistor

enum **gpio_pulldown_t**
*Values:*

**GPIO_PULLDOWN_DISABLE** = 0x0
Disable GPIO pull-down resistor

**GPIO_PULLDOWN_ENABLE** = 0x1
Enable GPIO pull-down resistor

enum **gpio_pull_mode_t**
*Values:*

**GPIO_PULLUP_ONLY**
Pad pull up

**GPIO_PULLDOWN_ONLY**
Pad pull down

**GPIO_PULLUP_PULLDOWN**
Pad pull up + pull down

**GPIO_FLOATING**
Pad floating

### RTC GPIO

enum **rtc_gpio_mode_t**
*Values:*

**RTC_GPIO_MODE_INPUT_ONLY**
Pad output

**RTC_GPIO_MODE_OUTPUT_ONLY**
Pad input

**RTC_GPIO_MODE_INPUT_OUTUT**
Pad pull output + input

**RTC_GPIO_MODE_DISABLED**
Pad (output + input) disable

### Structures

### Normal GPIO

struct **gpio_config_t**
Configuration parameters of GPIO pad for gpio_config function.

#### Public Members

uint64_t **pin_bit_mask**
GPIO pin: set with bit mask, each bit maps to a GPIO

*gpio_mode_t* **mode**
GPIO mode: set input/output mode

*gpio_pullup_t* **pull_up_en**
GPIO pull-up

*gpio_pulldown_t* **pull_down_en**
GPIO pull-down

*gpio_int_type_t* **intr_type**
GPIO interrupt type

### Functions

### Normal GPIO

esp_err_t **gpio_config**(*gpio_config_t *pGPIOConfig*)
GPIO common configuration.

Configure GPIO's Mode,pull-up,PullDown,IntrType

**Return**

- ESP_OK success
- ESP_ERR_INVALID_ARG Parameter error

**Parameters**

- `pGPIOConfig`: Pointer to GPIO configure struct

esp_err_t **gpio_set_intr_type**(*gpio_num_t gpio_num*, *gpio_int_type_t intr_type*)
GPIO set interrupt trigger type.

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_ARG Parameter error

**Parameters**

- `gpio_num`: GPIO number. If you want to set the trigger type of e.g. of GPIO16, gpio_num should be GPIO_NUM_16 (16);
- `intr_type`: Interrupt type, select from gpio_int_type_t

esp_err_t **gpio_intr_enable**(*gpio_num_t gpio_num*)
Enable GPIO module interrupt signal.

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_ARG Parameter error

**Parameters**

- `gpio_num`: GPIO number. If you want to enable an interrupt on e.g. GPIO16, gpio_num should be GPIO_NUM_16 (16);

esp_err_t **gpio_intr_disable**(*gpio_num_t gpio_num*)
Disable GPIO module interrupt signal.

**Return**

- ESP_OK success
- ESP_ERR_INVALID_ARG Parameter error

**Parameters**

- `gpio_num`: GPIO number. If you want to disable the interrupt of e.g. GPIO16, gpio_num should be GPIO_NUM_16 (16);

esp_err_t **gpio_set_level** (*gpio_num_t gpio_num*, uint32_t *level*)

GPIO set output level.

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_ARG GPIO number error

**Parameters**

- `gpio_num`: GPIO number. If you want to set the output level of e.g. GPIO16, gpio_num should be GPIO_NUM_16 (16);
- `level`: Output level. 0: low ; 1: high

int **gpio_get_level** (*gpio_num_t gpio_num*)

GPIO get input level.

**Return**

- 0 the GPIO input level is 0
- 1 the GPIO input level is 1

**Parameters**

- `gpio_num`: GPIO number. If you want to get the logic level of e.g. pin GPIO16, gpio_num should be GPIO_NUM_16 (16);

esp_err_t **gpio_set_direction** (*gpio_num_t gpio_num*, *gpio_mode_t mode*)

GPIO set direction.

Configure GPIO direction,such as output_only,input_only,output_and_input

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_ARG GPIO error

**Parameters**

- `gpio_num`: Configure GPIO pins number, it should be GPIO number. If you want to set direction of e.g. GPIO16, gpio_num should be GPIO_NUM_16 (16);
- `mode`: GPIO direction

esp_err_t **gpio_set_pull_mode** (*gpio_num_t gpio_num*, *gpio_pull_mode_t pull*)

Configure GPIO pull-up/pull-down resistors.

Only pins that support both input & output have integrated pull-up and pull-down resistors. Input-only GPIOs 34-39 do not.

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_ARG : Parameter error

**Parameters**

- `gpio_num`: GPIO number. If you want to set pull up or down mode for e.g. GPIO16, gpio_num should be GPIO_NUM_16 (16);
- `pull`: GPIO pull up/down mode.

esp_err_t **gpio_wakeup_enable** (*gpio_num_t gpio_num*, *gpio_int_type_t intr_type*)
Enable GPIO wake-up function.

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_ARG Parameter error

**Parameters**

- `gpio_num`: GPIO number.
- `intr_type`: GPIO wake-up type. Only GPIO_INTR_LOW_LEVEL or GPIO_INTR_HIGH_LEVEL can be used.

esp_err_t **gpio_wakeup_disable** (*gpio_num_t gpio_num*)
Disable GPIO wake-up function.

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_ARG Parameter error

**Parameters**

- `gpio_num`: GPIO number

esp_err_t **gpio_isr_register** (void (*fn)) void *
, void **arg*, int *intr_alloc_flags*, *gpio_isr_handle_t *handle*Register GPIO interrupt handler, the handler is an ISR. The handler will be attached to the same CPU core that this function is running on.

This ISR function is called whenever any GPIO interrupt occurs. See the alternative gpio_install_isr_service() and gpio_isr_handler_add() API in order to have the driver support per-GPIO ISRs.

To disable or remove the ISR, pass the returned handle to the *interrupt allocation functions*.

**Parameters**

- `fn`: Interrupt handler function.
- `intr_alloc_flags`: Flags used to allocate the interrupt. One or multiple (ORred) ESP_INTR_FLAG_* values. See esp_intr_alloc.h for more info.
- `arg`: Parameter for handler function
- `handle`: Pointer to return handle. If non-NULL, a handle for the interrupt will be returned here.

**Return**

- ESP_OK Success ;

- ESP_ERR_INVALID_ARG GPIO error

esp_err_t **gpio_pullup_en** (*gpio_num_t gpio_num*)

Enable pull-up on GPIO.

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_ARG Parameter error

**Parameters**

- `gpio_num`: GPIO number

esp_err_t **gpio_pullup_dis** (*gpio_num_t gpio_num*)

Disable pull-up on GPIO.

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_ARG Parameter error

**Parameters**

- `gpio_num`: GPIO number

esp_err_t **gpio_pulldown_en** (*gpio_num_t gpio_num*)

Enable pull-down on GPIO.

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_ARG Parameter error

**Parameters**

- `gpio_num`: GPIO number

esp_err_t **gpio_pulldown_dis** (*gpio_num_t gpio_num*)

Disable pull-down on GPIO.

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_ARG Parameter error

**Parameters**

- `gpio_num`: GPIO number

esp_err_t **gpio_install_isr_service** (int *intr_alloc_flags*)

Install the driver's GPIO ISR handler service, which allows per-pin GPIO interrupt handlers.

This function is incompatible with gpio_isr_register() - if that function is used, a single global ISR is registered for all GPIO interrupts. If this function is used, the ISR service provides a global GPIO ISR and individual pin handlers are registered via the gpio_isr_register() function.

**Return**

- ESP_OK Success
- ESP_FAIL Operation fail
- ESP_ERR_NO_MEM No memory to install this service

**Parameters**

- `intr_alloc_flags`: Flags used to allocate the interrupt. One or multiple (ORred) ESP_INTR_FLAG_* values. See esp_intr_alloc.h for more info.

void **gpio_uninstall_isr_service**()

Uninstall the driver's GPIO ISR service, freeing related resources.

esp_err_t **gpio_isr_handler_add**(*gpio_num_t gpio_num*, *gpio_isr_t isr_handler*, void **args*)

Add ISR handler for the corresponding GPIO pin.

Call this function after using gpio_install_isr_service() to install the driver's GPIO ISR handler service.

The pin ISR handlers no longer need to be declared with IRAM_ATTR, unless you pass the ESP_INTR_FLAG_IRAM flag when allocating the ISR in gpio_install_isr_service().

This ISR handler will be called from an ISR. So there is a stack size limit (configurable as "ISR stack size" in menuconfig). This limit is smaller compared to a global GPIO interrupt handler due to the additional level of indirection.

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_STATE Wrong state, the ISR service has not been initialized.
- ESP_ERR_INVALID_ARG Parameter error

**Parameters**

- `gpio_num`: GPIO number
- `isr_handler`: ISR handler function for the corresponding GPIO number.
- `args`: parameter for ISR handler.

esp_err_t **gpio_isr_handler_remove**(*gpio_num_t gpio_num*)

Remove ISR handler for the corresponding GPIO pin.

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_STATE Wrong state, the ISR service has not been initialized.
- ESP_ERR_INVALID_ARG Parameter error

**Parameters**

- `gpio_num`: GPIO number

### RTC GPIO

**static** bool **rtc_gpio_is_valid_gpio**(*gpio_num_t gpio_num*)

Determine if the specified GPIO is a valid RTC GPIO.

**Return** true if GPIO is valid for RTC GPIO use. talse otherwise.

**Parameters**

- `gpio_num`: GPIO number

esp_err_t **rtc_gpio_init** (*gpio_num_t gpio_num*)
Init a GPIO as RTC GPIO.

This function must be called when initializing a pad for an analog function.

**Return**

- ESP_OK success
- ESP_ERR_INVALID_ARG GPIO is not an RTC IO

**Parameters**

- `gpio_num`: GPIO number (e.g. GPIO_NUM_12)

esp_err_t **rtc_gpio_deinit** (*gpio_num_t gpio_num*)
Init a GPIO as digital GPIO.

**Return**

- ESP_OK success
- ESP_ERR_INVALID_ARG GPIO is not an RTC IO

**Parameters**

- `gpio_num`: GPIO number (e.g. GPIO_NUM_12)

uint32_t **rtc_gpio_get_level** (*gpio_num_t gpio_num*)
Get the RTC IO input level.

**Return**

- 1 High level
- 0 Low level
- ESP_ERR_INVALID_ARG GPIO is not an RTC IO

**Parameters**

- `gpio_num`: GPIO number (e.g. GPIO_NUM_12)

esp_err_t **rtc_gpio_set_level** (*gpio_num_t gpio_num*, uint32_t *level*)
Set the RTC IO output level.

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_ARG GPIO is not an RTC IO

**Parameters**

- `gpio_num`: GPIO number (e.g. GPIO_NUM_12)
- `level`: output level

esp_err_t **rtc_gpio_set_direction** (*gpio_num_t gpio_num*, *rtc_gpio_mode_t mode*)
RTC GPIO set direction.

Configure RTC GPIO direction, such as output only, input only, output and input.

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_ARG GPIO is not an RTC IO

**Parameters**

- `gpio_num`: GPIO number (e.g. GPIO_NUM_12)
- `mode`: GPIO direction

esp_err_t **rtc_gpio_pullup_en** (*gpio_num_t gpio_num*)
RTC GPIO pullup enable.

This function only works for RTC IOs. In general, call gpio_pullup_en, which will work both for normal GPIOs and RTC IOs.

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_ARG GPIO is not an RTC IO

**Parameters**

- `gpio_num`: GPIO number (e.g. GPIO_NUM_12)

esp_err_t **rtc_gpio_pulldown_en** (*gpio_num_t gpio_num*)
RTC GPIO pulldown enable.

This function only works for RTC IOs. In general, call gpio_pulldown_en, which will work both for normal GPIOs and RTC IOs.

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_ARG GPIO is not an RTC IO

**Parameters**

- `gpio_num`: GPIO number (e.g. GPIO_NUM_12)

esp_err_t **rtc_gpio_pullup_dis** (*gpio_num_t gpio_num*)
RTC GPIO pullup disable.

This function only works for RTC IOs. In general, call gpio_pullup_dis, which will work both for normal GPIOs and RTC IOs.

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_ARG GPIO is not an RTC IO

**Parameters**

- `gpio_num`: GPIO number (e.g. GPIO_NUM_12) esp_err_t **rtc_gpio_pulldown_dis**(*gpio_num_t gpio_num*)

RTC GPIO pulldown disable.

This function only works for RTC IOs. In general, call gpio_pulldown_dis, which will work both for normal GPIOs and RTC IOs.

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_ARG GPIO is not an RTC IO

**Parameters**

- `gpio_num`: GPIO number (e.g. GPIO_NUM_12)

> **Warning:** doxygenfunction: Cannot find function "rtc_gpio_unhold_all" in doxygen xml output for project "esp32-idf" from directory: xml/

# I2C

## Overview

ESP32 has two I2C controllers which can be set as master mode or slave mode.

## Application Example

I2C master and slave example: peripherals/i2c.

## API Reference

### Header Files

- driver/include/driver/i2c.h

### Macros

**I2C_APB_CLK_FREQ** APB_CLK_FREQ

I2C source clock is APB clock, 80MHz

**I2C_FIFO_LEN** (32)

I2C hardware fifo length

### Type Definitions

**typedef** void ***i2c_cmd_handle_t**

I2C command handle

### Enumerations

**enum i2c_mode_t**
*Values:*

**I2C_MODE_SLAVE** = 0
I2C slave mode

**I2C_MODE_MASTER**
I2C master mode

**I2C_MODE_MAX**

**enum i2c_rw_t**
*Values:*

**I2C_MASTER_WRITE** = 0
I2C write data

**I2C_MASTER_READ**
I2C read data

**enum i2c_trans_mode_t**
*Values:*

**I2C_DATA_MODE_MSB_FIRST** = 0
I2C data msb first

**I2C_DATA_MODE_LSB_FIRST** = 1
I2C data lsb first

**I2C_DATA_MODE_MAX**

**enum i2c_opmode_t**
*Values:*

**I2C_CMD_RESTART** = 0
I2C restart command

**I2C_CMD_WRITE**
I2C write command

**I2C_CMD_READ**
I2C read command

**I2C_CMD_STOP**
I2C stop command

**I2C_CMD_END**
I2C end command

**enum i2c_port_t**
*Values:*

**I2C_NUM_0** = 0
I2C port 0

**I2C_NUM_1**
I2C port 1

**I2C_NUM_MAX**

**enum i2c_addr_mode_t**
*Values:*

**I2C_ADDR_BIT_7** = 0
I2C 7bit address for slave mode

**I2C_ADDR_BIT_10**
I2C 10bit address for slave mode

**I2C_ADDR_BIT_MAX**

### Structures

struct **i2c_config_t**
I2C initialization parameters.

#### Public Members

*i2c_mode_t* **mode**
I2C mode

*gpio_num_t* **sda_io_num**
GPIO number for I2C sda signal

*gpio_pullup_t* **sda_pullup_en**
Internal GPIO pull mode for I2C sda signal

*gpio_num_t* **scl_io_num**
GPIO number for I2C scl signal

*gpio_pullup_t* **scl_pullup_en**
Internal GPIO pull mode for I2C scl signal

uint32_t **clk_speed**
I2C clock frequency for master mode, (no higher than 1MHz for now)

uint8_t **addr_10bit_en**
I2C 10bit address mode enable for slave mode

uint16_t **slave_addr**
I2C address for slave mode

### Functions

esp_err_t **i2c_driver_install**(*i2c_port_t i2c_num*, *i2c_mode_t mode*, size_t *slv_rx_buf_len*, size_t *slv_tx_buf_len*, int *intr_alloc_flags*)
I2C driver install.

**Note** Only slave mode will use this value, driver will ignore this value in master mode.

**Note** Only slave mode will use this value, driver will ignore this value in master mode.

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_ARG Parameter error
- ESP_FAIL Driver install error

**Parameters**

- `i2c_num`: I2C port number

- `mode`: I2C mode( master or slave )
- `slv_rx_buf_len`: receiving buffer size for slave mode

**Parameters**

- `slv_tx_buf_len`: sending buffer size for slave mode

**Parameters**

- `intr_alloc_flags`: Flags used to allocate the interrupt. One or multiple (ORred) ESP_INTR_FLAG_* values. See esp_intr_alloc.h for more info.

esp_err_t **`i2c_driver_delete`**(*i2c_port_t i2c_num*)

I2C driver delete.

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_ARG Parameter error

**Parameters**

- `i2c_num`: I2C port number

esp_err_t **`i2c_param_config`**(*i2c_port_t i2c_num*, *i2c_config_t *i2c_conf*)

I2C parameter initialization.

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_ARG Parameter error

**Parameters**

- `i2c_num`: I2C port number
- `i2c_conf`: pointer to I2C parameter settings

esp_err_t **`i2c_reset_tx_fifo`**(*i2c_port_t i2c_num*)

reset I2C tx hardware fifo

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_ARG Parameter error

**Parameters**

- `i2c_num`: I2C port number

esp_err_t **`i2c_reset_rx_fifo`**(*i2c_port_t i2c_num*)

reset I2C rx fifo

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_ARG Parameter error

**Parameters**

- `i2c_num`: I2C port number

esp_err_t **i2c_isr_register** (*i2c_port_t* *i2c_num*, void (**fn*)) void *
, void **arg*, int *intr_alloc_flags*, intr_handle_t **handle*I2C isr handler register.

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_ARG Parameter error

**Parameters**

- `i2c_num`: I2C port number
- `fn`: isr handler function
- `arg`: parameter for isr handler function
- `intr_alloc_flags`: Flags used to allocate the interrupt. One or multiple (ORred) ESP_INTR_FLAG_* values. See esp_intr_alloc.h for more info.
- `handle`: handle return from esp_intr_alloc.

esp_err_t **i2c_isr_free** (intr_handle_t *handle*)
to delete and free I2C isr.

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_ARG Parameter error

**Parameters**

- `handle`: handle of isr.

esp_err_t **i2c_set_pin** (*i2c_port_t* *i2c_num*, *gpio_num_t* *sda_io_num*, *gpio_num_t* *scl_io_num*, *gpio_pullup_t* *sda_pullup_en*, *gpio_pullup_t* *scl_pullup_en*, *i2c_mode_t* *mode*)
Configure GPIO signal for I2C sck and sda.

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_ARG Parameter error

**Parameters**

- `i2c_num`: I2C port number
- `sda_io_num`: GPIO number for I2C sda signal
- `scl_io_num`: GPIO number for I2C scl signal
- `sda_pullup_en`: Whether to enable the internal pullup for sda pin
- `scl_pullup_en`: Whether to enable the internal pullup for scl pin
- `mode`: I2C mode

esp_err_t **i2c_master_start** (*i2c_cmd_handle_t* *cmd_handle*)
Queue command for I2C master to generate a start signal.

**Note** Only call this function in I2C master mode Call i2c_master_cmd_begin() to send all queued commands

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_ARG Parameter error

**Parameters**

- `cmd_handle`: I2C cmd link

esp_err_t **`i2c_master_write_byte`**(*i2c_cmd_handle_t cmd_handle*, uint8_t *data*, bool *ack_en*)
Queue command for I2C master to write one byte to I2C bus.

**Note** Only call this function in I2C master mode Call i2c_master_cmd_begin() to send all queued commands

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_ARG Parameter error

**Parameters**

- `cmd_handle`: I2C cmd link
- `data`: I2C one byte command to write to bus
- `ack_en`: enable ack check for master

esp_err_t **`i2c_master_write`**(*i2c_cmd_handle_t cmd_handle*, uint8_t **data*, size_t *data_len*, bool *ack_en*)
Queue command for I2C master to write buffer to I2C bus.

**Note** Only call this function in I2C master mode Call i2c_master_cmd_begin() to send all queued commands

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_ARG Parameter error

**Parameters**

- `cmd_handle`: I2C cmd link
- `data`: data to send
- `data_len`: data length
- `ack_en`: enable ack check for master

esp_err_t **`i2c_master_read_byte`**(*i2c_cmd_handle_t cmd_handle*, uint8_t **data*, int *ack*)
Queue command for I2C master to read one byte from I2C bus.

**Note** Only call this function in I2C master mode Call i2c_master_cmd_begin() to send all queued commands

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_ARG Parameter error

**Parameters**

- `cmd_handle`: I2C cmd link
- `data`: pointer accept the data byte

- `ack`: ack value for read command

esp_err_t **i2c_master_read**(*i2c_cmd_handle_t cmd_handle*, uint8_t **data*, size_t *data_len*, int *ack*)

Queue command for I2C master to read data from I2C bus.

**Note** Only call this function in I2C master mode Call i2c_master_cmd_begin() to send all queued commands

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_ARG Parameter error

**Parameters**

- `cmd_handle`: I2C cmd link
- `data`: data buffer to accept the data from bus
- `data_len`: read data length
- `ack`: ack value for read command

esp_err_t **i2c_master_stop**(*i2c_cmd_handle_t cmd_handle*)

Queue command for I2C master to generate a stop signal.

**Note** Only call this function in I2C master mode Call i2c_master_cmd_begin() to send all queued commands

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_ARG Parameter error

**Parameters**

- `cmd_handle`: I2C cmd link

esp_err_t **i2c_master_cmd_begin**(*i2c_port_t i2c_num*, *i2c_cmd_handle_t cmd_handle*, portBASE_TYPE *ticks_to_wait*)

I2C master send queued commands. This function will trigger sending all queued commands. The task will be blocked until all the commands have been sent out. The I2C APIs are not thread-safe, if you want to use one I2C port in different tasks, you need to take care of the multi-thread issue.

**Note** Only call this function in I2C master mode

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_ARG Parameter error
- ESP_FAIL Sending command error, slave doesn't ACK the transfer.
- ESP_ERR_INVALID_STATE I2C driver not installed or not in master mode.
- ESP_ERR_TIMEOUT Operation timeout because the bus is busy.

**Parameters**

- `i2c_num`: I2C port number
- `cmd_handle`: I2C command handler
- `ticks_to_wait`: maximum wait ticks.

int **i2c_slave_write_buffer** (*i2c_port_t i2c_num*, uint8_t **data*, int *size*, portBASE_TYPE *ticks_to_wait*)

I2C slave write data to internal ringbuffer, when tx fifo empty, isr will fill the hardware fifo from the internal ringbuffer.

**Note** Only call this function in I2C slave mode

**Return**

- ESP_FAIL(-1) Parameter error
- Others(>=0) The number of data bytes that pushed to the I2C slave buffer.

**Parameters**

- `i2c_num`: I2C port number
- `data`: data pointer to write into internal buffer
- `size`: data size
- `ticks_to_wait`: Maximum waiting ticks

**Warning:** doxygenfunction: Cannot find function "i2c_slave_read" in doxygen xml output for project "esp32-idf" from directory: xml/

esp_err_t **i2c_set_period** (*i2c_port_t i2c_num*, int *high_period*, int *low_period*)

set I2C master clock period

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_ARG Parameter error

**Parameters**

- `i2c_num`: I2C port number
- `high_period`: clock cycle number during SCL is high level, high_period is a 14 bit value
- `low_period`: clock cycle number during SCL is low level, low_period is a 14 bit value

esp_err_t **i2c_get_period** (*i2c_port_t i2c_num*, int **high_period*, int **low_period*)

get I2C master clock period

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_ARG Parameter error

**Parameters**

- `i2c_num`: I2C port number
- `high_period`: pointer to get clock cycle number during SCL is high level, will get a 14 bit value
- `low_period`: pointer to get clock cycle number during SCL is low level, will get a 14 bit value

esp_err_t **i2c_set_start_timing** (*i2c_port_t i2c_num*, int *setup_time*, int *hold_time*)

set I2C master start signal timing

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_ARG Parameter error

**Parameters**

- `i2c_num`: I2C port number
- `setup_time`: clock number between the falling-edge of SDA and rising-edge of SCL for start mark, it's a 10-bit value.
- `hold_time`: clock num between the falling-edge of SDA and falling-edge of SCL for start mark, it's a 10-bit value.

esp_err_t **i2c_get_start_timing**(*i2c_port_t* *i2c_num*, int **setup_time*, int **hold_time*)
get I2C master start signal timing

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_ARG Parameter error

**Parameters**

- `i2c_num`: I2C port number
- `setup_time`: pointer to get setup time
- `hold_time`: pointer to get hold time

esp_err_t **i2c_set_stop_timing**(*i2c_port_t* *i2c_num*, int *setup_time*, int *hold_time*)
set I2C master stop signal timing

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_ARG Parameter error

**Parameters**

- `i2c_num`: I2C port number
- `setup_time`: clock num between the rising-edge of SCL and the rising-edge of SDA, it's a 10-bit value.
- `hold_time`: clock number after the STOP bit's rising-edge, it's a 14-bit value.

esp_err_t **i2c_get_stop_timing**(*i2c_port_t* *i2c_num*, int **setup_time*, int **hold_time*)
get I2C master stop signal timing

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_ARG Parameter error

**Parameters**

- `i2c_num`: I2C port number
- `setup_time`: pointer to get setup time.

- `hold_time`: pointer to get hold time.

esp_err_t **i2c_set_data_timing**(*i2c_port_t* *i2c_num*, int *sample_time*, int *hold_time*)
set I2C data signal timing

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_ARG Parameter error

**Parameters**

- `i2c_num`: I2C port number
- `sample_time`: clock number I2C used to sample data on SDA after the rising-edge of SCL, it's a 10-bit value
- `hold_time`: clock number I2C used to hold the data after the falling-edge of SCL, it's a 10-bit value

esp_err_t **i2c_get_data_timing**(*i2c_port_t* *i2c_num*, int **sample_time*, int **hold_time*)
get I2C data signal timing

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_ARG Parameter error

**Parameters**

- `i2c_num`: I2C port number
- `sample_time`: pointer to get sample time
- `hold_time`: pointer to get hold time

esp_err_t **i2c_set_data_mode**(*i2c_port_t* *i2c_num*, *i2c_trans_mode_t* *tx_trans_mode*, *i2c_trans_mode_t* *rx_trans_mode*)
set I2C data transfer mode

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_ARG Parameter error

**Parameters**

- `i2c_num`: I2C port number
- `tx_trans_mode`: I2C sending data mode
- `rx_trans_mode`: I2C receving data mode

esp_err_t **i2c_get_data_mode**(*i2c_port_t* *i2c_num*, *i2c_trans_mode_t* **tx_trans_mode*, *i2c_trans_mode_t* **rx_trans_mode*)
get I2C data transfer mode

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_ARG Parameter error

**Parameters**

- `i2c_num`: I2C port number
- `tx_trans_mode`: pointer to get I2C sending data mode
- `rx_trans_mode`: pointer to get I2C receiving data mode

*i2c_cmd_handle_t* **`i2c_cmd_link_create`**()

Create and init I2C command link.

**Note** Before we build I2C command link, we need to call i2c_cmd_link_create() to create a command link. After we finish sending the commands, we need to call i2c_cmd_link_delete() to release and return the resources.

**Return** i2c command link handler

void **`i2c_cmd_link_delete`**(*i2c_cmd_handle_t cmd_handle*)

Free I2C command link.

**Note** Before we build I2C command link, we need to call i2c_cmd_link_create() to create a command link. After we finish sending the commands, we need to call i2c_cmd_link_delete() to release and return the resources.

**Parameters**

- `cmd_handle`: I2C command handle

# I2S

## Overview

ESP32 contains two I2S peripherals. These peripherals can be configured to input and output sample data via the I2S driver.

The I2S peripheral supports DMA meaning it can stream sample data without requiring each sample to be read or written by the CPU.

I2S output can also be routed directly to the Digital/Analog Converter output channels (GPIO 25 & GPIO 26) to produce analog output directly, rather than via an external I2S codec.

## Application Example

A full I2S example is available in esp-idf: peripherals/i2s.

Short example of I2S configuration:

```
#include "driver/i2s.h"
#include "freertos/queue.h"

static const int i2s_num = 0; // i2s port number

static const i2s_config_t i2s_config = {
     .mode = I2S_MODE_MASTER | I2S_MODE_TX,
     .sample_rate = 44100,
     .bits_per_sample = 16,
```

```
     .channel_format = I2S_CHANNEL_FMT_RIGHT_LEFT,
     .communication_format = I2S_COMM_FORMAT_I2S | I2S_COMM_FORMAT_I2S_MSB,
     .intr_alloc_flags = ESP_INTR_FLAG_LEVEL1, // high interrupt priority
     .dma_buf_count = 8,
     .dma_buf_len = 64
};

static const i2s_pin_config_t pin_config = {
    .bck_io_num = 26,
    .ws_io_num = 25,
    .data_out_num = 22,
    .data_in_num = I2S_PIN_NO_CHANGE
};

...

    i2s_driver_install(i2s_num, &i2s_config, 0, NULL);   //install and start i2s␣
↪driver

    i2s_set_pin(i2s_num, &pin_config);

    i2s_set_sample_rates(i2s_num, 22050); //set sample rates

    i2s_driver_uninstall(i2s_num); //stop & destroy i2s driver
```

Short example configuring I2S to use internal DAC for analog output:

```
#include "driver/i2s.h"
#include "freertos/queue.h"

static const int i2s_num = 0; // i2s port number

static const i2s_config_t i2s_config = {
     .mode = I2S_MODE_MASTER | I2S_MODE_TX | I2S_MODE_DAC_BUILT_IN,
     .sample_rate = 44100,
     .bits_per_sample = 8, /* must be 8 for built-in DAC */
     .channel_format = I2S_CHANNEL_FMT_RIGHT_LEFT,
     .communication_format = I2S_COMM_FORMAT_I2S_MSB,
     .intr_alloc_flags = ESP_INTR_FLAG_LEVEL1, // high interrupt priority
     .dma_buf_count = 8,
     .dma_buf_len = 64
};

...

    i2s_driver_install(i2s_num, &i2s_config, 0, NULL);   //install and start i2s␣
↪driver

    i2s_set_pin(i2s_num, NULL); //for internal DAC

    i2s_set_sample_rates(i2s_num, 22050); //set sample rates

    i2s_driver_uninstall(i2s_num); //stop & destroy i2s driver
```

## API Reference

### Header Files

- *components/driver/include/driver/i2s.h*

### Data Structures

**struct i2s_config_t**
I2S configuration parameters for i2s_param_config function.

#### Public Members

*i2s_mode_t* **mode**
I2S work mode

int **sample_rate**
I2S sample rate

*i2s_bits_per_sample_t* **bits_per_sample**
I2S bits per sample

*i2s_channel_fmt_t* **channel_format**
I2S channel format

*i2s_comm_format_t* **communication_format**
I2S communication format

int **intr_alloc_flags**
Flags used to allocate the interrupt. One or multiple (ORred) ESP_INTR_FLAG_* values. See esp_intr_alloc.h for more info

int **dma_buf_count**
I2S DMA Buffer Count

int **dma_buf_len**
I2S DMA Buffer Length

**struct i2s_event_t**
Event structure used in I2S event queue.

#### Public Members

*i2s_event_type_t* **type**
I2S event type

size_t **size**
I2S data size for I2S_DATA event

**struct i2s_pin_config_t**
I2S pin number for i2s_set_pin.

#### Public Members

int **bck_io_num**
BCK in out pin

int **ws_io_num**
WS in out pin

int **data_out_num**
DATA out pin

int **data_in_num**
DATA in pin

### Macros

**I2S_PIN_NO_CHANGE** (-1)
Use in *i2s_pin_config_t* for pins which should not be changed

### Enumerations

**enum i2s_bits_per_sample_t**
I2S bit width per sample.

*Values:*

**I2S_BITS_PER_SAMPLE_8BIT** = 8
I2S bits per sample: 8-bits

**I2S_BITS_PER_SAMPLE_16BIT** = 16
I2S bits per sample: 16-bits

**I2S_BITS_PER_SAMPLE_24BIT** = 24
I2S bits per sample: 24-bits

**I2S_BITS_PER_SAMPLE_32BIT** = 32
I2S bits per sample: 32-bits

**enum i2s_comm_format_t**
I2S communication standard format.

*Values:*

**I2S_COMM_FORMAT_I2S** = 0x01
I2S communication format I2S

**I2S_COMM_FORMAT_I2S_MSB** = 0x02
I2S format MSB

**I2S_COMM_FORMAT_I2S_LSB** = 0x04
I2S format LSB

**I2S_COMM_FORMAT_PCM** = 0x08
I2S communication format PCM

**I2S_COMM_FORMAT_PCM_SHORT** = 0x10
PCM Short

**I2S_COMM_FORMAT_PCM_LONG** = 0x20
PCM Long

**enum i2s_channel_fmt_t**
I2S channel format type.

*Values:*

**I2S_CHANNEL_FMT_RIGHT_LEFT** = 0x00

**I2S_CHANNEL_FMT_ALL_RIGHT**

**I2S_CHANNEL_FMT_ALL_LEFT**

**I2S_CHANNEL_FMT_ONLY_RIGHT**

**I2S_CHANNEL_FMT_ONLY_LEFT**

**enum pdm_sample_rate_ratio_t**
PDM sample rate ratio, measured in Hz.

*Values:*

**PDM_SAMPLE_RATE_RATIO_64**

**PDM_SAMPLE_RATE_RATIO_128**

**enum pdm_pcm_conv_t**
PDM PCM convter enable/disable.

*Values:*

**PDM_PCM_CONV_ENABLE**

**PDM_PCM_CONV_DISABLE**

**enum i2s_port_t**
I2S Peripheral, 0 & 1.

*Values:*

**I2S_NUM_0** = 0x0
I2S 0

**I2S_NUM_1** = 0x1
I2S 1

**I2S_NUM_MAX**

**enum i2s_mode_t**
I2S Mode, defaut is I2S_MODE_MASTER | I2S_MODE_TX.

*Values:*

**I2S_MODE_MASTER** = 1

**I2S_MODE_SLAVE** = 2

**I2S_MODE_TX** = 4

**I2S_MODE_RX** = 8

**I2S_MODE_DAC_BUILT_IN** = 16

**enum i2s_event_type_t**
I2S event types.

*Values:*

**I2S_EVENT_DMA_ERROR**

**I2S_EVENT_TX_DONE**
I2S DMA finish sent 1 buffer

**I2S_EVENT_RX_DONE**
I2S DMA finish received 1 buffer

**I2S_EVENT_MAX**
I2S event max index

## Functions

esp_err_t **i2s_set_pin** (*i2s_port_t i2s_num*, **const** *i2s_pin_config_t *pin*)
Set I2S pin number.

Inside the pin configuration structure, set I2S_PIN_NO_CHANGE for any pin where the current configuration should not be changed.

**Note** The I2S peripheral output signals can be connected to multiple GPIO pads. However, the I2S peripheral input signal can only be connected to one GPIO pad.

**Parameters**

- `i2s_num`: I2S_NUM_0 or I2S_NUM_1
- `pin`: I2S Pin structure, or NULL to set 2-channel 8-bit internal DAC pin configuration (GPIO25 & GPIO26)

**Return**

- ESP_OK Success
- ESP_FAIL Parameter error

esp_err_t **i2s_driver_install** (*i2s_port_t i2s_num*, **const** *i2s_config_t *i2s_config*, int *queue_size*, void **i2s_queue*)
Install and start I2S driver.

This function must be called before any I2S driver read/write operations.

**Parameters**

- `i2s_num`: I2S_NUM_0, I2S_NUM_1
- `i2s_config`: I2S configurations - see *i2s_config_t* struct
- `queue_size`: I2S event queue size/depth.
- `i2s_queue`: I2S event queue handle, if set NULL, driver will not use an event queue.

**Return**

- ESP_OK Success
- ESP_FAIL Parameter error

esp_err_t **i2s_driver_uninstall** (*i2s_port_t i2s_num*)
Uninstall I2S driver.

**Return**

- ESP_OK Success
- ESP_FAIL Parameter error

**Parameters**

- `i2s_num`: I2S_NUM_0, I2S_NUM_1

int **i2s_write_bytes** (*i2s_port_t i2s_num*, **const** char **src*, size_t *size*, TickType_t *ticks_to_wait*)
Write data to I2S DMA transmit buffer.

Format of the data in source buffer is determined by the I2S configuration (see *i2s_config_t*).

**Parameters**

- `i2s_num`: I2S_NUM_0, I2S_NUM_1
- `src`: Source address to write from
- `size`: Size of data in bytes
- `ticks_to_wait`: TX buffer wait timeout in RTOS ticks. If this many ticks pass without space becoming available in the DMA transmit buffer, then the function will return (note that if the data is written to the DMA buffer in pieces, the overall operation may still take longer than this timeout.) Pass portMAX_DELAY for no timeout.

**Return** Number of bytes written, or ESP_FAIL (-1) for parameter error. If a timeout occurred, bytes written will be less than total size.

int **i2s_read_bytes** (*i2s_port_t i2s_num*, char **dest*, size_t *size*, TickType_t *ticks_to_wait*)
Read data from I2S DMA receive buffer.

Format of the data in source buffer is determined by the I2S configuration (see *i2s_config_t*).

**Parameters**

- `i2s_num`: I2S_NUM_0, I2S_NUM_1
- `dest`: Destination address to read into
- `size`: Size of data in bytes
- `ticks_to_wait`: RX buffer wait timeout in RTOS ticks. If this many ticks pass without bytes becoming available in the DMA receive buffer, then the function will return (note that if data is read from the DMA buffer in pieces, the overall operation may still take longer than this timeout.) Pass portMAX_DELAY for no timeout.

**Return** Number of bytes read, or ESP_FAIL (-1) for parameter error. If a timeout occurred, bytes read will be less than total size.

int **i2s_push_sample** (*i2s_port_t i2s_num*, **const** char **sample*, TickType_t *ticks_to_wait*)
Push (write) a single sample to the I2S DMA TX buffer.

Size of the sample is determined by the channel_format (mono or stereo)) & bits_per_sample configuration (see *i2s_config_t*).

**Return** Number of bytes successfully pushed to DMA buffer, or ESP_FAIL (-1) for parameter error. Will be either zero or the size of configured sample buffer.

**Parameters**

- `i2s_num`: I2S_NUM_0, I2S_NUM_1
- `sample`: Pointer to buffer containing sample to write. Size of buffer (in bytes) = (number of channels) * bits_per_sample / 8.
- `ticks_to_wait`: Push timeout in RTOS ticks. If space is not available in the DMA TX buffer within this period, no data is written and function returns 0.

int **i2s_pop_sample** (*i2s_port_t i2s_num*, char **sample*, TickType_t *ticks_to_wait*)
Pop (read) a single sample from the I2S DMA RX buffer.

Size of the sample is determined by the channel_format (mono or stereo)) & bits_per_sample configuration (see *i2s_config_t*).

**Return** Number of bytes successfully read from DMA buffer, or ESP_FAIL (-1) for parameter error. Byte count will be either zero or the size of the configured sample buffer.

**Parameters**

- `i2s_num`: I2S_NUM_0, I2S_NUM_1
- `sample`: Buffer sample data will be read into. Size of buffer (in bytes) = (number of channels) * bits_per_sample / 8.
- `ticks_to_wait`: Pop timeout in RTOS ticks. If a sample is not available in the DMA buffer within this period, no data is read and function returns zero.

esp_err_t **i2s_set_sample_rates** (*i2s_port_t i2s_num*, uint32_t *rate*)
Set sample rate used for I2S RX and TX.

The bit clock rate is determined by the sample rate and *i2s_config_t* configuration parameters (number of channels, bits_per_sample).

`bit_clock = rate * (number of channels) * bits_per_sample`

**Return**

- ESP_OK Success
- ESP_FAIL Parameter error

**Parameters**

- `i2s_num`: I2S_NUM_0, I2S_NUM_1
- `rate`: I2S sample rate (ex: 8000, 44100...)

esp_err_t **i2s_start** (*i2s_port_t i2s_num*)
Start I2S driver.

It is not necessary to call this function after i2s_driver_install() (it is started automatically), however it is necessary to call it after i2s_stop().

**Return**

- ESP_OK Success
- ESP_FAIL Parameter error

**Parameters**

- `i2s_num`: I2S_NUM_0, I2S_NUM_1

esp_err_t **i2s_stop** (*i2s_port_t i2s_num*)
Stop I2S driver.

Disables I2S TX/RX, until i2s_start() is called.

**Return**

- ESP_OK Success

- ESP_FAIL Parameter error

**Parameters**

- `i2s_num`: I2S_NUM_0, I2S_NUM_1

esp_err_t **i2s_zero_dma_buffer** (*i2s_port_t i2s_num*)

Zero the contents of the TX DMA buffer.

Pushes zero-byte samples into the TX DMA buffer, until it is full.

**Return**

- ESP_OK Success
- ESP_FAIL Parameter error

**Parameters**

- `i2s_num`: I2S_NUM_0, I2S_NUM_1

# LED Control

## Overview

The LED control module is primarily designed to control the intensity of LEDs, although it can be used to generate PWM signals for other purposes as well. It has 16 channels which can generate independent waveforms that can be used to drive e.g. RGB LED devices. For maximum flexibility, the high-speed as well as the low-speed channels can be driven from one of four high-speed/low-speed timers. The PWM controller also has the ability to automatically increase or decrease the duty cycle gradually, allowing for fades without any processor interference.

## Application Example

LEDC change duty cycle and fading control example: peripherals/ledc.

## API Reference

### Header Files

- driver/include/driver/ledc.h

### Macros

**LEDC_APB_CLK_HZ** (APB_CLK_FREQ)

**LEDC_REF_CLK_HZ** (1*1000000)

### Type Definitions

**typedef** intr_handle_t **ledc_isr_handle_t**

### Enumerations

**enum ledc_mode_t**
*Values:*

**LEDC_HIGH_SPEED_MODE** = 0
LEDC high speed speed_mode

**LEDC_LOW_SPEED_MODE**
LEDC low speed speed_mode

**LEDC_SPEED_MODE_MAX**
LEDC speed limit

**enum ledc_intr_type_t**
*Values:*

**LEDC_INTR_DISABLE** = 0
Disable LEDC interrupt

**LEDC_INTR_FADE_END**
Enable LEDC interrupt

**enum ledc_duty_direction_t**
*Values:*

**LEDC_DUTY_DIR_DECREASE** = 0
LEDC duty decrease direction

**LEDC_DUTY_DIR_INCREASE** = 1
LEDC duty increase direction

**enum ledc_clk_src_t**
*Values:*

**LEDC_REF_TICK** = 0
LEDC timer clock divided from reference tick(1Mhz)

**LEDC_APB_CLK**
LEDC timer clock divided from APB clock(80Mhz)

**enum ledc_timer_t**
*Values:*

**LEDC_TIMER_0** = 0
LEDC source timer TIMER0

**LEDC_TIMER_1**
LEDC source timer TIMER1

**LEDC_TIMER_2**
LEDC source timer TIMER2

**LEDC_TIMER_3**
LEDC source timer TIMER3

**enum ledc_channel_t**
*Values:*

**LEDC_CHANNEL_0** = 0
LEDC channel 0

**LEDC_CHANNEL_1**
LEDC channel 1

**LEDC_CHANNEL_2**
LEDC channel 2

**LEDC_CHANNEL_3**
LEDC channel 3

**LEDC_CHANNEL_4**
LEDC channel 4

**LEDC_CHANNEL_5**
LEDC channel 5

**LEDC_CHANNEL_6**
LEDC channel 6

**LEDC_CHANNEL_7**
LEDC channel 7

**LEDC_CHANNEL_MAX**

**enum ledc_timer_bit_t**
*Values:*

**LEDC_TIMER_10_BIT** = 10
LEDC PWM depth 10Bit

**LEDC_TIMER_11_BIT** = 11
LEDC PWM depth 11Bit

**LEDC_TIMER_12_BIT** = 12
LEDC PWM depth 12Bit

**LEDC_TIMER_13_BIT** = 13
LEDC PWM depth 13Bit

**LEDC_TIMER_14_BIT** = 14
LEDC PWM depth 14Bit

**LEDC_TIMER_15_BIT** = 15
LEDC PWM depth 15Bit

## Structures

**struct ledc_channel_config_t**
Configuration parameters of LEDC channel for ledc_channel_config function.

### Public Members

int **gpio_num**
the LEDC output gpio_num, if you want to use gpio16, gpio_num = 16

*ledc_mode_t* **speed_mode**
LEDC speed speed_mode, high-speed mode or low-speed mode

*ledc_channel_t* **channel**
LEDC channel(0 - 7)

*ledc_intr_type_t* **intr_type**
configure interrupt, Fade interrupt enable or Fade interrupt disable

*ledc_timer_t* **timer_sel**
Select the timer source of channel (0 - 3)

uint32_t **duty**
LEDC channel duty, the duty range is [0, (2**bit_num) - 1],

**struct ledc_timer_config_t**
Configuration parameters of LEDC Timer timer for ledc_timer_config function.

### Public Members

*ledc_mode_t* **speed_mode**
LEDC speed speed_mode, high-speed mode or low-speed mode

*ledc_timer_bit_t* **bit_num**
LEDC channel duty depth

*ledc_timer_t* **timer_num**
The timer source of channel (0 - 3)

uint32_t **freq_hz**
LEDC timer frequency(Hz)

## Functions

esp_err_t **ledc_channel_config** (*ledc_channel_config_t *ledc_conf*)
LEDC channel configuration Configure LEDC channel with the given channel/output gpio_num/interrupt/source timer/frequency(Hz)/LEDC depth.

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_ARG Parameter error

**Parameters**

- `ledc_conf`: Pointer of LEDC channel configure struct

esp_err_t **ledc_timer_config** (*ledc_timer_config_t *timer_conf*)
LEDC timer configuration Configure LEDC timer with the given source timer/frequency(Hz)/bit_num.

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_ARG Parameter error
- ESP_FAIL Can not find a proper pre-divider number base on the given frequency and the current bit_num.

**Parameters**

- `timer_conf`: Pointer of LEDC timer configure struct

esp_err_t **ledc_update_duty** (*ledc_mode_t speed_mode*, *ledc_channel_t channel*)
LEDC update channel parameters Call this function to activate the LEDC updated parameters. After ledc_set_duty, ledc_set_fade, we need to call this function to update the settings.

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_ARG Parameter error

**Parameters**

- `speed_mode`: Select the LEDC speed_mode, high-speed mode and low-speed mode,
- `channel`: LEDC channel(0-7), select from ledc_channel_t

esp_err_t **ledc_stop**(*ledc_mode_t speed_mode*, *ledc_channel_t channel*, uint32_t *idle_level*)
LEDC stop. Disable LEDC output, and set idle level.

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_ARG Parameter error

**Parameters**

- `speed_mode`: Select the LEDC speed_mode, high-speed mode and low-speed mode
- `channel`: LEDC channel(0-7), select from ledc_channel_t
- `idle_level`: Set output idle level after LEDC stops.

esp_err_t **ledc_set_freq**(*ledc_mode_t speed_mode*, *ledc_timer_t timer_num*, uint32_t *freq_hz*)
LEDC set channel frequency(Hz)

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_ARG Parameter error
- ESP_FAIL Can not find a proper pre-divider number base on the given frequency and the current bit_num.

**Parameters**

- `speed_mode`: Select the LEDC speed_mode, high-speed mode and low-speed mode
- `timer_num`: LEDC timer index(0-3), select from ledc_timer_t
- `freq_hz`: Set the LEDC frequency

uint32_t **ledc_get_freq**(*ledc_mode_t speed_mode*, *ledc_timer_t timer_num*)
LEDC get channel frequency(Hz)

**Return**

- 0 error
- Others Current LEDC frequency

**Parameters**

- `speed_mode`: Select the LEDC speed_mode, high-speed mode and low-speed mode
- `timer_num`: LEDC timer index(0-3), select from ledc_timer_t

esp_err_t **ledc_set_duty** (*ledc_mode_t speed_mode*, *ledc_channel_t channel*, uint32_t *duty*)
LEDC set duty Only after calling ledc_update_duty will the duty update.

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_ARG Parameter error

**Parameters**

- `speed_mode`: Select the LEDC speed_mode, high-speed mode and low-speed mode
- `channel`: LEDC channel(0-7), select from ledc_channel_t
- `duty`: Set the LEDC duty, the duty range is [0, (2**bit_num) - 1]

int **ledc_get_duty** (*ledc_mode_t speed_mode*, *ledc_channel_t channel*)
LEDC get duty.

**Return**

- (-1) parameter error
- Others Current LEDC duty

**Parameters**

- `speed_mode`: Select the LEDC speed_mode, high-speed mode and low-speed mode
- `channel`: LEDC channel(0-7), select from ledc_channel_t

esp_err_t **ledc_set_fade** (*ledc_mode_t speed_mode*, *ledc_channel_t channel*, uint32_t *duty*, *ledc_duty_direction_t gradule_direction*, uint32_t *step_num*, uint32_t *duty_cyle_num*, uint32_t *duty_scale*)
LEDC set gradient Set LEDC gradient, After the function calls the ledc_update_duty function, the function can take effect.

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_ARG Parameter error

**Parameters**

- `speed_mode`: Select the LEDC speed_mode, high-speed mode and low-speed mode
- `channel`: LEDC channel(0-7), select from ledc_channel_t
- `duty`: Set the start of the gradient duty, the duty range is [0, (2**bit_num) - 1]
- `gradule_direction`: Set the direction of the gradient
- `step_num`: Set the number of the gradient
- `duty_cyle_num`: Set how many LEDC tick each time the gradient lasts
- `duty_scale`: Set gradient change amplitude

esp_err_t **ledc_isr_register** (void (*fn)) void *
, void **arg*, int *intr_alloc_flags*, *ledc_isr_handle_t *handle*Register LEDC interrupt handler, the handler is an ISR. The handler will be attached to the same CPU core that this function is running on.

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_ARG Function pointer error.

**Parameters**

- `fn`: Interrupt handler function.
- `arg`: User-supplied argument passed to the handler function.
- `intr_alloc_flags`: Flags used to allocate the interrupt. One or multiple (ORred) ESP_INTR_FLAG_* values. See esp_intr_alloc.h for more info.
- `arg`: Parameter for handler function
- `handle`: Pointer to return handle. If non-NULL, a handle for the interrupt will be returned here.

esp_err_t **ledc_timer_set** (*ledc_mode_t speed_mode*, *ledc_timer_t timer_sel*, uint32_t *div_num*, uint32_t *bit_num*, *ledc_clk_src_t clk_src*)

Configure LEDC settings.

**Return**

- (-1) Parameter error
- Other Current LEDC duty

**Parameters**

- `speed_mode`: Select the LEDC speed_mode, high-speed mode and low-speed mode
- `timer_sel`: Timer index(0-3), there are 4 timers in LEDC module
- `div_num`: Timer clock divide number, the timer clock is divided from the selected clock source
- `bit_num`: The count number of one period, counter range is 0 ~ ((2 ** bit_num) - 1)
- `clk_src`: Select LEDC source clock.

esp_err_t **ledc_timer_rst** (*ledc_mode_t speed_mode*, uint32_t *timer_sel*)

Reset LEDC timer.

**Return**

- ESP_ERR_INVALID_ARG Parameter error
- ESP_OK Success

**Parameters**

- `speed_mode`: Select the LEDC speed_mode, high-speed mode and low-speed mode
- `timer_sel`: LEDC timer index(0-3), select from ledc_timer_t

esp_err_t **ledc_timer_pause** (*ledc_mode_t speed_mode*, uint32_t *timer_sel*)

Pause LEDC timer counter.

**Return**

- ESP_ERR_INVALID_ARG Parameter error
- ESP_OK Success

**Parameters**

- `speed_mode`: Select the LEDC speed_mode, high-speed mode and low-speed mode

- `timer_sel`: LEDC timer index(0-3), select from ledc_timer_t

esp_err_t **ledc_timer_resume**(*ledc_mode_t speed_mode*, uint32_t *timer_sel*)
Resume LEDC timer.

**Return**

- ESP_ERR_INVALID_ARG Parameter error
- ESP_OK Success

**Parameters**

- `speed_mode`: Select the LEDC speed_mode, high-speed mode and low-speed mode
- `timer_sel`: LEDC timer index(0-3), select from ledc_timer_t

esp_err_t **ledc_bind_channel_timer**(*ledc_mode_t speed_mode*, uint32_t *channel*, uint32_t *timer_idx*)
Bind LEDC channel with the selected timer.

**Return**

- ESP_ERR_INVALID_ARG Parameter error
- ESP_OK Success

**Parameters**

- `speed_mode`: Select the LEDC speed_mode, high-speed mode and low-speed mode
- `channel`: LEDC channel index(0-7), select from ledc_channel_t
- `timer_idx`: LEDC timer index(0-3), select from ledc_timer_t

esp_err_t **ledc_set_fade_with_step**(*ledc_mode_t speed_mode*, *ledc_channel_t channel*, int *target_duty*, int *scale*, int *cycle_num*)
Set LEDC fade function. Should call ledc_fade_func_install() before calling this function. Call ledc_fade_start() after this to start fading.

**Return**

- ESP_ERR_INVALID_ARG Parameter error
- ESP_OK Success
- ESP_ERR_INVALID_STATE Fade function not installed.
- ESP_FAIL Fade function init error

**Parameters**

- `speed_mode`: Select the LEDC speed_mode, high-speed mode and low-speed mode,
- `channel`: LEDC channel index(0-7), select from ledc_channel_t
- `target_duty`: Target duty of fading.( 0 - (2 ** bit_num - 1)))
- `scale`: Controls the increase or decrease step scale.
- `cycle_num`: increase or decrease the duty every cycle_num cycles

esp_err_t **ledc_set_fade_with_time**(*ledc_mode_t speed_mode*, *ledc_channel_t channel*, int *target_duty*, int *max_fade_time_ms*)
Set LEDC fade function, with a limited time. Should call ledc_fade_func_install() before calling this function. Call ledc_fade_start() after this to start fading.

**Return**

- ESP_ERR_INVALID_ARG Parameter error
- ESP_OK Success
- ESP_ERR_INVALID_STATE Fade function not installed.
- ESP_FAIL Fade function init error

**Parameters**

- `speed_mode`: Select the LEDC speed_mode, high-speed mode and low-speed mode,
- `channel`: LEDC channel index(0-7), select from ledc_channel_t
- `target_duty`: Target duty of fading.( 0 - (2 ** bit_num - 1)))
- `max_fade_time_ms`: The maximum time of the fading ( ms ).

esp_err_t **ledc_fade_func_install**(int *intr_alloc_flags*)
Install ledc fade function. This function will occupy interrupt of LEDC module.

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_STATE Fade function already installed.

**Parameters**

- `intr_alloc_flags`: Flags used to allocate the interrupt. One or multiple (ORred) ESP_INTR_FLAG_* values. See esp_intr_alloc.h for more info.

void **ledc_fade_func_uninstall**()
Uninstall LEDC fade function.

esp_err_t **ledc_fade_start**(*ledc_mode_t speed_mode*, *ledc_channel_t channel*, ledc_fade_mode_t *wait_done*)
Start LEDC fading.

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_STATE Fade function not installed.
- ESP_ERR_INVALID_ARG Parameter error.

**Parameters**

- `speed_mode`: Select the LEDC speed_mode, high-speed mode and low-speed mode
- `channel`: LEDC channel number
- `wait_done`: Whether to block until fading done.

## Pulse Counter

### Overview

The PCNT (Pulse Counter) module is designed to count the number of rising and/or falling edges of an input signal. Each pulse counter unit has a 16-bit signed counter register and two channels that can be configured to either increment or decrement the counter. Each channel has a signal input that accepts signal edges to be detected, as well as a control input that can be used to enable or disable the signal input. The inputs have optional filters that can be used to discard unwanted glitches in the signal.

## Application Example

Pulse counter with control signal and event interrupt example: peripherals/pcnt.

## API Reference

### Header Files

- driver/include/driver/pcnt.h

### Macros

### Type Definitions

### Enumerations

**enum pcnt_ctrl_mode_t**
*Values:*

**PCNT_MODE_KEEP** = 0
Control mode: won't change counter mode

**PCNT_MODE_REVERSE** = 1
Control mode: invert counter mode(increase -> decrease, decrease -> increase);

**PCNT_MODE_DISABLE** = 2
Control mode: Inhibit counter(counter value will not change in this condition)

**PCNT_MODE_MAX**

**enum pcnt_count_mode_t**
*Values:*

**PCNT_COUNT_DIS** = 0
Counter mode: Inhibit counter(counter value will not change in this condition)

**PCNT_COUNT_INC** = 1
Counter mode: Increase counter value

**PCNT_COUNT_DEC** = 2
Counter mode: Decrease counter value

**PCNT_COUNT_MAX**

**enum pcnt_unit_t**
*Values:*

**PCNT_UNIT_0** = 0
PCNT unit0

**PCNT_UNIT_1** = 1
PCNT unit1

**PCNT_UNIT_2** = 2
PCNT unit2

**PCNT_UNIT_3** = 3
PCNT unit3

**PCNT_UNIT_4** = 4
PCNT unit4

**PCNT_UNIT_5** = 5
PCNT unit5

**PCNT_UNIT_6** = 6
PCNT unit6

**PCNT_UNIT_7** = 7
PCNT unit7

**PCNT_UNIT_MAX**

**enum pcnt_channel_t**
*Values:*

**PCNT_CHANNEL_0** = 0x00
PCNT channel0

**PCNT_CHANNEL_1** = 0x01
PCNT channel1

**PCNT_CHANNEL_MAX**

**enum pcnt_evt_type_t**
*Values:*

**PCNT_EVT_L_LIM** = 0
PCNT watch point event: Minimum counter value

**PCNT_EVT_H_LIM** = 1
PCNT watch point event: Maximum counter value

**PCNT_EVT_THRES_0** = 2
PCNT watch point event: threshold0 value event

**PCNT_EVT_THRES_1** = 3
PCNT watch point event: threshold1 value event

**PCNT_EVT_ZERO** = 4
PCNT watch point event: counter value zero event

**PCNT_EVT_MAX**

### Structures

**struct pcnt_config_t**
Pulse Counter configure struct.

### Functions

esp_err_t **pcnt_unit_config** (*pcnt_config_t *pcnt_config*)
Configure Pulse Counter unit.

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_ARG Parameter error

**Parameters**

- `pcnt_config`: Pointer of Pulse Counter unit configure parameter

esp_err_t **pcnt_get_counter_value** (*pcnt_unit_t pcnt_unit*, int16_t **count*)
Get pulse counter value.

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_ARG Parameter error

**Parameters**

- `pcnt_unit`: Pulse Counter unit number
- `count`: Pointer to accept counter value

esp_err_t **pcnt_counter_pause** (*pcnt_unit_t pcnt_unit*)
Pause PCNT counter of PCNT unit.

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_ARG Parameter error

**Parameters**

- `pcnt_unit`: PCNT unit number

esp_err_t **pcnt_counter_resume** (*pcnt_unit_t pcnt_unit*)
Resume counting for PCNT counter.

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_ARG Parameter error

**Parameters**

- `pcnt_unit`: PCNT unit number, select from pcnt_unit_t

esp_err_t **pcnt_counter_clear** (*pcnt_unit_t pcnt_unit*)
Clear and reset PCNT counter value to zero.

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_ARG Parameter error

**Parameters**

- `pcnt_unit`: PCNT unit number, select from pcnt_unit_t esp_err_t **pcnt_intr_enable** (*pcnt_unit_t pcnt_unit*)

Enable PCNT interrupt for PCNT unit.

**Note** Each Pulse counter unit has five watch point events that share the same interrupt. Configure events with pcnt_event_enable() and pcnt_event_disable()

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_ARG Parameter error

**Parameters**

- `pcnt_unit`: PCNT unit number

esp_err_t **pcnt_intr_disable** (*pcnt_unit_t pcnt_unit*)

Disable PCNT interrupt for PCNT uint.

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_ARG Parameter error

**Parameters**

- `pcnt_unit`: PCNT unit number

esp_err_t **pcnt_event_enable** (*pcnt_unit_t unit*, *pcnt_evt_type_t evt_type*)

Enable PCNT event of PCNT unit.

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_ARG Parameter error

**Parameters**

- `unit`: PCNT unit number
- `evt_type`: Watch point event type. All enabled events share the same interrupt (one interrupt per pulse counter unit).

esp_err_t **pcnt_event_disable** (*pcnt_unit_t unit*, *pcnt_evt_type_t evt_type*)

Disable PCNT event of PCNT unit.

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_ARG Parameter error

**Parameters**

- `unit`: PCNT unit number
- `evt_type`: Watch point event type. All enabled events share the same interrupt (one interrupt per pulse counter unit).

esp_err_t **pcnt_set_event_value** (*pcnt_unit_t unit*, *pcnt_evt_type_t evt_type*, int16_t *value*)

Set PCNT event value of PCNT unit.

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_ARG Parameter error

**Parameters**

- `unit`: PCNT unit number
- `evt_type`: Watch point event type. All enabled events share the same interrupt (one interrupt per pulse counter unit).
- `value`: Counter value for PCNT event

esp_err_t **pcnt_get_event_value** (*pcnt_unit_t unit*, *pcnt_evt_type_t evt_type*, int16_t **value*)

Get PCNT event value of PCNT unit.

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_ARG Parameter error

**Parameters**

- `unit`: PCNT unit number
- `evt_type`: Watch point event type. All enabled events share the same interrupt (one interrupt per pulse counter unit).
- `value`: Pointer to accept counter value for PCNT event

esp_err_t **pcnt_isr_register** (void (**fn*)) void *

, void **arg*, int *intr_alloc_flags*, pcnt_isr_handle_t **handle*Register PCNT interrupt handler, the handler is an ISR. The handler will be attached to the same CPU core that this function is running on.

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_ARG Function pointer error.

**Parameters**

- `fn`: Interrupt handler function.
- `arg`: Parameter for handler function
- `intr_alloc_flags`: Flags used to allocate the interrupt. One or multiple (ORred) ESP_INTR_FLAG_* values. See esp_intr_alloc.h for more info.
- `handle`: Pointer to return handle. If non-NULL, a handle for the interrupt will be returned here.

esp_err_t **pcnt_set_pin** (*pcnt_unit_t unit*, *pcnt_channel_t channel*, int *pulse_io*, int *ctrl_io*)

Configure PCNT pulse signal input pin and control input pin.

**Note** Set to PCNT_PIN_NOT_USED if unused.

**Note** Set to PCNT_PIN_NOT_USED if unused.

**Return**

- ESP_OK Success

- ESP_ERR_INVALID_ARG Parameter error

**Parameters**

- `unit`: PCNT unit number
- `channel`: PCNT channel number
- `pulse_io`: Pulse signal input GPIO

**Parameters**

- `ctrl_io`: Control signal input GPIO

esp_err_t **pcnt_filter_enable** (*pcnt_unit_t unit*)
Enable PCNT input filter.

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_ARG Parameter error

**Parameters**

- `unit`: PCNT unit number

esp_err_t **pcnt_filter_disable** (*pcnt_unit_t unit*)
Disable PCNT input filter.

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_ARG Parameter error

**Parameters**

- `unit`: PCNT unit number

esp_err_t **pcnt_set_filter_value** (*pcnt_unit_t unit*, uint16_t *filter_val*)
Set PCNT filter value.

**Note** filter_val is a 10-bit value, so the maximum filter_val should be limited to 1023.

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_ARG Parameter error

**Parameters**

- `unit`: PCNT unit number
- `filter_val`: PCNT signal filter value, counter in APB_CLK cycles. Any pulses lasting shorter than this will be ignored when the filter is enabled.

esp_err_t **pcnt_get_filter_value** (*pcnt_unit_t unit*, uint16_t **filter_val*)
Get PCNT filter value.

**Return**

- ESP_OK Success

- ESP_ERR_INVALID_ARG Parameter error

**Parameters**

- `unit`: PCNT unit number
- `filter_val`: Pointer to accept PCNT filter value.

esp_err_t **pcnt_set_mode** (*pcnt_unit_t unit*, *pcnt_channel_t channel*, *pcnt_count_mode_t pos_mode*, *pcnt_count_mode_t neg_mode*, *pcnt_ctrl_mode_t hctrl_mode*, *pcnt_ctrl_mode_t lctrl_mode*)

Set PCNT counter mode.

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_ARG Parameter error

**Parameters**

- `unit`: PCNT unit number
- `channel`: PCNT channel number
- `pos_mode`: Counter mode when detecting positive edge
- `neg_mode`: Counter mode when detecting negative edge
- `hctrl_mode`: Counter mode when control signal is high level
- `lctrl_mode`: Counter mode when control signal is low level

## SDMMC Host Peripheral

### Overview

SDMMC peripheral supports SD and MMC memory cards and SDIO cards. SDMMC software builds on top of SDMMC driver and consists of the following parts:

1. SDMMC host driver (`driver/sdmmc_host.h`) — this driver provides APIs to send commands to the slave device(s), send and receive data, and handling error conditions on the bus.
2. SDMMC protocol layer (`sdmmc_cmd.h`) — this component handles specifics of SD protocol such as card initialization and data transfer commands. Despite the name, only SD (SDSC/SDHC/SDXC) cards are supported at the moment. Support for MCC/eMMC cards can be added in the future.

Protocol layer works with the host via `sdmmc_host_t` structure. This structure contains pointers to various functions of the host. This design makes it possible to implement an SD host using SPI interface later.

### Application Example

An example which combines SDMMC driver with FATFS library is provided in `examples/storage/sd_card` directory. This example initializes the card, writes and reads data from it using POSIX and C library APIs. See README.md file in the example directory for more information.

## Protocol layer APIs

Protocol layer is given `sdmmc_host_t` structure which describes the SD/MMC host driver, lists its capabilites, and provides pointers to functions of the driver. Protocol layer stores card-specific information in `sdmmc_card_t` structure. When sending commands to the SD/MMC host driver, protocol layer uses `sdmmc_command_t` structure to describe the command, argument, expected return value, and data to transfer, if any.

Normal usage of the protocol layer is as follows:

1. Call the host driver functions to initialize the host (e.g. `sdmmc_host_init`, `sdmmc_host_init_slot`).
2. Call `sdmmc_card_init` to initialize the card, passing it host driver information (`host`) and a pointer to `sdmmc_card_t` structure which will be filled in (`card`).
3. To read and write sectors of the card, use `sdmmc_read_sectors` and `sdmmc_write_sectors`, passing the pointer to card information structure (`card`).
4. When card is not used anymore, call the host driver function to disable SDMMC host peripheral and free resources allocated by the driver (e.g. `sdmmc_host_deinit`).

Most applications need to use the protocol layer only in one task; therefore the protocol layer doesn't implement any kind of locking on the `sdmmc_card_t` structure, or when accessing SDMMC host driver. Such locking has to be implemented in the higher layer, if necessary (e.g. in the filesystem driver).

**struct `sdmmc_host_t`**

SD/MMC Host description

This structure defines properties of SD/MMC host and functions of SD/MMC host which can be used by upper layers.

### Public Members

uint32_t **`flags`**

flags defining host properties

int **`slot`**

slot number, to be passed to host functions

int **`max_freq_khz`**

max frequency supported by the host

float **`io_voltage`**

I/O voltage used by the controller (voltage switching is not supported)

esp_err_t (***`init`**)(void)

Host function to initialize the driver

esp_err_t (***`set_bus_width`**)(int *slot*, size_t width)

host function to set bus width

esp_err_t (***`set_card_clk`**)(int *slot*, uint32_t freq_khz)

host function to set card clock frequency

esp_err_t (***`do_transaction`**)(int *slot*, *sdmmc_command_t* *cmdinfo)

host function to do a transaction

esp_err_t (***`deinit`**)(void)

host function to deinitialize the driver

**`SDMMC_HOST_FLAG_1BIT`** BIT(0)

host supports 1-line SD and MMC protocol

**SDMMC_HOST_FLAG_4BIT** BIT(1)
host supports 4-line SD and MMC protocol

**SDMMC_HOST_FLAG_8BIT** BIT(2)
host supports 8-line MMC protocol

**SDMMC_HOST_FLAG_SPI** BIT(3)
host supports SPI protocol

**SDMMC_FREQ_DEFAULT** 20000
SD/MMC Default speed (limited by clock divider)

**SDMMC_FREQ_HIGHSPEED** 40000
SD High speed (limited by clock divider)

**SDMMC_FREQ_PROBING** 4000
SD/MMC probing speed

**struct sdmmc_command_t**
SD/MMC command information

### Public Members

uint32_t **opcode**
SD or MMC command index

uint32_t **arg**
SD/MMC command argument

sdmmc_response_t **response**
response buffer

void ***data**
buffer to send or read into

size_t **datalen**
length of data buffer

size_t **blklen**
block length

int **flags**
see below

esp_err_t **error**
error returned from transfer

**struct sdmmc_card_t**
SD/MMC card information structure

### Public Members

*sdmmc_host_t* **host**
Host with which the card is associated

uint32_t **ocr**
OCR (Operation Conditions Register) value

*sdmmc_cid_t* **cid**
decoded CID (Card IDentification) register value

*sdmmc_csd_t* **csd**
decoded CSD (Card-Specific Data) register value

*sdmmc_scr_t* **scr**
decoded SCR (SD card Configuration Register) value

uint16_t **rca**
RCA (Relative Card Address)

**struct sdmmc_csd_t**
Decoded values from SD card Card Specific Data register

### Public Members

int **csd_ver**
CSD structure format

int **mmc_ver**
MMC version (for CID format)

int **capacity**
total number of sectors

int **sector_size**
sector size in bytes

int **read_block_len**
block length for reads

int **card_command_class**
Card Command Class for SD

int **tr_speed**
Max transfer speed

**struct sdmmc_cid_t**
Decoded values from SD card Card IDentification register

### Public Members

int **mfg_id**
manufacturer identification number

int **oem_id**
OEM/product identification number

char **name**[8]
product name (MMC v1 has the longest)

int **revision**
product revision

int **serial**
product serial number

int **date**
manufacturing date

**struct sdmmc_scr_t**
Decoded values from SD Configuration Register

### Public Members

int **sd_spec**
SD Physical layer specification version, reported by card

int **bus_width**
bus widths supported by card: BIT(0) — 1-bit bus, BIT(2) — 4-bit bus

esp_err_t **sdmmc_card_init** (**const** *sdmmc_host_t* **host*, *sdmmc_card_t* **out_card*)
Probe and initialize SD/MMC card using given host

**Note** Only SD cards (SDSC and SDHC/SDXC) are supported now. Support for MMC/eMMC cards will be added later.

**Return**

- ESP_OK on success
- One of the error codes from SDMMC host controller

**Parameters**

- `host`: pointer to structure defining host controller
- `out_card`: pointer to structure which will receive information about the card when the function completes

esp_err_t **sdmmc_write_sectors** (*sdmmc_card_t* **card*, **const** void **src*, size_t *start_sector*, size_t *sector_count*)
Write given number of sectors to SD/MMC card

**Return**

- ESP_OK on success
- One of the error codes from SDMMC host controller

**Parameters**

- `card`: pointer to card information structure previously initialized using sdmmc_card_init
- `src`: pointer to data buffer to read data from; data size must be equal to sector_count * card->csd.sector_size
- `start_sector`: sector where to start writing
- `sector_count`: number of sectors to write

esp_err_t **sdmmc_read_sectors** (*sdmmc_card_t* **card*, void **dst*, size_t *start_sector*, size_t *sector_count*)
Write given number of sectors to SD/MMC card

**Return**

- ESP_OK on success
- One of the error codes from SDMMC host controller

**Parameters**

- `card`: pointer to card information structure previously initialized using sdmmc_card_init
- `dst`: pointer to data buffer to write into; buffer size must be at least sector_count * card->csd.sector_size

- `start_sector`: sector where to start reading
- `sector_count`: number of sectors to read

## SDMMC host driver APIs

On the ESP32, SDMMC host peripheral has two slots:

- Slot 0 (`SDMMC_HOST_SLOT_0`) is an 8-bit slot. It uses `HS1_*` signals in the PIN MUX.
- Slot 1 (`SDMMC_HOST_SLOT_1`) is a 4-bit slot. It uses `HS2_*` signals in the PIN MUX.

Card Detect and Write Protect signals can be routed to arbitrary pins using GPIO matrix. To use these pins, set `gpio_cd` and `gpio_wp` members of `sdmmc_slot_config_t` structure when calling `sdmmc_host_init_slot`.

Of all the funtions listed below, only `sdmmc_host_init`, `sdmmc_host_init_slot`, and `sdmmc_host_deinit` will be used directly by most applications. Other functions, such as `sdmmc_host_set_bus_width`, `sdmmc_host_set_card_clk`, and `sdmmc_host_do_transaction` will be called by the SD/MMC protocol layer via function pointers in `sdmmc_host_t` structure.

esp_err_t **sdmmc_host_init**()

Initialize SDMMC host peripheral.

**Note** This function is not thread safe

**Return**

- ESP_OK on success
- ESP_ERR_INVALID_STATE if sdmmc_host_init was already called
- ESP_ERR_NO_MEM if memory can not be allocated

**SDMMC_HOST_SLOT_0** 0

SDMMC slot 0.

**SDMMC_HOST_SLOT_1** 1

SDMMC slot 1.

**SDMMC_HOST_DEFAULT** {\ .flags = SDMMC_HOST_FLAG_4BIT, \ .slot = SDMMC_HOST_SLOT_1, \ .max_freq_khz = SDMMC_

Default *sdmmc_host_t* structure initializer for SDMMC peripheral.

Uses SDMMC peripheral, with 4-bit mode enabled, and max frequency set to 20MHz

**SDMMC_SLOT_WIDTH_DEFAULT** 0

use the default width for the slot (8 for slot 0, 4 for slot 1)

esp_err_t **sdmmc_host_init_slot**(int *slot*, **const** *sdmmc_slot_config_t* **slot_config*)

Initialize given slot of SDMMC peripheral.

On the ESP32, SDMMC peripheral has two slots:

- Slot 0: 8-bit wide, maps to HS1_* signals in PIN MUX
- Slot 1: 4-bit wide, maps to HS2_* signals in PIN MUX

Card detect and write protect signals can be routed to arbitrary GPIOs using GPIO matrix.

**Note** This function is not thread safe

**Return**

- ESP_OK on success

- ESP_ERR_INVALID_STATE if host has not been initialized using sdmmc_host_init

**Parameters**

- `slot`: slot number (SDMMC_HOST_SLOT_0 or SDMMC_HOST_SLOT_1)
- `slot_config`: additional configuration for the slot

**struct sdmmc_slot_config_t**
Extra configuration for SDMMC peripheral slot

### Public Members

*gpio_num_t* **gpio_cd**
GPIO number of card detect signal.

*gpio_num_t* **gpio_wp**
GPIO number of write protect signal.

uint8_t **width**
Bus width used by the slot (might be less than the max width supported)

**SDMMC_SLOT_NO_CD** ((gpio_num_t) -1)
indicates that card detect line is not used

**SDMMC_SLOT_NO_WP** ((gpio_num_t) -1)
indicates that write protect line is not used

**SDMMC_SLOT_CONFIG_DEFAULT** {\ .gpio_cd = SDMMC_SLOT_NO_CD, \ .gpio_wp = SDMMC_SLOT_NO_WP, \ .width = SDM
Macro defining default configuration of SDMMC host slot

esp_err_t **sdmmc_host_set_bus_width** (int *slot*, size_t *width*)
Select bus width to be used for data transfer.

SD/MMC card must be initialized prior to this command, and a command to set bus width has to be sent to the card (e.g. SD_APP_SET_BUS_WIDTH)

**Note** This function is not thread safe

**Return**

- ESP_OK on success
- ESP_ERR_INVALID_ARG if slot number or width is not valid

**Parameters**

- `slot`: slot number (SDMMC_HOST_SLOT_0 or SDMMC_HOST_SLOT_1)
- `width`: bus width (1, 4, or 8 for slot 0; 1 or 4 for slot 1)

esp_err_t **sdmmc_host_set_card_clk** (int *slot*, uint32_t *freq_khz*)
Set card clock frequency.

Currently only integer fractions of 40MHz clock can be used. For High Speed cards, 40MHz can be used. For Default Speed cards, 20MHz can be used.

**Note** This function is not thread safe

**Return**

- ESP_OK on success

- other error codes may be returned in the future

**Parameters**

- `slot`: slot number (SDMMC_HOST_SLOT_0 or SDMMC_HOST_SLOT_1)
- `freq_khz`: card clock frequency, in kHz

esp_err_t **sdmmc_host_do_transaction** (int *slot*, *sdmmc_command_t* **cmdinfo*)

Send command to the card and get response.

This function returns when command is sent and response is received, or data is transferred, or timeout occurs.

**Note** This function is not thread safe w.r.t. init/deinit functions, and bus width/clock speed configuration functions. Multiple tasks can call sdmmc_host_do_transaction as long as other sdmmc_host_* functions are not called.

**Return**

- ESP_OK on success
- ESP_ERR_TIMEOUT if response or data transfer has timed out
- ESP_ERR_INVALID_CRC if response or data transfer CRC check has failed
- ESP_ERR_INVALID_RESPONSE if the card has sent an invalid response

**Parameters**

- `slot`: slot number (SDMMC_HOST_SLOT_0 or SDMMC_HOST_SLOT_1)
- `cmdinfo`: pointer to structure describing command and data to transfer

esp_err_t **sdmmc_host_deinit** ()

Disable SDMMC host and release allocated resources.

**Note** This function is not thread safe

**Return**

- ESP_OK on success
- ESP_ERR_INVALID_STATE if sdmmc_host_init function has not been called

# Sigma-delta Modulation

## Overview

ESP32 has a second-order sigma-delta modulation module. This driver configures the channels of the sigma-delta module.

## Application Example

Sigma-delta Modulation example: peripherals/sigmadelta.

## API Reference

### Header Files

- driver/include/driver/sigmadelta.h

### Macros

### Type Definitions

### Enumerations

**enum sigmadelta_channel_t**
Sigma-delta channel list.

*Values:*

**SIGMADELTA_CHANNEL_0** = 0
Sigma-delta channel0

**SIGMADELTA_CHANNEL_1** = 1
Sigma-delta channel1

**SIGMADELTA_CHANNEL_2** = 2
Sigma-delta channel2

**SIGMADELTA_CHANNEL_3** = 3
Sigma-delta channel3

**SIGMADELTA_CHANNEL_4** = 4
Sigma-delta channel4

**SIGMADELTA_CHANNEL_5** = 5
Sigma-delta channel5

**SIGMADELTA_CHANNEL_6** = 6
Sigma-delta channel6

**SIGMADELTA_CHANNEL_7** = 7
Sigma-delta channel7

**SIGMADELTA_CHANNEL_MAX**

### Structures

**struct sigmadelta_config_t**
Sigma-delta configure struct.

#### Public Members

*sigmadelta_channel_t* **channel**
Sigma-delta channel number

int8_t **sigmadelta_duty**
Sigma-delta duty, duty ranges from -128 to 127.

uint8_t **sigmadelta_prescale**
Sigma-delta prescale, prescale ranges from 0 to 255.

uint8_t **sigmadelta_gpio**
Sigma-delta output io number, refer to gpio.h for more details.

### Functions

esp_err_t **sigmadelta_config**(*sigmadelta_config_t *config*)
Configure Sigma-delta channel.

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_ARG Parameter error

**Parameters**

- `config`: Pointer of Sigma-delta channel configuration struct

esp_err_t **sigmadelta_set_duty**(*sigmadelta_channel_t channel*, int8_t *duty*)
Set Sigma-delta channel duty.

This function is used to set Sigma-delta channel duty, If you add a capacitor between the output pin and ground, the average output voltage Vdc = VDDIO / 256 * duty + VDDIO/2, VDDIO is power supply voltage.

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_ARG Parameter error

**Parameters**

- `channel`: Sigma-delta channel number
- `duty`: Sigma-delta duty of one channel, the value ranges from -128 to 127, recommended range is -90 ~ 90. The waveform is more like a random one in this range.

esp_err_t **sigmadelta_set_prescale**(*sigmadelta_channel_t channel*, uint8_t *prescale*)
Set Sigma-delta channel's clock pre-scale value. The source clock is APP_CLK, 80MHz. The clock frequency of the sigma-delta channel is APP_CLK / pre_scale.

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_ARG Parameter error

**Parameters**

- `channel`: Sigma-delta channel number
- `prescale`: The divider of source clock, ranges from 0 to 255

esp_err_t **sigmadelta_set_pin**(*sigmadelta_channel_t channel*, *gpio_num_t gpio_num*)
Set Sigma-delta signal output pin.

**Return**

- ESP_OK Success

- ESP_ERR_INVALID_ARG Parameter error

**Parameters**

- `channel`: Sigma-delta channel number
- `gpio_num`: GPIO number of output pin.

# SPI Master driver

## Overview

The ESP32 has four SPI peripheral devices, called SPI0, SPI1, HSPI and VSPI. SPI0 is entirely dedicated to the flash cache the ESP32 uses to map the SPI flash device it is connected to into memory. SPI1 is connected to the same hardware lines as SPI0 and is used to write to the flash chip. HSPI and VSPI are free to use. SPI1, HSPI and VSPI all have three chip select lines, allowing them to drive up to three SPI devices each as a master. The SPI peripherals also can be used in slave mode, driven from another SPI master.

### The spi_master driver

The spi_master driver allows easy communicating with SPI slave devices, even in a multithreaded environment. It fully transparently handles DMA transfers to read and write data and automatically takes care of multiplexing between different SPI slaves on the same master

### Terminology

The spi_master driver uses the following terms:

- Host: The SPI peripheral inside the ESP32 initiating the SPI transmissions. One of SPI, HSPI or VSPI. (For now, only HSPI or VSPI are actually supported in the driver; it will support all 3 peripherals somewhere in the future.)
- Bus: The SPI bus, common to all SPI devices connected to one host. In general the bus consists of the miso, mosi, sclk and optionally quadwp and quadhd signals. The SPI slaves are connected to these signals in parallel.
  - miso - Also known as q, this is the input of the serial stream into the ESP32
  - mosi - Also known as d, this is the output of the serial stream from the ESP32
  - sclk - Clock signal. Each data bit is clocked out or in on the positive or negative edge of this signal
  - quadwp - Write Protect signal. Only used for 4-bit (qio/qout) transactions.
  - quadhd - Hold signal. Only used for 4-bit (qio/qout) transactions.
- Device: A SPI slave. Each SPI slave has its own chip select (CS) line, which is made active when a transmission to/from the SPI slave occurs.
- Transaction: One instance of CS going active, data transfer from and/or to a device happening, and CS going inactive again. Transactions are atomic, as in they will never be interrupted by another transaction.

### SPI transactions

A transaction on the SPI bus consists of five phases, any of which may be skipped:

- The command phase. In this phase, a command (0-16 bit) is clocked out.

- The address phase. In this phase, an address (0-64 bit) is clocked out.
- The read phase. The slave sends data to the master.
- The write phase. The master sends data to the slave.

In full duplex, the read and write phases are combined, causing the SPI host to read and write data simultaneously.

The command and address phase are optional in that not every SPI device will need to be sent a command and/or address. Tis is reflected in the device configuration: when the `command_bits` or `data_bits` fields are set to zero, no command or address phase is done.

Something similar is true for the read and write phase: not every transaction needs both data to be written as well as data to be read. When `rx_buffer` is NULL (and SPI_USE_RXDATA) is not set) the read phase is skipped. When `tx_buffer` is NULL (and SPI_USE_TXDATA) is not set) the write phase is skipped.

### Using the spi_master driver

- Initialize a SPI bus by calling `spi_bus_initialize`. Make sure to set the correct IO pins in the `bus_config` struct. Take care to set signals that are not needed to -1.
- Tell the driver about a SPI slave device conencted to the bus by calling spi_bus_add_device. Make sure to configure any timing requirements the device has in the `dev_config` structure. You should now have a handle for the device, to be used when sending it a transaction.
- To interact with the device, fill one or more spi_transaction_t structure with any transaction parameters you need. Either queue all transactions by calling `spi_device_queue_trans`, later quering the result using `spi_device_get_trans_result`, or handle all requests synchroneously by feeding them into `spi_device_transmit`.
- Optional: to unload the driver for a device, call `spi_bus_remove_device` with the device handle as an argument
- Optional: to remove the driver for a bus, make sure no more drivers are attached and call `spi_bus_free`.

### Transaction data

Normally, data to be transferred to or from a device will be read from or written to a chunk of memory indicated by the `rx_buffer` and `tx_buffer` members of the transaction structure. The SPI driver may decide to use DMA for transfers, so these buffers should be allocated in DMA-capable memory using `pvPortMallocCaps(size, MALLOC_CAP_DMA)`.

Sometimes, the amount of data is very small making it less than optimal allocating a separate buffer for it. If the data to be transferred is 32 bits or less, it can be stored in the transaction struct itself. For transmitted data, use the `tx_data` member for this and set the `SPI_USE_TXDATA` flag on the transmission. For received data, use `rx_data` and set `SPI_USE_RXDATA`. In both cases, do not touch the `tx_buffer` or `rx_buffer` members, because they use the same memory locations as `tx_data` and `rx_data`.

## Application Example

Display graphics on the ILI9341-based 320x240 LCD: peripherals/spi_master.

## API Reference

### Header Files

- driver/include/driver/spi_master.h

### Macros

**SPI_DEVICE_TXBIT_LSBFIRST** (1<<0)
Transmit command/address/data LSB first instead of the default MSB first.

**SPI_DEVICE_RXBIT_LSBFIRST** (1<<1)
Receive data LSB first instead of the default MSB first.

**SPI_DEVICE_BIT_LSBFIRST** (SPI_TXBIT_LSBFIRST|SPI_RXBIT_LSBFIRST);
Transmit and receive LSB first.

**SPI_DEVICE_3WIRE** (1<<2)
Use spiq for both sending and receiving data.

**SPI_DEVICE_POSITIVE_CS** (1<<3)
Make CS positive during a transaction instead of negative.

**SPI_DEVICE_HALFDUPLEX** (1<<4)
Transmit data before receiving it, instead of simultaneously.

**SPI_DEVICE_CLK_AS_CS** (1<<5)
Output clock on CS line if CS is active.

**SPI_TRANS_MODE_DIO** (1<<0)
Transmit/receive data in 2-bit mode.

**SPI_TRANS_MODE_QIO** (1<<1)
Transmit/receive data in 4-bit mode.

**SPI_TRANS_MODE_DIOQIO_ADDR** (1<<2)
Also transmit address in mode selected by SPI_MODE_DIO/SPI_MODE_QIO.

**SPI_TRANS_USE_RXDATA** (1<<2)
Receive into rx_data member of *spi_transaction_t* instead into memory at rx_buffer.

**SPI_TRANS_USE_TXDATA** (1<<3)
Transmit tx_data member of *spi_transaction_t* instead of data at tx_buffer. Do not set tx_buffer when using this.

### Type Definitions

**typedef struct** spi_device_t ***spi_device_handle_t**
Handle for a device on a SPI bus.

### Enumerations

**enum spi_host_device_t**
Enum with the three SPI peripherals that are software-accessible in it.

*Values:*

**SPI_HOST** =0
SPI1, SPI.

**HSPI_HOST** =1
SPI2, HSPI.

**VSPI_HOST** =2
SPI3, VSPI.

### Structures

struct **spi_transaction_t**
This structure describes one SPI transaction

#### Public Members

uint32_t **flags**
Bitwise OR of SPI_TRANS_* flags.

uint16_t **command**
Command data. Specific length was given when device was added to the bus.

uint64_t **address**
Address. Specific length was given when device was added to the bus.

size_t **length**
Total data length, in bits.

size_t **rxlength**
Total data length received, if different from length. (0 defaults this to the value of `length`)

void ***user**
User-defined variable. Can be used to store eg transaction ID.

**const** void ***tx_buffer**
Pointer to transmit buffer, or NULL for no MOSI phase.

uint8_t **tx_data**[4]
If SPI_USE_TXDATA is set, data set here is sent directly from this variable.

void ***rx_buffer**
Pointer to receive buffer, or NULL for no MISO phase.

uint8_t **rx_data**[4]
If SPI_USE_RXDATA is set, data is received directly to this variable.

struct **spi_bus_config_t**
This is a configuration structure for a SPI bus.

You can use this structure to specify the GPIO pins of the bus. Normally, the driver will use the GPIO matrix to route the signals. An exception is made when all signals either can be routed through the IO_MUX or are -1. In that case, the IO_MUX is used, allowing for >40MHz speeds.

#### Public Members

int **mosi_io_num**
GPIO pin for Master Out Slave In (=spi_d) signal, or -1 if not used.

int **miso_io_num**
GPIO pin for Master In Slave Out (=spi_q) signal, or -1 if not used.

int **sclk_io_num**
GPIO pin for Spi CLocK signal, or -1 if not used.

int **quadwp_io_num**
GPIO pin for WP (Write Protect) signal which is used as D2 in 4-bit communication modes, or -1 if not used.

int **quadhd_io_num**
GPIO pin for HD (HolD) signal which is used as D3 in 4-bit communication modes, or -1 if not used.

**struct spi_device_interface_config_t**
This is a configuration for a SPI slave device that is connected to one of the SPI buses.

### Public Members

uint8_t **command_bits**
Amount of bits in command phase (0-16)

uint8_t **address_bits**
Amount of bits in address phase (0-64)

uint8_t **dummy_bits**
Amount of dummy bits to insert between address and data phase.

uint8_t **mode**
SPI mode (0-3)

uint8_t **duty_cycle_pos**
Duty cycle of positive clock, in 1/256th increments (128 = 50%/50% duty). Setting this to 0 (=not setting it) is equivalent to setting this to 128.

uint8_t **cs_ena_pretrans**
Amount of SPI bit-cycles the cs should be activated before the transmission (0-16). This only works on half-duplex transactions.

uint8_t **cs_ena_posttrans**
Amount of SPI bit-cycles the cs should stay active after the transmission (0-16)

int **clock_speed_hz**
Clock speed, in Hz.

int **spics_io_num**
CS GPIO pin for this device, or -1 if not used.

uint32_t **flags**
Bitwise OR of SPI_DEVICE_* flags.

int **queue_size**
Transaction queue size. This sets how many transactions can be 'in the air' (queued using spi_device_queue_trans but not yet finished using spi_device_get_trans_result) at the same time.

transaction_cb_t **pre_cb**
Callback to be called before a transmission is started. This callback is called within interrupt context.

transaction_cb_t **post_cb**
Callback to be called after a transmission has completed. This callback is called within interrupt context.

## Functions

esp_err_t **spi_bus_initialize** (*spi_host_device_t host*, *spi_bus_config_t *bus_config*, int *dma_chan*)
Initialize a SPI bus.

**Warning** For now, only supports HSPI and VSPI.

**Return**

- ESP_ERR_INVALID_ARG if configuration is invalid
- ESP_ERR_INVALID_STATE if host already is in use
- ESP_ERR_NO_MEM if out of memory
- ESP_OK on success

**Parameters**

- `host`: SPI peripheral that controls this bus
- `bus_config`: Pointer to a *spi_bus_config_t* struct specifying how the host should be initialized
- `dma_chan`: Either 1 or 2. A SPI bus used by this driver must have a DMA channel associated with it. The SPI hardware has two DMA channels to share. This parameter indicates which one to use.

esp_err_t **spi_bus_free**(*spi_host_device_t host*)

Free a SPI bus.

**Warning** In order for this to succeed, all devices have to be removed first.

**Return**

- ESP_ERR_INVALID_ARG if parameter is invalid
- ESP_ERR_INVALID_STATE if not all devices on the bus are freed
- ESP_OK on success

**Parameters**

- `host`: SPI peripheral to free

esp_err_t **spi_bus_add_device**(*spi_host_device_t host*, *spi_device_interface_config_t *dev_config*, *spi_device_handle_t *handle*)

Allocate a device on a SPI bus.

This initializes the internal structures for a device, plus allocates a CS pin on the indicated SPI master peripheral and routes it to the indicated GPIO. All SPI master devices have three CS pins and can thus control up to three devices.

**Note** While in general, speeds up to 80MHz on the dedicated SPI pins and 40MHz on GPIO-matrix-routed pins are supported, full-duplex transfers routed over the GPIO matrix only support speeds up to 26MHz.

**Return**

- ESP_ERR_INVALID_ARG if parameter is invalid
- ESP_ERR_NOT_FOUND if host doesn't have any free CS slots
- ESP_ERR_NO_MEM if out of memory
- ESP_OK on success

**Parameters**

- `host`: SPI peripheral to allocate device on
- `dev_config`: SPI interface protocol config for the device
- `handle`: Pointer to variable to hold the device handle

esp_err_t **spi_bus_remove_device** (*spi_device_handle_t handle*)

Remove a device from the SPI bus.

**Return**

- ESP_ERR_INVALID_ARG if parameter is invalid
- ESP_ERR_INVALID_STATE if device already is freed
- ESP_OK on success

**Parameters**

- `handle`: Device handle to free

esp_err_t **spi_device_queue_trans** (*spi_device_handle_t handle*, *spi_transaction_t *trans_desc*, TickType_t *ticks_to_wait*)

Queue a SPI transaction for execution.

**Return**

- ESP_ERR_INVALID_ARG if parameter is invalid
- ESP_OK on success

**Parameters**

- `handle`: Device handle obtained using spi_host_add_dev
- `trans_desc`: Description of transaction to execute
- `ticks_to_wait`: Ticks to wait until there's room in the queue; use portMAX_DELAY to never time out.

esp_err_t **spi_device_get_trans_result** (*spi_device_handle_t handle*, *spi_transaction_t **trans_desc*, TickType_t *ticks_to_wait*)

Get the result of a SPI transaction queued earlier.

This routine will wait until a transaction to the given device (queued earlier with spi_device_queue_trans) has succesfully completed. It will then return the description of the completed transaction so software can inspect the result and e.g. free the memory or re-use the buffers.

**Return**

- ESP_ERR_INVALID_ARG if parameter is invalid
- ESP_OK on success

**Parameters**

- `handle`: Device handle obtained using spi_host_add_dev
- `trans_desc`: Pointer to variable able to contain a pointer to the description of the transaction that is executed
- `ticks_to_wait`: Ticks to wait until there's a returned item; use portMAX_DELAY to never time out.

esp_err_t **spi_device_transmit** (*spi_device_handle_t handle*, *spi_transaction_t *trans_desc*)

Do a SPI transaction.

Essentially does the same as spi_device_queue_trans followed by spi_device_get_trans_result. Do not use this when there is still a transaction queued that hasn't been finalized using spi_device_get_trans_result.

**Return**

- ESP_ERR_INVALID_ARG if parameter is invalid
- ESP_OK on success

**Parameters**

- `handle`: Device handle obtained using spi_host_add_dev
- `trans_desc`: Pointer to variable able to contain a pointer to the description of the transaction that is executed

# RMT

## Overview

The RMT (Remote Control) module driver can be used to send and receive infrared remote control signals. Due to flexibility of RMT module, the driver can also be used to generate many other types of signals.

## Application Example

NEC remote control TX and RX example: peripherals/rmt_nec_tx_rx.

## API Reference

### Header Files

- driver/include/driver/rmt.h

### Macros

**`RMT_MEM_BLOCK_BYTE_NUM`** (256)

**`RMT_MEM_ITEM_NUM`** (RMT_MEM_BLOCK_BYTE_NUM/4)

### Enumerations

**enum `rmt_channel_t`**

*Values:*

**`RMT_CHANNEL_0`** =0
RMT Channel0

**`RMT_CHANNEL_1`**
RMT Channel1

**`RMT_CHANNEL_2`**
RMT Channel2

**`RMT_CHANNEL_3`**
RMT Channel3

**RMT_CHANNEL_4**
RMT Channel4

**RMT_CHANNEL_5**
RMT Channel5

**RMT_CHANNEL_6**
RMT Channel6

**RMT_CHANNEL_7**
RMT Channel7

**RMT_CHANNEL_MAX**

**enum rmt_mem_owner_t**
*Values:*

**RMT_MEM_OWNER_TX** = 0
RMT RX mode, RMT transmitter owns the memory block

**RMT_MEM_OWNER_RX** = 1
RMT RX mode, RMT receiver owns the memory block

**RMT_MEM_OWNER_MAX**

**enum rmt_source_clk_t**
*Values:*

**RMT_BASECLK_REF** = 0
RMT source clock system reference tick, 1MHz by default(Not supported in this version)

**RMT_BASECLK_APB**
RMT source clock is APB CLK, 80Mhz by default

**RMT_BASECLK_MAX**

**enum rmt_data_mode_t**
*Values:*

**RMT_DATA_MODE_FIFO** = 0

**RMT_DATA_MODE_MEM** = 1

**RMT_DATA_MODE_MAX**

**enum rmt_mode_t**
*Values:*

**RMT_MODE_TX** =0
RMT TX mode

**RMT_MODE_RX**
RMT RX mode

**RMT_MODE_MAX**

**enum rmt_idle_level_t**
*Values:*

**RMT_IDLE_LEVEL_LOW** =0
RMT TX idle level: low Level

**RMT_IDLE_LEVEL_HIGH**
RMT TX idle level: high Level

**RMT_IDLE_LEVEL_MAX**

**enum rmt_carrier_level_t**

*Values:*

**RMT_CARRIER_LEVEL_LOW** =0
RMT carrier wave is modulated for low Level output

**RMT_CARRIER_LEVEL_HIGH**
RMT carrier wave is modulated for high Level output

**RMT_CARRIER_LEVEL_MAX**

## Structures

**struct rmt_tx_config_t**
Data struct of RMT TX configure parameters.

### Public Members

bool **loop_en**
RMT loop output mode

uint32_t **carrier_freq_hz**
RMT carrier frequency

uint8_t **carrier_duty_percent**
RMT carrier duty (%)

*rmt_carrier_level_t* **carrier_level**
RMT carrier level

bool **carrier_en**
RMT carrier enable

*rmt_idle_level_t* **idle_level**
RMT idle level

bool **idle_output_en**
RMT idle level output enable

**struct rmt_rx_config_t**
Data struct of RMT RX configure parameters.

### Public Members

bool **filter_en**
RMT receiver filer enable

uint8_t **filter_ticks_thresh**
RMT filter tick number

uint16_t **idle_threshold**
RMT RX idle threshold

**struct rmt_config_t**
Data struct of RMT configure parameters.

### Public Members

*rmt_mode_t* **rmt_mode**
RMT mode: transmitter or receiver

*rmt_channel_t* **channel**
RMT channel

uint8_t **clk_div**
RMT channel counter divider

*gpio_num_t* **gpio_num**
RMT GPIO number

uint8_t **mem_block_num**
RMT memory block number

*rmt_tx_config_t* **tx_config**
RMT TX parameter

*rmt_rx_config_t* **rx_config**
RMT RX parameter

## Functions

esp_err_t **rmt_set_clk_div**(*rmt_channel_t channel*, uint8_t *div_cnt*)
Set RMT clock divider, channel clock is divided from source clock.

**Return**

- ESP_ERR_INVALID_ARG Parameter error
- ESP_OK Success

**Parameters**

- `channel`: RMT channel (0-7)
- `div_cnt`: RMT counter clock divider

esp_err_t **rmt_get_clk_div**(*rmt_channel_t channel*, uint8_t **div_cnt*)
Get RMT clock divider, channel clock is divided from source clock.

**Return**

- ESP_ERR_INVALID_ARG Parameter error
- ESP_OK Success

**Parameters**

- `channel`: RMT channel (0-7)
- `div_cnt`: pointer to accept RMT counter divider

esp_err_t **rmt_set_rx_idle_thresh**(*rmt_channel_t channel*, uint16_t *thresh*)
Set RMT RX idle threshold value.

In receive mode, when no edge is detected on the input signal for longer than idle_thres channel clock cycles, the receive process is finished.

**Return**

- ESP_ERR_INVALID_ARG Parameter error
- ESP_OK Success

**Parameters**

- `channel`: RMT channel (0-7)
- `thresh`: RMT RX idle threshold

esp_err_t **rmt_get_rx_idle_thresh**(*rmt_channel_t channel*, uint16_t **thresh*)

Get RMT idle threshold value.

In receive mode, when no edge is detected on the input signal for longer than idle_thres channel clock cycles, the receive process is finished.

**Return**

- ESP_ERR_INVALID_ARG Parameter error
- ESP_OK Success

**Parameters**

- `channel`: RMT channel (0-7)
- `thresh`: pointer to accept RMT RX idle threshold value

esp_err_t **rmt_set_mem_block_num**(*rmt_channel_t channel*, uint8_t *rmt_mem_num*)

Set RMT memory block number for RMT channel.

This function is used to configure the amount of memory blocks allocated to channel n The 8 channels share a 512x32-bit RAM block which can be read and written by the processor cores over the APB bus, as well as read by the transmitters and written by the receivers. The RAM address range for channel n is start_addr_CHn to end_addr_CHn, which are defined by: Memory block start address is RMT_CHANNEL_MEM(n) (in soc/rmt_reg.h), that is, start_addr_chn = RMT base address + 0x800 + 64 4 n, and end_addr_chn = RMT base address + 0x800 + 64 4 n + 64 4 RMT_MEM_SIZE_CHn mod 512 4

**Note** If memory block number of one channel is set to a value greater than 1, this channel will occupy the memory block of the next channel. Channel0 can use at most 8 blocks of memory, accordingly channel7 can only use one memory block.

**Return**

- ESP_ERR_INVALID_ARG Parameter error
- ESP_OK Success

**Parameters**

- `channel`: RMT channel (0-7)
- `rmt_mem_num`: RMT RX memory block number, one block has 64 * 32 bits.

esp_err_t **rmt_get_mem_block_num**(*rmt_channel_t channel*, uint8_t **rmt_mem_num*)

Get RMT memory block number.

**Return**

- ESP_ERR_INVALID_ARG Parameter error
- ESP_OK Success

**Parameters**

- `channel`: RMT channel (0-7)
- `rmt_mem_num`: Pointer to accept RMT RX memory block number

esp_err_t **rmt_set_tx_carrier**(*rmt_channel_t channel*, bool *carrier_en*, uint16_t *high_level*, uint16_t *low_level*, *rmt_carrier_level_t carrier_level*)

Configure RMT carrier for TX signal.

Set different values for carrier_high and carrier_low to set different frequency of carrier. The unit of carrier_high/low is the source clock tick, not the divided channel counter clock.

**Return**

- ESP_ERR_INVALID_ARG Parameter error
- ESP_OK Success

**Parameters**

- `channel`: RMT channel (0-7)
- `carrier_en`: Whether to enable output carrier.
- `high_level`: High level duration of carrier
- `low_level`: Low level duration of carrier.
- `carrier_level`: Configure the way carrier wave is modulated for channel0-7.

```
1'b1:transmit on low output level

1'b0:transmit on high output level
```

esp_err_t **rmt_set_mem_pd**(*rmt_channel_t channel*, bool *pd_en*)

Set RMT memory in low power mode.

Reduce power consumed by memory. 1:memory is in low power state.

**Return**

- ESP_ERR_INVALID_ARG Parameter error
- ESP_OK Success

**Parameters**

- `channel`: RMT channel (0-7)
- `pd_en`: RMT memory low power enable.

esp_err_t **rmt_get_mem_pd**(*rmt_channel_t channel*, bool **pd_en*)

Get RMT memory low power mode.

**Return**

- ESP_ERR_INVALID_ARG Parameter error
- ESP_OK Success

**Parameters**

- `channel`: RMT channel (0-7)

- `pd_en`: Pointer to accept RMT memory low power mode.

esp_err_t **rmt_tx_start** (*rmt_channel_t channel*, bool *tx_idx_rst*)
Set RMT start sending data from memory.

**Return**

- ESP_ERR_INVALID_ARG Parameter error
- ESP_OK Success

**Parameters**

- `channel`: RMT channel (0-7)
- `tx_idx_rst`: Set true to reset memory index for TX. Otherwise, transmitter will continue sending from the last index in memory.

esp_err_t **rmt_tx_stop** (*rmt_channel_t channel*)
Set RMT stop sending.

**Return**

- ESP_ERR_INVALID_ARG Parameter error
- ESP_OK Success

**Parameters**

- `channel`: RMT channel (0-7)

esp_err_t **rmt_rx_start** (*rmt_channel_t channel*, bool *rx_idx_rst*)
Set RMT start receiving data.

**Return**

- ESP_ERR_INVALID_ARG Parameter error
- ESP_OK Success

**Parameters**

- `channel`: RMT channel (0-7)
- `rx_idx_rst`: Set true to reset memory index for receiver. Otherwise, receiver will continue receiving data to the last index in memory.

esp_err_t **rmt_rx_stop** (*rmt_channel_t channel*)
Set RMT stop receiving data.

**Return**

- ESP_ERR_INVALID_ARG Parameter error
- ESP_OK Success

**Parameters**

- `channel`: RMT channel (0-7)

esp_err_t **rmt_memory_rw_rst** (*rmt_channel_t channel*)
Reset RMT TX/RX memory index.

**Return**

- ESP_ERR_INVALID_ARG Parameter error
- ESP_OK Success

**Parameters**

- `channel`: RMT channel (0-7)

esp_err_t **rmt_set_memory_owner** (*rmt_channel_t channel*, *rmt_mem_owner_t owner*)
Set RMT memory owner.

**Return**

- ESP_ERR_INVALID_ARG Parameter error
- ESP_OK Success

**Parameters**

- `channel`: RMT channel (0-7)
- `owner`: To set when the transmitter or receiver can process the memory of channel.

esp_err_t **rmt_get_memory_owner** (*rmt_channel_t channel*, *rmt_mem_owner_t *owner*)
Get RMT memory owner.

**Return**

- ESP_ERR_INVALID_ARG Parameter error
- ESP_OK Success

**Parameters**

- `channel`: RMT channel (0-7)
- `owner`: Pointer to get memory owner.

esp_err_t **rmt_set_tx_loop_mode** (*rmt_channel_t channel*, bool *loop_en*)
Set RMT tx loop mode.

**Return**

- ESP_ERR_INVALID_ARG Parameter error
- ESP_OK Success

**Parameters**

- `channel`: RMT channel (0-7)
- `loop_en`: To enable RMT transmitter loop sending mode.

```
        If set true, transmitter will continue sending from the first
↪data
        to the last data in channel0-7 again and again.
```

esp_err_t **rmt_get_tx_loop_mode** (*rmt_channel_t channel*, bool **loop_en*)
Get RMT tx loop mode.

**Return**

- ESP_ERR_INVALID_ARG Parameter error
- ESP_OK Success

**Parameters**

- `channel`: RMT channel (0-7)
- `loop_en`: Pointer to accept RMT transmitter loop sending mode.

esp_err_t **rmt_set_rx_filter**(*rmt_channel_t channel*, bool *rx_filter_en*, uint8_t *thresh*)

Set RMT RX filter.

In receive mode, channel0-7 will ignore input pulse when the pulse width is smaller than threshold. Counted in source clock, not divided counter clock.

**Return**

- ESP_ERR_INVALID_ARG Parameter error
- ESP_OK Success

**Parameters**

- `channel`: RMT channel (0-7)
- `rx_filter_en`: To enable RMT receiver filter.
- `thresh`: Threshold of pulse width for receiver.

esp_err_t **rmt_set_source_clk**(*rmt_channel_t channel*, *rmt_source_clk_t base_clk*)

Set RMT source clock.

RMT module has two source clock:

1.APB clock which is 80Mhz

2.REF tick clock, which would be 1Mhz( not supported in this version).

**Return**

- ESP_ERR_INVALID_ARG Parameter error
- ESP_OK Success

**Parameters**

- `channel`: RMT channel (0-7)
- `base_clk`: To choose source clock for RMT module.

esp_err_t **rmt_get_source_clk**(*rmt_channel_t channel*, *rmt_source_clk_t *src_clk*)

Get RMT source clock.

RMT module has two source clock:

1.APB clock which is 80Mhz

2.REF tick clock, which would be 1Mhz( not supported in this version).

**Return**

- ESP_ERR_INVALID_ARG Parameter error
- ESP_OK Success

**Parameters**

- `channel`: RMT channel (0-7)
- `src_clk`: Pointer to accept source clock for RMT module.

esp_err_t **rmt_set_idle_level** (*rmt_channel_t channel*, bool *idle_out_en*, *rmt_idle_level_t level*)
Set RMT idle output level for transmitter.

**Return**

- ESP_ERR_INVALID_ARG Parameter error
- ESP_OK Success

**Parameters**

- `channel`: RMT channel (0-7)
- `idle_out_en`: To enable idle level output.
- `level`: To set the output signal's level for channel0-7 in idle state.

esp_err_t **rmt_get_status** (*rmt_channel_t channel*, uint32_t **status*)
Get RMT status.

**Return**

- ESP_ERR_INVALID_ARG Parameter error
- ESP_OK Success

**Parameters**

- `channel`: RMT channel (0-7)
- `status`: Pointer to accept channel status.

void **rmt_set_intr_enable_mask** (uint32_t *mask*)
Set mask value to RMT interrupt enable register.

**Parameters**

- `mask`: Bit mask to set to the register

void **rmt_clr_intr_enable_mask** (uint32_t *mask*)
Clear mask value to RMT interrupt enable register.

**Parameters**

- `mask`: Bit mask to clear the register

esp_err_t **rmt_set_rx_intr_en** (*rmt_channel_t channel*, bool *en*)
Set RMT RX interrupt enable.

**Return**

- ESP_ERR_INVALID_ARG Parameter error
- ESP_OK Success

**Parameters**

- `channel`: RMT channel (0 - 7)
- `en`: enable or disable RX interrupt.

esp_err_t **rmt_set_err_intr_en**(*rmt_channel_t channel*, bool *en*)
Set RMT RX error interrupt enable.

**Return**

- ESP_ERR_INVALID_ARG Parameter error
- ESP_OK Success

**Parameters**

- `channel`: RMT channel (0 - 7)
- `en`: enable or disable RX err interrupt.

esp_err_t **rmt_set_tx_intr_en**(*rmt_channel_t channel*, bool *en*)
Set RMT TX interrupt enable.

**Return**

- ESP_ERR_INVALID_ARG Parameter error
- ESP_OK Success

**Parameters**

- `channel`: RMT channel (0 - 7)
- `en`: enable or disable TX interrupt.

**Warning:** doxygenfunction: Cannot find function "rmt_set_evt_intr_en" in doxygen xml output for project "esp32-idf" from directory: xml/

esp_err_t **rmt_set_pin**(*rmt_channel_t channel*, *rmt_mode_t mode*, *gpio_num_t gpio_num*)
Set RMT pins.

**Return**

- ESP_ERR_INVALID_ARG Parameter error
- ESP_OK Success

**Parameters**

- `channel`: RMT channel (0 - 7)
- `mode`: TX or RX mode for RMT
- `gpio_num`: GPIO number to transmit or receive the signal.

esp_err_t **rmt_config**(*rmt_config_t *rmt_param*)
Configure RMT parameters.

**Return**

- ESP_ERR_INVALID_ARG Parameter error
- ESP_OK Success

**Parameters**

- `rmt_param`: RMT parameter structor

esp_err_t **rmt_isr_register** (void (**fn*)) void *
, void **arg*, int *intr_alloc_flags*, rmt_isr_handle_t **handle*register RMT interrupt handler, the handler is an ISR.

The handler will be attached to the same CPU core that this function is running on.

**Note** If you already called rmt_driver_install to use system RMT driver, please do not register ISR handler again.

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_ARG Function pointer error.
- ESP_FAIL System driver installed, can not register ISR handler for RMT

**Parameters**

- `fn`: Interrupt handler function.
- `arg`: Parameter for handler function
- `intr_alloc_flags`: Flags used to allocate the interrupt. One or multiple (ORred) ESP_INTR_FLAG_* values. See esp_intr_alloc.h for more info.
- `handle`: If non-zero, a handle to later clean up the ISR gets stored here.

esp_err_t **rmt_fill_tx_items** (*rmt_channel_t channel*, rmt_item32_t **item*, uint16_t *item_num*, uint16_t *mem_offset*)
Fill memory data of channel with given RMT items.

**Return**

- ESP_ERR_INVALID_ARG Parameter error
- ESP_OK Success

**Parameters**

- `channel`: RMT channel (0 - 7)
- `item`: Pointer of items.
- `item_num`: RMT sending items number.
- `mem_offset`: Index offset of memory.

esp_err_t **rmt_driver_install** (*rmt_channel_t channel*, size_t *rx_buf_size*, int *intr_alloc_flags*)
Initialize RMT driver.

**Return**

- ESP_ERR_INVALID_STATE Driver is already installed, call rmt_driver_uninstall first.
- ESP_ERR_NO_MEM Memory allocation failure
- ESP_ERR_INVALID_ARG Parameter error
- ESP_OK Success

**Parameters**

- `channel`: RMT channel (0 - 7)

- `rx_buf_size`: Size of RMT RX ringbuffer. Can be 0 if the RX ringbuffer is not used.
- `intr_alloc_flags`: Flags for the RMT driver interrupt handler. Pass 0 for default flags. See esp_intr_alloc.h for details.

esp_err_t **rmt_driver_uninstall** (*rmt_channel_t channel*)

Uninstall RMT driver.

**Return**

- ESP_ERR_INVALID_ARG Parameter error
- ESP_OK Success

**Parameters**

- `channel`: RMT channel (0 - 7)

esp_err_t **rmt_write_items** (*rmt_channel_t channel*, rmt_item32_t **rmt_item*, int *item_num*, bool *wait_tx_done*)

RMT send waveform from rmt_item array.

This API allows user to send waveform with any length.

**Return**

- ESP_ERR_INVALID_ARG Parameter error
- ESP_OK Success

**Parameters**

- `channel`: RMT channel (0 - 7)
- `rmt_item`: head point of RMT items array.
- `item_num`: RMT data item number.
- `wait_tx_done`: If set 1, it will block the task and wait for sending done.

```
                 If set 0, it will not wait and return immediately.

                 @note
                 This function will not copy data, instead, it will point␣
↪to the original items,
                 and send the waveform items.
                 If wait_tx_done is set to true, this function will block␣
↪and will not return until
                 all items have been sent out.
                 If wait_tx_done is set to false, this function will␣
↪return immediately, and the driver
                 interrupt will continue sending the items. We must make␣
↪sure the item data will not be
                 damaged when the driver is still sending items in driver␣
↪interrupt.
```

esp_err_t **rmt_wait_tx_done** (*rmt_channel_t channel*)

Wait RMT TX finished.

**Return**

- ESP_ERR_INVALID_ARG Parameter error

- ESP_OK Success

**Parameters**

- `channel`: RMT channel (0 - 7)

esp_err_t **rmt_get_ringbuf_handler** (*rmt_channel_t channel*, RingbufHandle_t **buf_handler*)

Get ringbuffer from UART.

Users can get the RMT RX ringbuffer handler, and process the RX data.

**Return**

- ESP_ERR_INVALID_ARG Parameter error
- ESP_OK Success

**Parameters**

- `channel`: RMT channel (0 - 7)
- `buf_handler`: Pointer to buffer handler to accept RX ringbuffer handler.

# TIMER

## Overview

ESP32 chip contains two hardware timer groups, each containing two general-purpose hardware timers.

They are all 64-bit generic timers based on 16-bit prescalers and 64-bit auto-reload-capable up/down counters.

## Application Example

64-bit hardware timer example: peripherals/timer_group.

## API Reference

### Header Files

- driver/include/driver/timer.h

### Macros

**TIMER_BASE_CLK** (APB_CLK_FREQ)

### Type Definitions

### Enumerations

**enum timer_group_t**

Selects a Timer-Group out of 2 available groups.

*Values:*

**TIMER_GROUP_0** = 0
Hw timer group 0

**TIMER_GROUP_1** = 1
Hw timer group 1

**TIMER_GROUP_MAX**

**enum timer_idx_t**
Select a hardware timer from timer groups.

*Values:*

**TIMER_0** = 0
Select timer0 of GROUPx

**TIMER_1** = 1
Select timer1 of GROUPx

**TIMER_MAX**

**enum timer_count_dir_t**
Decides the direction of counter.

*Values:*

**TIMER_COUNT_DOWN** = 0
Descending Count from cnt.high|cnt.low

**TIMER_COUNT_UP** = 1
Ascending Count from Zero

**TIMER_COUNT_MAX**

**enum timer_start_t**
Decides whether timer is on or paused.

*Values:*

**TIMER_PAUSE** = 0
Pause timer counter

**TIMER_START** = 1
Start timer counter

**enum timer_alarm_t**
Decides whether to enable alarm mode.

*Values:*

**TIMER_ALARM_DIS** = 0
Disable timer alarm

**TIMER_ALARM_EN** = 1
Enable timer alarm

**TIMER_ALARM_MAX**

**enum timer_intr_mode_t**
Select interrupt type if running in alarm mode.

*Values:*

**TIMER_INTR_LEVEL** = 0
Interrupt mode: level mode

**TIMER_INTR_MAX**

enum **timer_autoreload_t**
Select if Alarm needs to be loaded by software or automatically reload by hardware.

*Values:*

**TIMER_AUTORELOAD_DIS** = 0
Disable auto-reload: hardware will not load counter value after an alarm event

**TIMER_AUTORELOAD_EN** = 1
Enable auto-reload: hardware will load counter value after an alarm event

**TIMER_AUTORELOAD_MAX**

### Structures

struct **timer_config_t**
timer configure struct

#### Public Members

bool **alarm_en**
Timer alarm enable

bool **counter_en**
Counter enable

*timer_intr_mode_t* **intr_type**
Interrupt mode

*timer_count_dir_t* **counter_dir**
Counter direction

bool **auto_reload**
Timer auto-reload

uint16_t **divider**
Counter clock divider

### Functions

esp_err_t **timer_get_counter_value**(*timer_group_t group_num*, *timer_idx_t timer_num*, uint64_t **timer_val*)
Read the counter value of hardware timer.

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_ARG Parameter error

**Parameters**

- `group_num`: Timer group, 0 for TIMERG0 or 1 for TIMERG1
- `timer_num`: Timer index, 0 for hw_timer[0] & 1 for hw_timer[1]
- `timer_val`: Pointer to accept timer counter value.

esp_err_t **timer_get_counter_time_sec** (*timer_group_t group_num*, *timer_idx_t timer_num*, double **time*)
Read the counter value of hardware timer, in unit of a given scale.

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_ARG Parameter error

**Parameters**

- `group_num`: Timer group, 0 for TIMERG0 or 1 for TIMERG1
- `timer_num`: Timer index, 0 for hw_timer[0] & 1 for hw_timer[1]
- `time`: Pointer, type of double*, to accept timer counter value, in seconds.

esp_err_t **timer_set_counter_value** (*timer_group_t group_num*, *timer_idx_t timer_num*, uint64_t *load_val*)
Set counter value to hardware timer.

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_ARG Parameter error

**Parameters**

- `group_num`: Timer group, 0 for TIMERG0 or 1 for TIMERG1
- `timer_num`: Timer index, 0 for hw_timer[0] & 1 for hw_timer[1]
- `load_val`: Counter value to write to the hardware timer.

esp_err_t **timer_start** (*timer_group_t group_num*, *timer_idx_t timer_num*)
Start the counter of hardware timer.

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_ARG Parameter error

**Parameters**

- `group_num`: Timer group number, 0 for TIMERG0 or 1 for TIMERG1
- `timer_num`: Timer index, 0 for hw_timer[0] & 1 for hw_timer[1]

esp_err_t **timer_pause** (*timer_group_t group_num*, *timer_idx_t timer_num*)
Pause the counter of hardware timer.

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_ARG Parameter error

**Parameters**

- `group_num`: Timer group number, 0 for TIMERG0 or 1 for TIMERG1
- `timer_num`: Timer index, 0 for hw_timer[0] & 1 for hw_timer[1]

esp_err_t **timer_set_counter_mode**(*timer_group_t group_num*, *timer_idx_t timer_num*, *timer_count_dir_t counter_dir*)
Set counting mode for hardware timer.

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_ARG Parameter error

**Parameters**

- `group_num`: Timer group number, 0 for TIMERG0 or 1 for TIMERG1
- `timer_num`: Timer index, 0 for hw_timer[0] & 1 for hw_timer[1]
- `counter_dir`: Counting direction of timer, count-up or count-down

esp_err_t **timer_set_auto_reload**(*timer_group_t group_num*, *timer_idx_t timer_num*, *timer_autoreload_t reload*)
Enable or disable counter reload function when alarm event occurs.

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_ARG Parameter error

**Parameters**

- `group_num`: Timer group number, 0 for TIMERG0 or 1 for TIMERG1
- `timer_num`: Timer index, 0 for hw_timer[0] & 1 for hw_timer[1]
- `reload`: Counter reload mode.

esp_err_t **timer_set_divider**(*timer_group_t group_num*, *timer_idx_t timer_num*, uint16_t *divider*)
Set hardware timer source clock divider. Timer groups clock are divider from APB clock.

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_ARG Parameter error

**Parameters**

- `group_num`: Timer group number, 0 for TIMERG0 or 1 for TIMERG1
- `timer_num`: Timer index, 0 for hw_timer[0] & 1 for hw_timer[1]
- `divider`: Timer clock divider value.

esp_err_t **timer_set_alarm_value**(*timer_group_t group_num*, *timer_idx_t timer_num*, uint64_t *alarm_value*)
Set timer alarm value.

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_ARG Parameter error

**Parameters**

- `group_num`: Timer group, 0 for TIMERG0 or 1 for TIMERG1

- `timer_num`: Timer index, 0 for hw_timer[0] & 1 for hw_timer[1]
- `alarm_value`: A 64-bit value to set the alarm value.

esp_err_t **timer_get_alarm_value**(*timer_group_t group_num*, *timer_idx_t timer_num*, uint64_t **alarm_value*)

Get timer alarm value.

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_ARG Parameter error

**Parameters**

- `group_num`: Timer group, 0 for TIMERG0 or 1 for TIMERG1
- `timer_num`: Timer index, 0 for hw_timer[0] & 1 for hw_timer[1]
- `alarm_value`: Pointer of A 64-bit value to accept the alarm value.

esp_err_t **timer_set_alarm**(*timer_group_t group_num*, *timer_idx_t timer_num*, *timer_alarm_t alarm_en*)

Get timer alarm value.

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_ARG Parameter error

**Parameters**

- `group_num`: Timer group, 0 for TIMERG0 or 1 for TIMERG1
- `timer_num`: Timer index, 0 for hw_timer[0] & 1 for hw_timer[1]
- `alarm_en`: To enable or disable timer alarm function.

esp_err_t **timer_isr_register**(*timer_group_t group_num*, *timer_idx_t timer_num*, void (**fn*)) void *

, void **arg*, int *intr_alloc_flags*, timer_isr_handle_t **handle*register Timer interrupt handler, the handler is an ISR. The handler will be attached to the same CPU core that this function is running on.

**Note** In case the this is called with the INIRAM flag, code inside the handler function can only call functions in IRAM, so it cannot call other timer APIs. Use direct register access to access timers from inside the ISR in this case.

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_ARG Function pointer error.

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_ARG Parameter error

**Parameters**

- `group_num`: Timer group number
- `timer_num`: Timer index of timer group

- `fn`: Interrupt handler function.

**Parameters**

- `arg`: Parameter for handler function
- `intr_alloc_flags`: Flags used to allocate the interrupt. One or multiple (ORred) ESP_INTR_FLAG_* values. See esp_intr_alloc.h for more info.
- `handle`: Pointer to return handle. If non-NULL, a handle for the interrupt will be returned here.

esp_err_t **timer_init** (*timer_group_t group_num*, *timer_idx_t timer_num*, *timer_config_t *config*)
Initializes and configure the timer.

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_ARG Parameter error

**Parameters**

- `group_num`: Timer group number, 0 for TIMERG0 or 1 for TIMERG1
- `timer_num`: Timer index, 0 for hw_timer[0] & 1 for hw_timer[1]
- `config`: Pointer to timer initialization parameters.

esp_err_t **timer_get_config** (*timer_group_t group_num*, *timer_idx_t timer_num*, *timer_config_t *config*)
Get timer configure value.

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_ARG Parameter error

**Parameters**

- `group_num`: Timer group number, 0 for TIMERG0 or 1 for TIMERG1
- `timer_num`: Timer index, 0 for hw_timer[0] & 1 for hw_timer[1]
- `config`: Pointer of struct to accept timer parameters.

esp_err_t **timer_group_intr_enable** (*timer_group_t group_num*, uint32_t *en_mask*)
Enable timer group interrupt, by enable mask.

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_ARG Parameter error

**Parameters**

- `group_num`: Timer group number, 0 for TIMERG0 or 1 for TIMERG1
- `en_mask`: Timer interrupt enable mask. Use TIMG_T0_INT_ENA_M to enable t0 interrupt Use TIMG_T1_INT_ENA_M to enable t1 interrupt

esp_err_t **timer_group_intr_disable** (*timer_group_t group_num*, uint32_t *disable_mask*)
Disable timer group interrupt, by disable mask.

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_ARG Parameter error

**Parameters**

- `group_num`: Timer group number, 0 for TIMERG0 or 1 for TIMERG1
- `disable_mask`: Timer interrupt disable mask. Use TIMG_T0_INT_ENA_M to disable t0 interrupt Use TIMG_T1_INT_ENA_M to disable t1 interrupt

esp_err_t **timer_enable_intr** (*timer_group_t group_num*, *timer_idx_t timer_num*)
Enable timer interrupt.

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_ARG Parameter error

**Parameters**

- `group_num`: Timer group number, 0 for TIMERG0 or 1 for TIMERG1
- `timer_num`: Timer index.

esp_err_t **timer_disable_intr** (*timer_group_t group_num*, *timer_idx_t timer_num*)
Disable timer interrupt.

**Return**

- ESP_OK Success
- ESP_ERR_INVALID_ARG Parameter error

**Parameters**

- `group_num`: Timer group number, 0 for TIMERG0 or 1 for TIMERG1
- `timer_num`: Timer index.

# UART

## Overview

Instructions

## Application Example

Configure uart settings and install uart driver to read/write using UART0 and UART1 interfaces: peripherals/uart.

## API Reference

### Header Files

- driver/include/driver/uart.h

### Data Structures

**struct uart_config_t**
UART configuration parameters for uart_param_config function.

#### Public Members

int **baud_rate**
UART baudrate

*uart_word_length_t* **data_bits**
UART byte size

*uart_parity_t* **parity**
UART parity mode

*uart_stop_bits_t* **stop_bits**
UART stop bits

*uart_hw_flowcontrol_t* **flow_ctrl**
UART HW flow control mode(cts/rts)

uint8_t **rx_flow_ctrl_thresh**
UART HW RTS threshold

**struct uart_intr_config_t**
UART interrupt configuration parameters for uart_intr_config function.

#### Public Members

uint32_t **intr_enable_mask**
UART interrupt enable mask, choose from UART_XXXX_INT_ENA_M under UART_INT_ENA_REG(i), connect with bit-or operator

uint8_t **rx_timeout_thresh**
UART timeout interrupt threshold(unit: time of sending one byte)

uint8_t **txfifo_empty_intr_thresh**
UART TX empty interrupt threshold.

uint8_t **rxfifo_full_thresh**
UART RX full interrupt threshold.

**struct uart_event_t**
Event structure used in UART event queue.

#### Public Members

*uart_event_type_t* **type**
UART event type

size_t **size**
UART data size for UART_DATA event

### Macros

**UART_FIFO_LEN** (128)
Length of the hardware FIFO buffers

**UART_INTR_MASK** 0x1ff
mask of all UART interrupts

**UART_LINE_INV_MASK** (0x3f << 19)
TBD

**UART_BITRATE_MAX** 5000000
Max bit rate supported by UART

**UART_PIN_NO_CHANGE** (-1)
Constant for uart_set_pin function which indicates that UART pin should not be changed

**UART_INVERSE_DISABLE** (0x0)
Disable UART signal inverse

**UART_INVERSE_RXD** (UART_RXD_INV_M)
UART RXD input inverse

**UART_INVERSE_CTS** (UART_CTS_INV_M)
UART CTS input inverse

**UART_INVERSE_TXD** (UART_TXD_INV_M)
UART TXD output inverse

**UART_INVERSE_RTS** (UART_RTS_INV_M)
UART RTS output inverse

### Enumerations

**enum uart_word_length_t**
UART word length constants.

*Values:*

**UART_DATA_5_BITS** = 0x0
word length: 5bits

**UART_DATA_6_BITS** = 0x1
word length: 6bits

**UART_DATA_7_BITS** = 0x2
word length: 7bits

**UART_DATA_8_BITS** = 0x3
word length: 8bits

**UART_DATA_BITS_MAX** = 0X4

**enum uart_stop_bits_t**
UART stop bits number.

*Values:*

**UART_STOP_BITS_1** = 0x1
stop bit: 1bit

**UART_STOP_BITS_1_5** = 0x2
stop bit: 1.5bits

**UART_STOP_BITS_2** = 0x3
stop bit: 2bits

**UART_STOP_BITS_MAX** = 0x4

**enum uart_port_t**
UART peripheral number.

*Values:*

**UART_NUM_0** = 0x0
UART base address 0x3ff40000

**UART_NUM_1** = 0x1
UART base address 0x3ff50000

**UART_NUM_2** = 0x2
UART base address 0x3ff6E000

**UART_NUM_MAX**

**enum uart_parity_t**
UART parity constants.

*Values:*

**UART_PARITY_DISABLE** = 0x0
Disable UART parity

**UART_PARITY_EVEN** = 0x2
Enable UART even parity

**UART_PARITY_ODD** = 0x3
Enable UART odd parity

**enum uart_hw_flowcontrol_t**
UART hardware flow control modes.

*Values:*

**UART_HW_FLOWCTRL_DISABLE** = 0x0
disable hardware flow control

**UART_HW_FLOWCTRL_RTS** = 0x1
enable RX hardware flow control (rts)

**UART_HW_FLOWCTRL_CTS** = 0x2
enable TX hardware flow control (cts)

**UART_HW_FLOWCTRL_CTS_RTS** = 0x3
enable hardware flow control

**UART_HW_FLOWCTRL_MAX** = 0x4

**enum uart_event_type_t**
UART event types used in the ringbuffer.

*Values:*

**UART_DATA**
UART data event

**UART_BREAK**
UART break event

**UART_BUFFER_FULL**
UART RX buffer full event

**UART_FIFO_OVF**
UART FIFO overflow event

**UART_FRAME_ERR**
UART RX frame error event

**UART_PARITY_ERR**
UART RX parity event

**UART_DATA_BREAK**
UART TX data and break event

**UART_EVENT_MAX**
UART event max index

**UART_PATTERN_DET**
UART pattern detected

### Functions

esp_err_t **uart_set_word_length** (*uart_port_t uart_num*, *uart_word_length_t data_bit*)
Set UART data bits.

**Return**

- ESP_OK Success
- ESP_FAIL Parameter error

**Parameters**

- `uart_num`: UART_NUM_0, UART_NUM_1 or UART_NUM_2
- `data_bit`: UART data bits

esp_err_t **uart_get_word_length** (*uart_port_t uart_num*, *uart_word_length_t *data_bit*)
Get UART data bits.

**Return**

- ESP_FAIL Parameter error
- ESP_OK Success, result will be put in (*data_bit)

**Parameters**

- `uart_num`: UART_NUM_0, UART_NUM_1 or UART_NUM_2
- `data_bit`: Pointer to accept value of UART data bits.

esp_err_t **uart_set_stop_bits** (*uart_port_t uart_num*, *uart_stop_bits_t stop_bits*)
Set UART stop bits.

**Return**

- ESP_OK Success
- ESP_FAIL Fail

**Parameters**

- `uart_num`: UART_NUM_0, UART_NUM_1 or UART_NUM_2
- `stop_bits`: UART stop bits

esp_err_t **uart_get_stop_bits** (*uart_port_t uart_num*, *uart_stop_bits_t *stop_bits*)
Set UART stop bits.

**Return**

- ESP_FAIL Parameter error
- ESP_OK Success, result will be put in (*stop_bit)

**Parameters**

- `uart_num`: UART_NUM_0, UART_NUM_1 or UART_NUM_2
- `stop_bits`: Pointer to accept value of UART stop bits.

esp_err_t **uart_set_parity** (*uart_port_t uart_num*, *uart_parity_t parity_mode*)
Set UART parity.

**Return**

- ESP_FAIL Parameter error
- ESP_OK Success

**Parameters**

- `uart_num`: UART_NUM_0, UART_NUM_1 or UART_NUM_2
- `parity_mode`: the enum of uart parity configuration

esp_err_t **uart_get_parity** (*uart_port_t uart_num*, *uart_parity_t *parity_mode*)
Get UART parity mode.

**Return**

- ESP_FAIL Parameter error
- ESP_OK Success, result will be put in (*parity_mode)

**Parameters**

- `uart_num`: UART_NUM_0, UART_NUM_1 or UART_NUM_2
- `parity_mode`: Pointer to accept value of UART parity mode.

esp_err_t **uart_set_baudrate** (*uart_port_t uart_num*, uint32_t *baudrate*)
Set UART baud rate.

**Return**

- ESP_FAIL Parameter error
- ESP_OK Success

**Parameters**

- `uart_num`: UART_NUM_0, UART_NUM_1 or UART_NUM_2
- `baudrate`: UART baud rate.

esp_err_t **uart_get_baudrate** (*uart_port_t uart_num*, uint32_t **baudrate*)

Get UART bit-rate.

**Return**

- ESP_FAIL Parameter error
- ESP_OK Success, result will be put in (*baudrate)

**Parameters**

- `uart_num`: UART_NUM_0, UART_NUM_1 or UART_NUM_2
- `baudrate`: Pointer to accept value of UART baud rate

esp_err_t **uart_set_line_inverse** (*uart_port_t uart_num*, uint32_t *inverse_mask*)

Set UART line inverse mode.

**Return**

- ESP_OK Success
- ESP_FAIL Parameter error

**Parameters**

- `uart_num`: UART_NUM_0, UART_NUM_1 or UART_NUM_2
- `inverse_mask`: Choose the wires that need to be inverted. Inverse_mask should be chosen from UART_INVERSE_RXD/UART_INVERSE_TXD/UART_INVERSE_RTS/UART_INVERSE_CTS, combine with OR operation.

esp_err_t **uart_set_hw_flow_ctrl** (*uart_port_t uart_num*, *uart_hw_flowcontrol_t flow_ctrl*, uint8_t *rx_thresh*)

Set hardware flow control.

**Return**

- ESP_OK Success
- ESP_FAIL Parameter error

**Parameters**

- `uart_num`: UART_NUM_0, UART_NUM_1 or UART_NUM_2
- `flow_ctrl`: Hardware flow control mode
- `rx_thresh`: Threshold of Hardware RX flow control(0 ~ UART_FIFO_LEN). Only when UART_HW_FLOWCTRL_RTS is set, will the rx_thresh value be set.

esp_err_t **uart_get_hw_flow_ctrl** (*uart_port_t uart_num*, *uart_hw_flowcontrol_t *flow_ctrl*)

Get hardware flow control mode.

**Return**

- ESP_FAIL Parameter error
- ESP_OK Success, result will be put in (*flow_ctrl)

**Parameters**

- `uart_num`: UART_NUM_0, UART_NUM_1 or UART_NUM_2
- `flow_ctrl`: Option for different flow control mode.

esp_err_t **uart_clear_intr_status** (*uart_port_t uart_num*, uint32_t *clr_mask*)
Clear UART interrupt status.

**Return**

- ESP_OK Success
- ESP_FAIL Parameter error

**Parameters**

- `uart_num`: UART_NUM_0, UART_NUM_1 or UART_NUM_2
- `clr_mask`: Bit mask of the status that to be cleared. enable_mask should be chosen from the fields of register UART_INT_CLR_REG.

esp_err_t **uart_enable_intr_mask** (*uart_port_t uart_num*, uint32_t *enable_mask*)
Set UART interrupt enable.

**Return**

- ESP_OK Success
- ESP_FAIL Parameter error

**Parameters**

- `uart_num`: UART_NUM_0, UART_NUM_1 or UART_NUM_2
- `enable_mask`: Bit mask of the enable bits. enable_mask should be chosen from the fields of register UART_INT_ENA_REG.

esp_err_t **uart_disable_intr_mask** (*uart_port_t uart_num*, uint32_t *disable_mask*)
Clear UART interrupt enable bits.

**Return**

- ESP_OK Success
- ESP_FAIL Parameter error

**Parameters**

- `uart_num`: UART_NUM_0, UART_NUM_1 or UART_NUM_2
- `disable_mask`: Bit mask of the disable bits. disable_mask should be chosen from the fields of register UART_INT_ENA_REG.

esp_err_t **uart_enable_rx_intr** (*uart_port_t uart_num*)
Enable UART RX interrupt(RX_FULL & RX_TIMEOUT INTERRUPT)

**Return**

- ESP_OK Success
- ESP_FAIL Parameter error

**Parameters**

- `uart_num`: UART_NUM_0, UART_NUM_1 or UART_NUM_2

esp_err_t **uart_disable_rx_intr** (*uart_port_t uart_num*)
Disable UART RX interrupt(RX_FULL & RX_TIMEOUT INTERRUPT)

**Return**

- ESP_OK Success
- ESP_FAIL Parameter error

**Parameters**

- `uart_num`: UART_NUM_0, UART_NUM_1 or UART_NUM_2

esp_err_t **uart_disable_tx_intr** (*uart_port_t uart_num*)

Disable UART TX interrupt(RX_FULL & RX_TIMEOUT INTERRUPT)

**Return**

- ESP_OK Success
- ESP_FAIL Parameter error

**Parameters**

- `uart_num`: UART_NUM_0, UART_NUM_1 or UART_NUM_2

esp_err_t **uart_enable_tx_intr** (*uart_port_t uart_num*, int *enable*, int *thresh*)

Enable UART TX interrupt(RX_FULL & RX_TIMEOUT INTERRUPT)

**Return**

- ESP_OK Success
- ESP_FAIL Parameter error

**Parameters**

- `uart_num`: UART_NUM_0, UART_NUM_1 or UART_NUM_2
- `enable`: 1: enable; 0: disable
- `thresh`: Threshold of TX interrupt, 0 ~ UART_FIFO_LEN

esp_err_t **uart_isr_register** (*uart_port_t uart_num*, void (**fn*)) void *

, void **arg*, int *intr_alloc_flags*, uart_isr_handle_t **handle*register UART interrupt handler(ISR).

**Note** UART ISR handler will be attached to the same CPU core that this function is running on.

**Return**

- ESP_OK Success
- ESP_FAIL Parameter error

**Parameters**

- `uart_num`: UART_NUM_0, UART_NUM_1 or UART_NUM_2
- `fn`: Interrupt handler function.
- `arg`: parameter for handler function
- `intr_alloc_flags`: Flags used to allocate the interrupt. One or multiple (ORred) ESP_INTR_FLAG_* values. See esp_intr_alloc.h for more info.
- `handle`: Pointer to return handle. If non-NULL, a handle for the interrupt will be returned here.

esp_err_t **uart_set_pin** (*uart_port_t uart_num*, int *tx_io_num*, int *rx_io_num*, int *rts_io_num*, int *cts_io_num*)

Set UART pin number.

**Note** Internal signal can be output to multiple GPIO pads. Only one GPIO pad can connect with input signal.

**Return**

- ESP_OK Success
- ESP_FAIL Parameter error

**Parameters**

- `uart_num`: UART_NUM_0, UART_NUM_1 or UART_NUM_2
- `tx_io_num`: UART TX pin GPIO number, if set to UART_PIN_NO_CHANGE, use the current pin.
- `rx_io_num`: UART RX pin GPIO number, if set to UART_PIN_NO_CHANGE, use the current pin.
- `rts_io_num`: UART RTS pin GPIO number, if set to UART_PIN_NO_CHANGE, use the current pin.
- `cts_io_num`: UART CTS pin GPIO number, if set to UART_PIN_NO_CHANGE, use the current pin.

esp_err_t **uart_set_rts** (*uart_port_t uart_num*, int *level*)

UART set RTS level (before inverse) UART rx hardware flow control should not be set.

**Return**

- ESP_OK Success
- ESP_FAIL Parameter error

**Parameters**

- `uart_num`: UART_NUM_0, UART_NUM_1 or UART_NUM_2
- `level`: 1: RTS output low(active); 0: RTS output high(block)

esp_err_t **uart_set_dtr** (*uart_port_t uart_num*, int *level*)

UART set DTR level (before inverse)

**Return**

- ESP_OK Success
- ESP_FAIL Parameter error

**Parameters**

- `uart_num`: UART_NUM_0, UART_NUM_1 or UART_NUM_2
- `level`: 1: DTR output low; 0: DTR output high

esp_err_t **uart_param_config** (*uart_port_t uart_num*, **const** *uart_config_t *uart_config*)

UART parameter configure.

**Return**

- ESP_OK Success
- ESP_FAIL Parameter error

**Parameters**

- `uart_num`: UART_NUM_0, UART_NUM_1 or UART_NUM_2
- `uart_config`: UART parameter settings

esp_err_t **uart_intr_config**(*uart_port_t uart_num*, **const** *uart_intr_config_t *intr_conf*)

UART interrupt configure.

**Return**

- ESP_OK Success
- ESP_FAIL Parameter error

**Parameters**

- `uart_num`: UART_NUM_0, UART_NUM_1 or UART_NUM_2
- `intr_conf`: UART interrupt settings

esp_err_t **uart_driver_install**(*uart_port_t uart_num*, int *rx_buffer_size*, int *tx_buffer_size*, int *queue_size*, QueueHandle_t **uart_queue*, int *intr_alloc_flags*)

Install UART driver.

UART ISR handler will be attached to the same CPU core that this function is running on.

**Return**

- ESP_OK Success
- ESP_FAIL Parameter error

**Parameters**

- `uart_num`: UART_NUM_0, UART_NUM_1 or UART_NUM_2
- `rx_buffer_size`: UART RX ring buffer size, rx_buffer_size should be greater than UART_FIFO_LEN.
- `tx_buffer_size`: UART TX ring buffer size. If set to zero, driver will not use TX buffer, TX function will block task until all data have been sent out..
- `queue_size`: UART event queue size/depth.
- `uart_queue`: UART event queue handle (out param). On success, a new queue handle is written here to provide access to UART events. If set to NULL, driver will not use an event queue.
- `intr_alloc_flags`: Flags used to allocate the interrupt. One or multiple (ORred) ESP_INTR_FLAG_* values. See esp_intr_alloc.h for more info. Do not set ESP_INTR_FLAG_IRAM here (the driver's ISR handler is not located in IRAM)

esp_err_t **uart_driver_delete**(*uart_port_t uart_num*)

Uninstall UART driver.

**Return**

- ESP_OK Success
- ESP_FAIL Parameter error

**Parameters**

- `uart_num`: UART_NUM_0, UART_NUM_1 or UART_NUM_2

esp_err_t **uart_wait_tx_done** (*uart_port_t uart_num*, TickType_t *ticks_to_wait*)
Wait UART TX FIFO empty.

**Return**

- ESP_OK Success
- ESP_FAIL Parameter error
- ESP_ERR_TIMEOUT Timeout

**Parameters**

- `uart_num`: UART_NUM_0, UART_NUM_1 or UART_NUM_2
- `ticks_to_wait`: Timeout, count in RTOS ticks

int **uart_tx_chars** (*uart_port_t uart_num*, **const** char **buffer*, uint32_t *len*)
Send data to the UART port from a given buffer and length.

This function will not wait for the space in TX FIFO, just fill the TX FIFO and return when the FIFO is full.

**Note** This function should only be used when UART TX buffer is not enabled.

**Return**

- (-1) Parameter error
- OTHERS(>=0) The number of data that pushed to the TX FIFO

**Parameters**

- `uart_num`: UART_NUM_0, UART_NUM_1 or UART_NUM_2
- `buffer`: data buffer address
- `len`: data length to send

int **uart_write_bytes** (*uart_port_t uart_num*, **const** char **src*, size_t *size*)
Send data to the UART port from a given buffer and length,.

If parameter tx_buffer_size is set to zero: This function will not return until all the data have been sent out, or at least pushed into TX FIFO.

Otherwise, if tx_buffer_size > 0, this function will return after copying all the data to tx ringbuffer, then, UART ISR will move data from ring buffer to TX FIFO gradually.

**Return**

- (-1) Parameter error
- OTHERS(>=0) The number of data that pushed to the TX FIFO

**Parameters**

- `uart_num`: UART_NUM_0, UART_NUM_1 or UART_NUM_2
- `src`: data buffer address
- `size`: data length to send

int **uart_write_bytes_with_break** (*uart_port_t uart_num*, **const** char **src*, size_t *size*, int *brk_len*)
Send data to the UART port from a given buffer and length,.

If parameter tx_buffer_size is set to zero: This function will not return until all the data and the break signal have been sent out. After all data send out, send a break signal.

Otherwise, if tx_buffer_size > 0, this function will return after copying all the data to tx ringbuffer, then, UART ISR will move data from ring buffer to TX FIFO gradually. After all data send out, send a break signal.

**Return**

- (-1) Parameter error
- OTHERS(>=0) The number of data that pushed to the TX FIFO

**Parameters**

- `uart_num`: UART_NUM_0, UART_NUM_1 or UART_NUM_2
- `src`: data buffer address
- `size`: data length to send
- `brk_len`: break signal length (unit: time of one data bit at current_baudrate)

int **uart_read_bytes** (*uart_port_t uart_num*, uint8_t **buf*, uint32_t *length*, TickType_t *ticks_to_wait*)

UART read bytes from UART buffer.

**Return**

- (-1) Error
- Others return a char data from uart fifo.

**Parameters**

- `uart_num`: UART_NUM_0, UART_NUM_1 or UART_NUM_2
- `buf`: pointer to the buffer.
- `length`: data length
- `ticks_to_wait`: sTimeout, count in RTOS ticks

esp_err_t **uart_flush** (*uart_port_t uart_num*)

UART ring buffer flush.

**Return**

- ESP_OK Success
- ESP_FAIL Parameter error

**Parameters**

- `uart_num`: UART_NUM_0, UART_NUM_1 or UART_NUM_2

esp_err_t **uart_get_buffered_data_len** (*uart_port_t uart_num*, size_t **size*)

UART get RX ring buffer cached data length.

**Return**

- ESP_OK Success
- ESP_FAIL Parameter error

**Parameters**

- `uart_num`: UART port number.
- `size`: Pointer of size_t to accept cached data length

esp_err_t **uart_disable_pattern_det_intr** (*uart_port_t uart_num*)

UART disable pattern detect function. Designed for applications like 'AT commands'. When the hardware detect a series of one same character, the interrupt will be triggered.

**Return**

- ESP_OK Success
- ESP_FAIL Parameter error

**Parameters**

- `uart_num`: UART port number.

esp_err_t **uart_enable_pattern_det_intr** (*uart_port_t uart_num*, char *pattern_chr*, uint8_t *chr_num*, int *chr_tout*, int *post_idle*, int *pre_idle*)

UART enable pattern detect function. Designed for applications like 'AT commands'. When the hardware detect a series of one same character, the interrupt will be triggered.

**Return**

- ESP_OK Success
- ESP_FAIL Parameter error

**Parameters**

- `uart_num`: UART port number.
- `pattern_chr`: character of the pattern
- `chr_num`: number of the character, 8bit value.
- `chr_tout`: timeout of the interval between each pattern characters, 24bit value, unit is APB(80Mhz) clock cycle.
- `post_idle`: idle time after the last pattern character, 24bit value, unit is APB(80Mhz) clock cycle.
- `pre_idle`: idle time before the first pattern character, 24bit value, unit is APB(80Mhz) clock cycle.

Example code for this API section is provided in peripherals directory of ESP-IDF examples.

CHAPTER 21

# System API

## Memory allocation

### Overview

The ESP32 has multiple types of RAM. Internally, there's IRAM, DRAM as well as RAM that can be used as both. It's also possible to connect external SPI flash to the ESP32; it's memory can be integrated into the ESP32s memory map using the flash cache.

In order to make use of all this memory, esp-idf has a capabilities-based memory allocator. Basically, if you want to have memory with certain properties (for example, DMA-capable, accessible by a certain PID, or capable of executing code), you can create an OR-mask of the required capabilities and pass that to pvPortMallocCaps. For instance, the normal malloc code internally allocates memory with ``pvPortMallocCaps(size, MALLOC_CAP_8BIT)`` in order to get data memory that is byte-addressable.

Because malloc uses this allocation system as well, memory allocated using pvPortMallocCaps can be freed by calling the standard ``free()`` function.

Internally, this allocator is split in two pieces. The allocator in the FreeRTOS directory can allocate memory from tagged regions: a tag is an integer value and every region of free memory has one of these tags. The esp32-specific code initializes these regions with specific tags, and contains the logic to select applicable tags from the capabilities given by the user. While shown in the public API, tags are used in the communication between the two parts and should not be used directly.

### Special Uses

If a certain memory structure is only addressed in 32-bit units, for example an array of ints or pointers, it can be useful to allocate it with the MALLOC_CAP_32BIT flag. This also allows the allocator to give out IRAM memory; something which it can't do for a normal malloc() call. This can help to use all the available memory in the ESP32.

### API Reference

### Header Files

- esp32/include/esp_heap_alloc_caps.h
- freertos/include/freertos/heap_regions.h

### Macros

**MALLOC_CAP_EXEC** (1<<0)
Flags to indicate the capabilities of the various memory systems.

Memory must be able to run executable code

**MALLOC_CAP_32BIT** (1<<1)
Memory must allow for aligned 32-bit data accesses.

**MALLOC_CAP_8BIT** (1<<2)
Memory must allow for 8/16/...-bit data accesses.

**MALLOC_CAP_DMA** (1<<3)
Memory must be able to accessed by DMA.

**MALLOC_CAP_PID2** (1<<4)
Memory must be mapped to PID2 memory space.

**MALLOC_CAP_PID3** (1<<5)
Memory must be mapped to PID3 memory space.

**MALLOC_CAP_PID4** (1<<6)
Memory must be mapped to PID4 memory space.

**MALLOC_CAP_PID5** (1<<7)
Memory must be mapped to PID5 memory space.

**MALLOC_CAP_PID6** (1<<8)
Memory must be mapped to PID6 memory space.

**MALLOC_CAP_PID7** (1<<9)
Memory must be mapped to PID7 memory space.

**MALLOC_CAP_SPISRAM** (1<<10)
Memory must be in SPI SRAM.

**MALLOC_CAP_INVALID** (1<<31)
Memory can't be used / list end marker.

### Type Definitions

**typedef struct** HeapRegionTagged **HeapRegionTagged_t**
Structure to define a memory region.

### Functions

void **heap_alloc_caps_init** ()
Initialize the capability-aware heap allocator.

For the ESP32, this is called once in the startup code.

void ***pvPortMallocCaps**(size_t *xWantedSize*, uint32_t *caps*)
Allocate a chunk of memory which has the given capabilities.

**Return** A pointer to the memory allocated on success, NULL on failure

**Parameters**

- `xWantedSize`: Size, in bytes, of the amount of memory to allocate
- `caps`: Bitwise OR of MALLOC_CAP_* flags indicating the type of memory to be returned

size_t **xPortGetFreeHeapSizeCaps**(uint32_t *caps*)
Get the total free size of all the regions that have the given capabilities.

This function takes all regions capable of having the given capabilities allocated in them and adds up the free space they have.

**Return** Amount of free bytes in the regions

**Parameters**

- `caps`: Bitwise OR of MALLOC_CAP_* flags indicating the type of memory

size_t **xPortGetMinimumEverFreeHeapSizeCaps**(uint32_t *caps*)
Get the total minimum free memory of all regions with the given capabilities.

This adds all the lowmarks of the regions capable of delivering the memory with the given capabilities

**Return** Amount of free bytes in the regions

**Parameters**

- `caps`: Bitwise OR of MALLOC_CAP_* flags indicating the type of memory

void **vPortDefineHeapRegionsTagged**(**const** *HeapRegionTagged_t* ***const** *pxHeapRegions*)
Initialize the heap allocator by feeding it the usable memory regions and their tags.

This takes an array of heapRegionTagged_t structs, the last entry of which is a dummy entry which has pucStartAddress set to NULL. It will initialize the heap allocator to serve memory from these ranges.

**Parameters**

- `pxHeapRegions`: Array of region definitions

void ***pvPortMallocTagged**(size_t *xWantedSize*, BaseType_t *tag*)
Allocate memory from a region with a certain tag.

Like pvPortMalloc, this returns an allocated chunk of memory. This function, however, forces the allocator to allocate from a region specified by a specific tag.

**Return** Pointer to allocated memory if succesful. NULL if unsuccesful.

**Parameters**

- `xWantedSize`: Size needed, in bytes
- `tag`: Tag of the memory region the allocation has to be from

void **vPortFreeTagged**(void **pv*)
Free memory allocated with pvPortMallocTagged.

This is basically an implementation of free().

**Parameters**

- `pv`: Pointer to region allocated by pvPortMallocTagged

size_t **`xPortGetMinimumEverFreeHeapSizeTagged`**(BaseType_t *tag*)

Get the lowest amount of memory free for a certain tag.

This function allows the user to see what the least amount of free memory for a certain tag is.

**Return** Minimum amount of free bytes available in the runtime of the program

**Parameters**

- `tag`: Tag of the memory region

size_t **`xPortGetFreeHeapSizeTagged`**(BaseType_t *tag*)

Get the amount of free bytes in a certain tagged region.

Works like xPortGetFreeHeapSize but allows the user to specify a specific tag

**Return** Remaining amount of free bytes in region

**Parameters**

- `tag`: Tag of the memory region

## Interrupt allocation

### Overview

The ESP32 has two cores, with 32 interrupts each. Each interrupt has a certain priority level, most (but not all) interrupts are connected to the interrupt mux. Because there are more interrupt sources than interrupts, sometimes it makes sense to share an interrupt in multiple drivers. The esp_intr_alloc abstraction exists to hide all these implementation details.

A driver can allocate an interrupt for a certain peripheral by calling esp_intr_alloc (or esp_intr_alloc_sintrstatus). It can use the flags passed to this function to set the type of interrupt allocated, specifying a specific level or trigger method. The interrupt allocation code will then find an applicable interrupt, use the interrupt mux to hook it up to the peripheral, and install the given interrupt handler and ISR to it.

This code has two different types of interrupts it handles differently: Shared interrupts and non-shared interrupts. The simplest of the two are non-shared interrupts: a separate interrupt is allocated per esp_intr_alloc call and this interrupt is solely used for the peripheral attached to it, with only one ISR that will get called. Non-shared interrupts can have multiple peripherals triggering it, with multiple ISRs being called when one of the peripherals attached signals an interrupt. Thus, ISRs that are intended for shared interrupts should check the interrupt status of the peripheral they service in order to see if any action is required.

Non-shared interrupts can be either level- or edge-triggered. Shared interrupts can only be level interrupts (because of the chance of missed interrupts when edge interrupts are used.) (The logic behind this: DevA and DevB share an int. DevB signals an int. Int line goes high. ISR handler calls code for DevA -> does nothing. ISR handler calls code for DevB, but while doing that, DevA signals an int. ISR DevB is done, clears int for DevB, exits interrupt code. Now an interrupt for DevA is still pending, but because the int line never went low (DevA kept it high even when the int for DevB was cleared) the interrupt is never serviced.)

## Multicore issues

Peripherals that can generate interrupts can be divided in two types:

- External peripherals, within the ESP32 but outside the Xtensa cores themselves. Most ESP32 peripherals are of this type.
- Internal peripherals, part of the Xtensa CPU cores themselves.

Interrupt handling differs slightly between these two types of peripherals.

### Internal peripheral interrupts

Each Xtensa CPU core has its own set of six internal peripherals:

- Three timer comparators
- A performance monitor
- Two software interrupts.

Internal interrupt sources are defined in esp_intr_alloc.h as `ETS_INTERNAL_*_INTR_SOURCE`.

These peripherals can only be configured from the core they are associated with. When generating an interrupt, the interrupt they generate is hard-wired to their associated core; it's not possible to have e.g. an internal timer comparator of one core generate an interrupt on another core. That is why these sources can only be managed using a task running on that specific core. Internal interrupt sources are still allocatable using esp_intr_alloc as normal, but they cannot be shared and will always have a fixed interrupt level (namely, the one associated in hardware with the peripheral).

### External Peripheral Interrupts

The remaining interrupt sources are from external peripherals. These are defined in soc/soc.h as `ETS_*_INTR_SOURCE`.

Non-internal interrupt slots in both CPU cores are wired to an interrupt multiplexer, which can be used to route any external interrupt source to any of these interrupt slots.

- Allocating an external interrupt will always allocate it on the core that does the allocation.
- Freeing an external interrupt must always happen on the same core it was allocated on.
- Disabling and enabling external interrupts from another core is allowed.
- Multiple external interrupt sources can share an interrupt slot by passing `ESP_INTR_FLAG_SHARED` as a flag to esp_intr_alloc().

Care should be taken when calling esp_intr_alloc() from a task which is not pinned to a core. During task switching, these tasks can migrate between cores. Therefore it is impossible to tell which CPU the interrupt is allocated on, which makes it difficult to free the interrupt handle and may also cause debugging difficulties. It is advised to use xTaskCreatePinnedToCore() with a specific CoreID argument to create tasks that will allocate interrupts. In the case of internal interrupt sources, this is required.

## IRAM-Safe Interrupt Handlers

The `ESP_INTR_FLAG_IRAM` flag registers an interrupt handler that always runs from IRAM (and reads all its data from DRAM), and therefore does not need to be disabled during flash erase and write operations.

This is useful for interrupts which need a guaranteed minimum execution latency, as flash write and erase operations can be slow (erases can take tens or hundreds of milliseconds to complete).

It can also be useful to keep an interrupt handler in IRAM if it is called very frequently, to avoid flash cache misses.

Refer to the *SPI flash API documentation* for more details.

## Application Example

## API Reference

### Header Files

- esp32/include/esp_intr_alloc.h

### Macros

**ESP_INTR_FLAG_LEVEL1** (1<<1)
Interrupt allocation flags.

These flags can be used to specify which interrupt qualities the code calling esp_intr_alloc* needs.Accept a Level 1 interrupt vector

**ESP_INTR_FLAG_LEVEL2** (1<<2)
Accept a Level 2 interrupt vector.

**ESP_INTR_FLAG_LEVEL3** (1<<3)
Accept a Level 3 interrupt vector.

**ESP_INTR_FLAG_LEVEL4** (1<<4)
Accept a Level 4 interrupt vector.

**ESP_INTR_FLAG_LEVEL5** (1<<5)
Accept a Level 5 interrupt vector.

**ESP_INTR_FLAG_LEVEL6** (1<<6)
Accept a Level 6 interrupt vector.

**ESP_INTR_FLAG_NMI** (1<<7)
Accept a Level 7 interrupt vector.

**ESP_INTR_FLAG_LOWMED** (*ESP_INTR_FLAG_LEVEL1*|*ESP_INTR_FLAG_LEVEL2*|*ESP_INTR_FLAG_LEVEL3*)
Low and medium prio interrupts. These can be handled in C.

**ESP_INTR_FLAG_HIGH** (*ESP_INTR_FLAG_LEVEL4*|*ESP_INTR_FLAG_LEVEL5*|*ESP_INTR_FLAG_LEVEL6*|*ESP_INTR_FLAG_N*
High level interrupts. Need to be handled in assembly.

**ESP_INTR_FLAG_SHARED** (1<<8)
Interrupt can be shared between ISRs.

**ESP_INTR_FLAG_EDGE** (1<<9)
Edge-triggered interrupt.

**ESP_INTR_FLAG_IRAM** (1<<10)
ISR can be called if cache is disabled.

**ESP_INTR_FLAG_INTRDISABLED** (1<<11)
Return with this interrupt disabled.

### Functions

esp_err_t **esp_intr_mark_shared**(int *intno*, int *cpu*, bool *is_in_iram*)
Mark an interrupt as a shared interrupt.

This will mark a certain interrupt on the specified CPU as an interrupt that can be used to hook shared interrupt handlers to.

**Return** ESP_ERR_INVALID_ARG if cpu or intno is invalid ESP_OK otherwise

**Parameters**

- `intno`: The number of the interrupt (0-31)
- `cpu`: CPU on which the interrupt should be marked as shared (0 or 1)
- `is_in_iram`: Shared interrupt is for handlers that reside in IRAM and the int can be left enabled while the flash cache is disabled.

esp_err_t **esp_intr_reserve**(int *intno*, int *cpu*)
Reserve an interrupt to be used outside of this framewoek.

This will mark a certain interrupt on the specified CPU as reserved, not to be allocated for any reason.

**Return** ESP_ERR_INVALID_ARG if cpu or intno is invalid ESP_OK otherwise

**Parameters**

- `intno`: The number of the interrupt (0-31)
- `cpu`: CPU on which the interrupt should be marked as shared (0 or 1)

esp_err_t **esp_intr_alloc**(int *source*, int *flags*, intr_handler_t *handler*, void **arg*, intr_handle_t **ret_handle*)
Allocate an interrupt with the given parameters.

This finds an interrupt that matches the restrictions as given in the flags parameter, maps the given interrupt source to it and hooks up the given interrupt handler (with optional argument) as well. If needed, it can return a handle for the interrupt as well.

The interrupt will always be allocated on the core that runs this function.

If ESP_INTR_FLAG_IRAM flag is used, and handler address is not in IRAM or RTC_FAST_MEM, then ESP_ERR_INVALID_ARG is returned.

**Return** ESP_ERR_INVALID_ARG if the combination of arguments is invalid. ESP_ERR_NOT_FOUND No free interrupt found with the specified flags ESP_OK otherwise

**Parameters**

- `source`: The interrupt source. One of the ETS_*_INTR_SOURCE interrupt mux sources, as defined in soc/soc.h, or one of the internal ETS_INTERNAL_*_INTR_SOURCE sources as defined in this header.
- `flags`: An ORred mask of the ESP_INTR_FLAG_* defines. These restrict the choice of interrupts that this routine can choose from. If this value is 0, it will default to allocating a non-shared interrupt of level 1, 2 or 3. If this is ESP_INTR_FLAG_SHARED, it will allocate a shared interrupt of level 1. Setting ESP_INTR_FLAG_INTRDISABLED will return from this function with the interrupt disabled.
- `handler`: The interrupt handler. Must be NULL when an interrupt of level >3 is requested, because these types of interrupts aren't C-callable.

- `arg`: Optional argument for passed to the interrupt handler
- `ret_handle`: Pointer to an intr_handle_t to store a handle that can later be used to request details or free the interrupt. Can be NULL if no handle is required.

esp_err_t **esp_intr_alloc_intrstatus**(int *source*, int *flags*, uint32_t *intrstatusreg*, uint32_t *intrstatusmask*, intr_handler_t *handler*, void **arg*, intr_handle_t **ret_handle*)

Allocate an interrupt with the given parameters.

This essentially does the same as esp_intr_alloc, but allows specifying a register and mask combo. For shared interrupts, the handler is only called if a read from the specified register, ANDed with the mask, returns non-zero. By passing an interrupt status register address and a fitting mask, this can be used to accelerate interrupt handling in the case a shared interrupt is triggered; by checking the interrupt statuses first, the code can decide which ISRs can be skipped

**Return** ESP_ERR_INVALID_ARG if the combination of arguments is invalid. ESP_ERR_NOT_FOUND No free interrupt found with the specified flags ESP_OK otherwise

**Parameters**

- `source`: The interrupt source. One of the ETS_*_INTR_SOURCE interrupt mux sources, as defined in soc/soc.h, or one of the internal ETS_INTERNAL_*_INTR_SOURCE sources as defined in this header.
- `flags`: An ORred mask of the ESP_INTR_FLAG_* defines. These restrict the choice of interrupts that this routine can choose from. If this value is 0, it will default to allocating a non-shared interrupt of level 1, 2 or 3. If this is ESP_INTR_FLAG_SHARED, it will allocate a shared interrupt of level 1. Setting ESP_INTR_FLAG_INTRDISABLED will return from this function with the interrupt disabled.
- `intrstatusreg`: The address of an interrupt status register
- `intrstatusmask`: A mask. If a read of address intrstatusreg has any of the bits that are 1 in the mask set, the ISR will be called. If not, it will be skipped.
- `handler`: The interrupt handler. Must be NULL when an interrupt of level >3 is requested, because these types of interrupts aren't C-callable.
- `arg`: Optional argument for passed to the interrupt handler
- `ret_handle`: Pointer to an intr_handle_t to store a handle that can later be used to request details or free the interrupt. Can be NULL if no handle is required.

esp_err_t **esp_intr_free**(intr_handle_t *handle*)

Disable and free an interrupt.

Use an interrupt handle to disable the interrupt and release the resources associated with it.

**Return** ESP_ERR_INVALID_ARG if handle is invalid, or esp_intr_free runs on another core than where the interrupt is allocated on. ESP_OK otherwise

**Parameters**

- `handle`: The handle, as obtained by esp_intr_alloc or esp_intr_alloc_intrstatus

int **esp_intr_get_cpu**(intr_handle_t *handle*)

Get CPU number an interrupt is tied to.

**Return** The core number where the interrupt is allocated

**Parameters**

- `handle`: The handle, as obtained by esp_intr_alloc or esp_intr_alloc_intrstatus

int **esp_intr_get_intno**(intr_handle_t *handle*)
Get the allocated interrupt for a certain handle.

**Return** The interrupt number

**Parameters**

- `handle`: The handle, as obtained by esp_intr_alloc or esp_intr_alloc_intrstatus

esp_err_t **esp_intr_disable**(intr_handle_t *handle*)
Disable the interrupt associated with the handle.

**Note** For local interrupts (ESP_INTERNAL_* sources), this function has to be called on the CPU the interrupt is allocated on. Other interrupts have no such restriction.

**Return** ESP_ERR_INVALID_ARG if the combination of arguments is invalid. ESP_OK otherwise

**Parameters**

- `handle`: The handle, as obtained by esp_intr_alloc or esp_intr_alloc_intrstatus

esp_err_t **esp_intr_enable**(intr_handle_t *handle*)
Ensable the interrupt associated with the handle.

**Note** For local interrupts (ESP_INTERNAL_* sources), this function has to be called on the CPU the interrupt is allocated on. Other interrupts have no such restriction.

**Return** ESP_ERR_INVALID_ARG if the combination of arguments is invalid. ESP_OK otherwise

**Parameters**

- `handle`: The handle, as obtained by esp_intr_alloc or esp_intr_alloc_intrstatus

void **esp_intr_noniram_disable**()
Disable interrupts that aren't specifically marked as running from IRAM.

void **esp_intr_noniram_enable**()
Re-enable interrupts disabled by esp_intr_noniram_disable.

# Watchdogs

## Overview

Esp-idf has support for two types of watchdogs: a task watchdog as well as an interrupt watchdog. Both can be enabled using `make menuconfig` and selecting the appropriate options.

### Interrupt watchdog

The interrupt watchdog makes sure the FreeRTOS task switching interrupt isn't blocked for a long time. This is bad because no other tasks, including potentially important ones like the WiFi task and the idle task, can't get any CPU runtime. A blocked task switching interrupt can happen because a program runs into an infinite loop with interrupts disabled or hangs in an interrupt.

The default action of the interrupt watchdog is to invoke the panic handler. causing a register dump and an opportunity for the programmer to find out, using either OpenOCD or gdbstub, what bit of code is stuck with interrupts disabled. Depending on the configuration of the panic handler, it can also blindly reset the CPU, which may be preferred in a production environment.

The interrupt watchdog is built around the hardware watchdog in timer group 1. If this watchdog for some reason cannot execute the NMI handler that invokes the panic handler (e.g. because IRAM is overwritten by garbage), it will hard-reset the SOC.

### Task watchdog

Any tasks can elect to be watched by the task watchdog. If such a task does not feed the watchdog within the time specified by the task watchdog timeout (which is configurable using `make menuconfig`), the watchdog will print out a warning with information about which processes are running on the ESP32 CPUs and which processes failed to feed the watchdog.

By default, the task watchdog watches the idle tasks. The usual cause of idle tasks not feeding the watchdog is a higher-priority process looping without yielding to the lower-priority processes, and can be an indicator of badly-written code that spinloops on a peripheral or a task that is stuck in an infinite loop.

Other task can elect to be watched by the task watchdog by calling `esp_task_wdt_feed()`. Calling this routine for the first time will register the task to the task watchdog; calling it subsequent times will feed the watchdog. If a task does not want to be watched anymore (e.g. because it is finished and will call `vTaskDelete()` on itself), it needs to call `esp_task_wdt_delete()`.

The task watchdog is built around the hardware watchdog in timer group 0. If this watchdog for some reason cannot execute the interrupt handler that prints the task data (e.g. because IRAM is overwritten by garbage or interrupts are disabled entirely) it will hard-reset the SOC.

### JTAG and watchdogs

While debugging using OpenOCD, if the CPUs are halted the watchdogs will keep running, eventually resetting the CPU. This makes it very hard to debug code; that is why the OpenOCD config will disable both watchdogs on startup. This does mean that you will not get any warnings or panics from either the task or interrupt watchdog when the ESP32 is connected to OpenOCD via JTAG.

## API Reference

### Header Files

- esp32/include/esp_int_wdt.h
- esp32/include/esp_task_wdt.h

## Functions

void **esp_int_wdt_init**()

Initialize the interrupt watchdog. This is called in the init code if the interrupt watchdog is enabled in menuconfig.

void **esp_task_wdt_init**()

Initialize the task watchdog. This is called in the init code, if the task watchdog is enabled in menuconfig.

void **esp_task_wdt_feed**()
: Feed the watchdog. After the first feeding session, the watchdog will expect the calling task to keep feeding the watchdog until task_wdt_delete() is called.

void **esp_task_wdt_delete**()
: Delete the watchdog for the current task.

# Over The Air Updates (OTA)

## OTA Process Overview

The OTA update mechanism allows a device to update itself based on data received while the normal firmware is running (for example, over WiFi or Bluetooth.)

OTA requires configuring the *Partition Table* of the device with at least two "OTA app slot" partitions (ie *ota_0* and *ota_1*) and an "OTA Data Partition".

The OTA operation functions write a new app firmware image to whichever OTA app slot is not currently being used for booting. Once the image is verified, the OTA Data partition is updated to specify that this image should be used for the next boot.

## OTA Data Partition

An OTA data partition (type `data`, subtype `ota`) must be included in the *Partition Table* of any project which uses the OTA functions.

For factory boot settings, the OTA data partition should contain no data (all bytes erased to 0xFF). In this case the esp-idf software bootloader will boot the factory app if it is present in the the partition table. If no factory app is included in the partition table, the first available OTA slot (usually `ota_0`) is booted.

After the first OTA update, the OTA data partition is updated to specify which OTA app slot partition should be booted next.

The OTA data partition is two flash sectors (0x2000 bytes) in size, to prevent problems if there is a power failure while it is being written. Sectors are independently erased and written with matching data, and if they disagree a counter field is used to determine which sector was written more recently.

### See also

- *Partition Table documentation*
- *Lower-Level SPI Flash/Partition API*

### Application Example

End-to-end example of OTA firmware update workflow: system/ota.

### API Reference

## Header Files

- app_update/include/esp_ota_ops.h

## Macros

**ESP_ERR_OTA_BASE** 0x1500
Base error code for ota_ops api

**ESP_ERR_OTA_PARTITION_CONFLICT** (ESP_ERR_OTA_BASE + 0x01)
Error if request was to write or erase the current running partition

**ESP_ERR_OTA_SELECT_INFO_INVALID** (ESP_ERR_OTA_BASE + 0x02)
Error if OTA data partition contains invalid content

**ESP_ERR_OTA_VALIDATE_FAILED** (ESP_ERR_OTA_BASE + 0x03)
Error if OTA app image is invalid

**OTA_SIZE_UNKNOWN** 0xffffffff
Used for esp_ota_begin() if new image size is unknown

## Type Definitions

**typedef** uint32_t **esp_ota_handle_t**
Opaque handle for an application OTA update.

esp_ota_begin() returns a handle which is then used for subsequent calls to esp_ota_write() and esp_ota_end().

## Functions

esp_err_t **esp_ota_begin**(**const** *esp_partition_t* **partition*, size_t *image_size*, *esp_ota_handle_t* **out_handle*)
Commence an OTA update writing to the specified partition.

The specified partition is erased to the specified image size.

If image size is not yet known, pass OTA_SIZE_UNKNOWN which will cause the entire partition to be erased.

On success, this function allocates memory that remains in use until esp_ota_end() is called with the returned handle.

**Return**

- ESP_OK: OTA operation commenced successfully.
- ESP_ERR_INVALID_ARG: partition or out_handle arguments were NULL, or partition doesn't point to an OTA app partition.
- ESP_ERR_NO_MEM: Cannot allocate memory for OTA operation.
- ESP_ERR_OTA_PARTITION_CONFLICT: Partition holds the currently running firmware, cannot update in place.
- ESP_ERR_NOT_FOUND: Partition argument not found in partition table.
- ESP_ERR_OTA_SELECT_INFO_INVALID: The OTA data partition contains invalid data.
- ESP_ERR_INVALID_SIZE: Partition doesn't fit in configured flash size.
- ESP_ERR_FLASH_OP_TIMEOUT or ESP_ERR_FLASH_OP_FAIL: Flash write failed.

**Parameters**

- `partition`: Pointer to info for partition which will receive the OTA update. Required.

- `image_size`: Size of new OTA app image. Partition will be erased in order to receive this size of image. If 0 or OTA_SIZE_UNKNOWN, the entire partition is erased.
- `out_handle`: On success, returns a handle which should be used for subsequent esp_ota_write() and esp_ota_end() calls.

esp_err_t **esp_ota_write** (*esp_ota_handle_t handle*, **const** void **data*, size_t *size*)

Write OTA update data to partition.

This function can be called multiple times as data is received during the OTA operation. Data is written sequentially to the partition.

**Return**

- ESP_OK: Data was written to flash successfully.
- ESP_ERR_INVALID_ARG: handle is invalid.
- ESP_ERR_OTA_VALIDATE_FAILED: First byte of image contains invalid app image magic byte.
- ESP_ERR_FLASH_OP_TIMEOUT or ESP_ERR_FLASH_OP_FAIL: Flash write failed.
- ESP_ERR_OTA_SELECT_INFO_INVALID: OTA data partition has invalid contents

**Parameters**

- `handle`: Handle obtained from esp_ota_begin
- `data`: Data buffer to write
- `size`: Size of data buffer in bytes.

esp_err_t **esp_ota_end** (*esp_ota_handle_t handle*)

Finish OTA update and validate newly written app image.

**Note** After calling esp_ota_end(), the handle is no longer valid and any memory associated with it is freed (regardless of result).

**Return**

- ESP_OK: Newly written OTA app image is valid.
- ESP_ERR_NOT_FOUND: OTA handle was not found.
- ESP_ERR_INVALID_ARG: Handle was never written to.
- ESP_ERR_OTA_VALIDATE_FAILED: OTA image is invalid (either not a valid app image, or - if secure boot is enabled - signature failed to verify.)
- ESP_ERR_INVALID_STATE: If flash encryption is enabled, this result indicates an internal error writing the final encrypted bytes to flash.

**Parameters**

- `handle`: Handle obtained from esp_ota_begin().

**const** *esp_partition_t* ***esp_ota_get_running_partition** (void)

Get partition info of currently running app.

This function is different to esp_ota_get_boot_partition() in that it ignores any change of selected boot partition caused by esp_ota_set_boot_partition(). Only the app whose code is currently running will have its partition information returned.

**Return** Pointer to info for partition structure, or NULL if no partition is found or flash read operation failed. Returned pointer is valid for the lifetime of the application.

esp_err_t **esp_ota_set_boot_partition**(**const** *esp_partition_t* **partition*)

Configure OTA data for a new boot partition.

**Note** If this function returns ESP_OK, calling esp_restart() will boot the newly configured app partition.

**Return**

- ESP_OK: OTA data updated, next reboot will use specified partition.
- ESP_ERR_INVALID_ARG: partition argument was NULL or didn't point to a valid OTA partition of type "app".
- ESP_ERR_OTA_VALIDATE_FAILED: Partition contained invalid app image. Also returned if secure boot is enabled and signature validation failed.
- ESP_ERR_NOT_FOUND: OTA data partition not found.
- ESP_ERR_FLASH_OP_TIMEOUT or ESP_ERR_FLASH_OP_FAIL: Flash erase or write failed.

**Parameters**

- `partition`: Pointer to info for partition containing app image to boot.

**const** *esp_partition_t* ***esp_ota_get_boot_partition**(void)

Get partition info of currently configured boot app.

If esp_ota_set_boot_partition() has been called, the partition which was set by that function will be returned.

If esp_ota_set_boot_partition() has not been called, the result is equivalent to esp_ota_get_running_partition().

**Return** Pointer to info for partition structure, or NULL if no partition is found or flash read operation failed. Returned pointer is valid for the lifetime of the application.

**const** *esp_partition_t* ***esp_ota_get_next_update_partition**(**const** *esp_partition_t* **start_from*)

Return the next OTA app partition which should be written with a new firmware.

Call this function to find an OTA app partition which can be passed to esp_ota_begin().

Finds next partition round-robin, starting from the current running partition.

**Return** Pointer to info for partition which should be updated next. NULL result indicates invalid OTA data partition, or that no eligible OTA app slot partition was found.

**Parameters**

- `start_from`: If set, treat this partition info as describing the current running partition. Can be NULL, in which case esp_ota_get_running_partition() is used to find the currently running partition. The result of this function is never the same as this argument.

## Deep Sleep

### Overview

ESP32 is capable of deep sleep power saving mode. In this mode CPUs, most of the RAM, and all the digital peripherals which are clocked from APB_CLK are powered off. The only parts of the chip which can still be powered on are: RTC controller, RTC peripherals (including ULP coprocessor), and RTC memories (slow and fast).

Wakeup from deep sleep mode can be done using several sources. These sources can be combined, in this case the chip will wake up when any one of the sources is triggered. Wakeup sources can be enabled using `esp_deep_sleep_enable_X_wakeup` APIs. Next section describes these APIs in detail. Wakeup sources can be configured at any moment before entering deep sleep mode.

Additionally, the application can force specific powerdown modes for the RTC peripherals and RTC memories using `esp_deep_sleep_pd_config` API.

Once wakeup sources are configured, application can start deep sleep using `esp_deep_sleep_start` API. At this point the hardware will be configured according to the requested wakeup sources, and RTC controller will power down the CPUs and digital peripherals.

## Wakeup sources

### Timer

RTC controller has a built in timer which can be used to wake up the chip after a predefined amount of time. Time is specified at microsecond precision, but the actual resolution depends on the clock source selected for RTC SLOW_CLK. See chapter "Reset and Clock" of the ESP32 Technical Reference Manual for details about RTC clock options.

This wakeup mode doesn't require RTC peripherals or RTC memories to be powered on during deep sleep.

The following function can be used to enable deep sleep wakeup using a timer.

esp_err_t **`esp_deep_sleep_enable_timer_wakeup`**(uint64_t *time_in_us*)

Enable wakeup by timer.

**Return**

- ESP_OK on success
- ESP_ERR_INVALID_ARG if value is out of range (TBD)

**Parameters**

- `time_in_us`: time before wakeup, in microseconds

### Touch pad

RTC IO module contains logic to trigger wakeup when a touch sensor interrupt occurs. You need to configure the touch pad interrupt before the chip starts deep sleep.

Revisions 0 and 1 of the ESP32 only support this wakeup mode when RTC peripherals are not forced to be powered on (i.e. ESP_PD_DOMAIN_RTC_PERIPH should be set to ESP_PD_OPTION_AUTO).

esp_err_t **`esp_deep_sleep_enable_touchpad_wakeup`**()

Enable wakeup by touch sensor.

**Note** In revisions 0 and 1 of the ESP32, touch wakeup source can not be used when RTC_PERIPH power domain is forced to be powered on (ESP_PD_OPTION_ON) or when ext0 wakeup source is used.

**Return**

- ESP_OK on success
- ESP_ERR_INVALID_STATE if wakeup triggers conflict

### External wakeup (ext0)

RTC IO module contains logic to trigger wakeup when one of RTC GPIOs is set to a predefined logic level. RTC IO is part of RTC peripherals power domain, so RTC peripherals will be kept powered on during deep sleep if this wakeup source is requested.

Because RTC IO module is enabled in this mode, internal pullup or pulldown resistors can also be used. They need to be configured by the application using `rtc_gpio_pullup_en` and `rtc_gpio_pulldown_en` functions, before calling `esp_deep_sleep_start`.

In revisions 0 and 1 of the ESP32, this wakeup source is incompatible with ULP and touch wakeup sources.

> **Warning:** After wake up from deep sleep, IO pad used for wakeup will be configured as RTC IO. Before using this pad as digital GPIO, reconfigure it using `rtc_gpio_deinit(gpio_num)` function.

esp_err_t **esp_deep_sleep_enable_ext0_wakeup**(*gpio_num_t gpio_num*, int *level*)

Enable wakeup using a pin.

This function uses external wakeup feature of RTC_IO peripheral. It will work only if RTC peripherals are kept on during deep sleep.

This feature can monitor any pin which is an RTC IO. Once the pin transitions into the state given by level argument, the chip will be woken up.

**Note** This function does not modify pin configuration. The pin is configured in esp_deep_sleep_start, immediately before entering deep sleep.

**Note** In revisions 0 and 1 of the ESP32, ext0 wakeup source can not be used together with touch or ULP wakeup sources.

**Return**

- ESP_OK on success
- ESP_ERR_INVALID_ARG if the selected GPIO is not an RTC GPIO, or the mode is invalid
- ESP_ERR_INVALID_STATE if wakeup triggers conflict

**Parameters**

- `gpio_num`: GPIO number used as wakeup source. Only GPIOs which are have RTC functionality can be used: 0,2,4,12-15,25-27,32-39.
- `level`: input level which will trigger wakeup (0=low, 1=high)

### External wakeup (ext1)

RTC controller contains logic to trigger wakeup using multiple RTC GPIOs. One of the two logic functions can be used to trigger wakeup:

- wake up if any of the selected pins is high (`ESP_EXT1_WAKEUP_ANY_HIGH`)
- wake up if all the selected pins are low (`ESP_EXT1_WAKEUP_ALL_LOW`)

This wakeup source is implemented by the RTC controller. As such, RTC peripherals and RTC memories can be powered off in this mode. However, if RTC peripherals are powered down, internal pullup and pulldown resistors will be disabled. To use internal pullup or pulldown resistors, request RTC peripherals power domain to be kept on during deep sleep, and configure pullup/pulldown resistors using `rtc_gpio_` functions, before entering deep sleep:

```
esp_deep_sleep_pd_config(ESP_PD_DOMAIN_RTC_PERIPH, ESP_PD_OPTION_ON);
gpio_pullup_dis(gpio_num);
gpio_pulldown_en(gpio_num);
```

> **Warning:** After wake up from deep sleep, IO pad(s) used for wakeup will be configured as RTC IO. Before using these pads as digital GPIOs, reconfigure them using `rtc_gpio_deinit(gpio_num)` function.

The following function can be used to enable this wakeup mode:

esp_err_t **esp_deep_sleep_enable_ext1_wakeup**(uint64_t *mask*, *esp_ext1_wakeup_mode_t* *mode*)

Enable wakeup using multiple pins.

This function uses external wakeup feature of RTC controller. It will work even if RTC peripherals are shut down during deep sleep.

This feature can monitor any number of pins which are in RTC IOs. Once any of the selected pins goes into the state given by mode argument, the chip will be woken up.

**Note** This function does not modify pin configuration. The pins are configured in esp_deep_sleep_start, immediately before entering deep sleep.

**Note** internal pullups and pulldowns don't work when RTC peripherals are shut down. In this case, external resistors need to be added. Alternatively, RTC peripherals (and pullups/pulldowns) may be kept enabled using esp_deep_sleep_pd_config function.

**Return**

- ESP_OK on success
- ESP_ERR_INVALID_ARG if any of the selected GPIOs is not an RTC GPIO, or mode is invalid

**Parameters**

- `mask`: bit mask of GPIO numbers which will cause wakeup. Only GPIOs which are have RTC functionality can be used in this bit map: 0,2,4,12-15,25-27,32-39.
- `mode`: select logic function used to determine wakeup condition:
  - ESP_EXT1_WAKEUP_ALL_LOW: wake up when all selected GPIOs are low
  - ESP_EXT1_WAKEUP_ANY_HIGH: wake up when any of the selected GPIOs is high

**enum esp_ext1_wakeup_mode_t**

Logic function used for EXT1 wakeup mode.

*Values:*

**ESP_EXT1_WAKEUP_ALL_LOW** = 0

Wake the chip when all selected GPIOs go low.

**ESP_EXT1_WAKEUP_ANY_HIGH** = 1

Wake the chip when any of the selected GPIOs go high.

### ULP coprocessor wakeup

ULP coprocessor can run while the chip is in deep sleep, and may be used to poll sensors, monitor ADC or touch sensor values, and wake up the chip when a specific event is detected. ULP coprocessor is part of RTC peripherals power domain, and it runs the program stored in RTC slow memeory. RTC slow memory will be powered on during deep sleep if this wakeup mode is requested. RTC peripherals will be automatically powered on before ULP coprocessor starts running the program; once the program stops running, RTC peripherals are automatically powered down again.

Revisions 0 and 1 of the ESP32 only support this wakeup mode when RTC peripherals are not forced to be powered on (i.e. ESP_PD_DOMAIN_RTC_PERIPH should be set to ESP_PD_OPTION_AUTO).

The following function can be used to enable this wakeup mode:

esp_err_t **esp_deep_sleep_enable_ulp_wakeup**()

Enable wakeup by ULP coprocessor.

**Note** In revisions 0 and 1 of the ESP32, ULP wakeup source can not be used when RTC_PERIPH power domain is forced to be powered on (ESP_PD_OPTION_ON) or when ext0 wakeup source is used.

**Return**

- ESP_OK on success
- ESP_ERR_INVALID_STATE if ULP co-processor is not enabled or if wakeup triggers conflict

## Power-down of RTC peripherals and memories

By default, `esp_deep_sleep_start` function will power down all RTC power domains which are not needed by the enabled wakeup sources. To override this behaviour, the following function is provided:

Note: in revision 0 of the ESP32, RTC fast memory will always be kept enabled in deep sleep, so that the deep sleep stub can run after reset. This can be overriden, if the application doesn't need clean reset behaviour after deep sleep.

If some variables in the program are placed into RTC slow memory (for example, using `RTC_DATA_ATTR` attribute), RTC slow memory will be kept powered on by default. This can be overriden using `esp_deep_sleep_pd_config` function, if desired.

esp_err_t **esp_deep_sleep_pd_config**(*esp_deep_sleep_pd_domain_t domain*, *esp_deep_sleep_pd_option_t option*)

Set power down mode for an RTC power domain in deep sleep.

If not set set using this API, all power domains default to ESP_PD_OPTION_AUTO.

**Return**

- ESP_OK on success
- ESP_ERR_INVALID_ARG if either of the arguments is out of range

**Parameters**

- `domain`: power domain to configure
- `option`: power down option (ESP_PD_OPTION_OFF, ESP_PD_OPTION_ON, or ESP_PD_OPTION_AUTO)

**enum esp_deep_sleep_pd_domain_t**

Power domains which can be powered down in deep sleep.

*Values:*

**ESP_PD_DOMAIN_RTC_PERIPH**

RTC IO, sensors and ULP co-processor.

**ESP_PD_DOMAIN_RTC_SLOW_MEM**

RTC slow memory.

**ESP_PD_DOMAIN_RTC_FAST_MEM**
RTC fast memory.

**ESP_PD_DOMAIN_MAX**
Number of domains.

**enum esp_deep_sleep_pd_option_t**
Power down options.

*Values:*

**ESP_PD_OPTION_OFF**
Power down the power domain in deep sleep.

**ESP_PD_OPTION_ON**
Keep power domain enabled during deep sleep.

**ESP_PD_OPTION_AUTO**
Keep power domain enabled in deep sleep, if it is needed by one of the wakeup options. Otherwise power it down.

## Entering deep sleep

The following function can be used to enter deep sleep once wakeup sources are configured. It is also possible to go into deep sleep with no wakeup sources configured, in this case the chip will be in deep sleep mode indefinetly, until external reset is applied.

void **esp_deep_sleep_start**()
Enter deep sleep with the configured wakeup options.

This function does not return.

## Checking deep sleep wakeup cause

The following function can be used to check which wakeup source has triggered wakeup from deep sleep mode. For touch pad and ext1 wakeup sources, it is possible to identify pin or touch pad which has caused wakeup.

*esp_deep_sleep_wakeup_cause_t* **esp_deep_sleep_get_wakeup_cause**()
Get the source which caused deep sleep wakeup.

**Return** wakeup cause, or ESP_DEEP_SLEEP_WAKEUP_UNDEFINED if reset reason is other than deep sleep reset.

**enum esp_deep_sleep_wakeup_cause_t**
Deep sleep wakeup cause.

*Values:*

**ESP_DEEP_SLEEP_WAKEUP_UNDEFINED**

**ESP_DEEP_SLEEP_WAKEUP_EXT0**
Wakeup was not caused by deep sleep.

**ESP_DEEP_SLEEP_WAKEUP_EXT1**
Wakeup caused by external signal using RTC_IO.

**ESP_DEEP_SLEEP_WAKEUP_TIMER**
Wakeup caused by external signal using RTC_CNTL.

**ESP_DEEP_SLEEP_WAKEUP_TOUCHPAD**
Wakeup caused by timer.

**ESP_DEEP_SLEEP_WAKEUP_ULP**
Wakeup caused by touchpad.

touch_pad_t **esp_deep_sleep_get_touchpad_wakeup_status**()
Get the touch pad which caused wakeup.

If wakeup was caused by another source, this function will return TOUCH_PAD_MAX;

**Return** touch pad which caused wakeup

uint64_t **esp_deep_sleep_get_ext1_wakeup_status**()
Get the bit mask of GPIOs which caused wakeup (ext1)

If wakeup was caused by another source, this function will return 0.

**Return** bit mask, if GPIOn caused wakeup, BIT(n) will be set

## Application Example

Implementation of basic functionality of deep sleep is shown in protocols/sntp example, where ESP module is periodically waken up to retrive time from NTP server.

More extensive example in system/deep_sleep illustrates usage of various deep sleep wakeup triggers and ULP coprocessor programming.

# Logging library

## Overview

Log library has two ways of managing log verbosity: compile time, set via menuconfig; and runtime, using `esp_log_level_set` function.

At compile time, filtering is done using `CONFIG_LOG_DEFAULT_LEVEL` macro, set via menuconfig. All logging statments for levels higher than `CONFIG_LOG_DEFAULT_LEVEL` will be removed by the preprocessor.

At run time, all logs below `CONFIG_LOG_DEFAULT_LEVEL` are enabled by default. `esp_log_level_set` function may be used to set logging level per module. Modules are identified by their tags, which are human-readable ASCII zero-terminated strings.

## How to use this library

In each C file which uses logging functionality, define TAG variable like this:

```
static const char* TAG = "MyModule";
```

then use one of logging macros to produce output, e.g:

```
ESP_LOGW(TAG, "Baud rate error %.1f%%. Requested: %d baud, actual: %d baud", error *␣
↪100, baud_req, baud_real);
```

Several macros are available for different verbosity levels:

- ESP_LOGE - error
- ESP_LOGW - warning
- ESP_LOGI - info
- ESP_LOGD - debug
- ESP_LOGV - verbose

Additionally there is an _EARLY_ variant for each of these macros (e.g. ESP_EARLY_LOGE ).These variants can run in startup code, before heap allocator and syscalls have been initialized. When compiling bootloader, normal ESP_LOGx macros fall back to the same implementation as ESP_EARLY_LOGx macros. So the only place where ESP_EARLY_LOGx have to be used explicitly is the early startup code, such as heap allocator initialization code.

(Note that such distinction would not have been necessary if we would have an ets_vprintf function in the ROM. Then it would be possible to switch implementation from _EARLY_ version to normal version on the fly. Unfortunately, ets_vprintf in ROM has been inlined by the compiler into ets_printf, so it is not accessible outside.)

To override default verbosity level at file or component scope, define LOG_LOCAL_LEVEL macro. At file scope, define it before including esp_log.h, e.g.:

```
#define LOG_LOCAL_LEVEL ESP_LOG_VERBOSE
#include "esp_log.h"
```

At component scope, define it in component makefile:

```
CFLAGS += -D LOG_LOCAL_LEVEL=ESP_LOG_DEBUG
```

To configure logging output per module at runtime, add calls to esp_log_level_set function:

```
esp_log_level_set("*", ESP_LOG_ERROR);        // set all components to ERROR level
esp_log_level_set("wifi", ESP_LOG_WARN);      // enable WARN logs from WiFi stack
esp_log_level_set("dhcpc", ESP_LOG_INFO);     // enable INFO logs from DHCP client
```

## Application Example

Log library is commonly used by most of esp-idf components and examples. For demonstration of log functionality check examples folder of espressif/esp-idf repository, that among others, contains the following examples:

- system/ota
- storage/sd_card
- protocols/https_request

## API Reference

### Header Files

- log/include/esp_log.h

### Macros

**LOG_COLOR_E**

**LOG_COLOR_W**

**LOG_COLOR_I**

**LOG_COLOR_D**

**LOG_COLOR_V**

**LOG_RESET_COLOR**

**LOG_FORMAT** (letter, format) LOG_COLOR_ ## letter #letter " (%d) %s: " format LOG_RESET_COLOR "\n"

**LOG_LOCAL_LEVEL** ((esp_log_level_t) CONFIG_LOG_DEFAULT_LEVEL)

**ESP_EARLY_LOGE** (tag, format, ...) if (LOG_LOCAL_LEVEL >= ESP_LOG_ERROR) { ets_printf(LOG_FORMAT(E, format), esp_log_timestamp(), tag, ##__VA_ARGS__); }

**ESP_EARLY_LOGW** (tag, format, ...) if (LOG_LOCAL_LEVEL >= ESP_LOG_WARN) { ets_printf(LOG_FORMAT(W, format), esp_log_timestamp(), tag, ##__VA_ARGS__); }

**ESP_EARLY_LOGI** (tag, format, ...) if (LOG_LOCAL_LEVEL >= ESP_LOG_INFO) { ets_printf(LOG_FORMAT(I, format), esp_log_timestamp(), tag, ##__VA_ARGS__); }

**ESP_EARLY_LOGD** (tag, format, ...) if (LOG_LOCAL_LEVEL >= ESP_LOG_DEBUG) { ets_printf(LOG_FORMAT(D, format), esp_log_timestamp(), tag, ##__VA_ARGS__); }

**ESP_EARLY_LOGV** (tag, format, ...) if (LOG_LOCAL_LEVEL >= ESP_LOG_VERBOSE) { ets_printf(LOG_FORMAT(V, format), esp_log_timestamp(), tag, ##__VA_ARGS__); }

**ESP_LOGE** (tag, format, ...) if (LOG_LOCAL_LEVEL >= ESP_LOG_ERROR) { esp_log_write(ESP_LOG_ERROR, tag, LOG_FORMAT(E, format), esp_log_timestamp(), tag, ##__VA_ARGS__); }

**ESP_LOGW** (tag, format, ...) if (LOG_LOCAL_LEVEL >= ESP_LOG_WARN) { esp_log_write(ESP_LOG_WARN, tag, LOG_FORMAT(W, format), esp_log_timestamp(), tag, ##__VA_ARGS__); }

**ESP_LOGI** (tag, format, ...) if (LOG_LOCAL_LEVEL >= ESP_LOG_INFO) { esp_log_write(ESP_LOG_INFO, tag, LOG_FORMAT(I, format), esp_log_timestamp(), tag, ##__VA_ARGS__); }

**ESP_LOGD** (tag, format, ...) if (LOG_LOCAL_LEVEL >= ESP_LOG_DEBUG) { esp_log_write(ESP_LOG_DEBUG, tag, LOG_FORMAT(D, format), esp_log_timestamp(), tag, ##__VA_ARGS__); }

**ESP_LOGV** (tag, format, ...) if (LOG_LOCAL_LEVEL >= ESP_LOG_VERBOSE) { esp_log_write(ESP_LOG_VERBOSE, tag, LOG_FORMAT(V, format), esp_log_timestamp(), tag, ##__VA_ARGS__); }

### Type Definitions

**typedef** int (***vprintf_like_t**) (**const** char *, va_list)

### Enumerations

**enum esp_log_level_t**

Log level.

*Values:*

**ESP_LOG_NONE**

No log output

**ESP_LOG_ERROR**
Critical errors, software module can not recover on its own

**ESP_LOG_WARN**
Error conditions from which recovery measures have been taken

**ESP_LOG_INFO**
Information messages which describe normal flow of events

**ESP_LOG_DEBUG**
Extra information which is not necessary for normal use (values, pointers, sizes, etc).

**ESP_LOG_VERBOSE**
Bigger chunks of debugging information, or frequent messages which can potentially flood the output.

### Functions

void **esp_log_level_set** (**const** char **tag*, *esp_log_level_t level*)
Set log level for given tag.

If logging for given component has already been enabled, changes previous setting.

**Parameters**

- `tag`: Tag of the log entries to enable. Must be a non-NULL zero terminated string. Value "*" resets log level for all tags to the given value.
- `level`: Selects log level to enable. Only logs at this and lower levels will be shown.

void **esp_log_set_vprintf** (*vprintf_like_t func*)
Set function used to output log entries.

By default, log output goes to UART0. This function can be used to redirect log output to some other destination, such as file or network.

**Parameters**

- `func`: Function used for output. Must have same signature as vprintf.

uint32_t **esp_log_timestamp** (void)
Function which returns timestamp to be used in log output.

This function is used in expansion of ESP_LOGx macros. In the 2nd stage bootloader, and at early application startup stage this function uses CPU cycle counter as time source. Later when FreeRTOS scheduler start running, it switches to FreeRTOS tick count.

For now, we ignore millisecond counter overflow.

**Return** timestamp, in milliseconds

void **esp_log_write** (*esp_log_level_t level*, **const** char **tag*, **const** char **format*, *...*)
Write message into the log.

This function is not intended to be used directly. Instead, use one of ESP_LOGE, ESP_LOGW, ESP_LOGI, ESP_LOGD, ESP_LOGV macros.

This function or these macros should not be used from an interrupt.

Example code for this API section is provided in system directory of ESP-IDF examples.

CHAPTER 22

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# Storage API

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## SPI Flash APIs

### Overview

The spi_flash component contains APIs related to reading, writing, erasing, memory mapping data in the external SPI flash. It also has higher-level APIs which work with partitions defined in the *partition table*.

Note that all the functionality is limited to the "main" SPI flash chip, the same SPI flash chip from which program runs. For `spi_flash_*` functions, this is a software limitation. The underlying ROM functions which work with SPI flash do not have provisions for working with flash chips attached to SPI peripherals other than SPI0.

### SPI flash access APIs

This is the set of APIs for working with data in flash:

- `spi_flash_read` used to read data from flash to RAM
- `spi_flash_write` used to write data from RAM to flash
- `spi_flash_erase_sector` used to erase individual sectors of flash
- `spi_flash_erase_range` used to erase range of addresses in flash
- `spi_flash_get_chip_size` returns flash chip size, in bytes, as configured in menuconfig

Generally, try to avoid using the raw SPI flash functions in favour of partition-specific functions.

### SPI Flash Size

The SPI flash size is configured by writing a field in the software bootloader image header, flashed at offset 0x1000.

By default, the SPI flash size is detected by esptool.py when this bootloader is written to flash, and the header is updated with the correct size. Alternatively, it is possible to generate a fixed flash size by disabling detection in `make menuconfig` (under Serial Flasher Config).

If it is necessary to override the configured flash size at runtime, is is possible to set the `chip_size` member of `g_rom_flashchip` structure. This size is used by `spi_flash_*` functions (in both software & ROM) for bounds checking.

## Concurrency Constraints

Because the SPI flash is also used for firmware execution (via the instruction & data caches), these caches much be disabled while reading/writing/erasing. This means that both CPUs must be running code from IRAM and only reading data from DRAM while flash write operations occur.

Refer to the *application memory layout* documentation for an explanation of the differences between IRAM, DRAM and flash cache.

To avoid reading flash cache accidentally, when one CPU commences a flash write or erase operation the other CPU is put into a blocked state and all non-IRAM-safe interrupts are disabled on both CPUs, until the flash operation completes.

### IRAM-Safe Interrupt Handlers

If you have an interrupt handler that you want to execute even when a flash operation is in progress (for example, for low latency operations), set the `ESP_INTR_FLAG_IRAM` flag when the *interrupt handler is registered*.

You must ensure all data and functions accessed by these interrupt handlers are located in IRAM or DRAM. This includes any functions that the handler calls.

Use the `IRAM_ATTR` attribute for functions:

```
#include "esp_attr.h"

void IRAM_ATTR gpio_isr_handler(void* arg)
{
    // ...
}
```

Use the `DRAM_ATTR` and `DRAM_STR` attributes for constant data:

```
void IRAM_ATTR gpio_isr_handler(void* arg)
{
   const static DRAM_ATTR uint8_t INDEX_DATA[] = { 45, 33, 12, 0 };
   const static char *MSG = DRAM_STR("I am a string stored in RAM");
}
```

Note that knowing which data should be marked with `DRAM_ATTR` can be hard, the compiler will sometimes recognise that a variable or expression is constant (even if it is not marked `const`) and optimise it into flash, unless it is marked with `DRAM_ATTR`.

If a function or symbol is not correctly put into IRAM/DRAM and the interrupt handler reads from the flash cache during a flash operation, it will cause a crash due to Illegal Instruction exception (for code which should be in IRAM) or garbage data to be read (for constant data which should be in DRAM).

## Partition table APIs

ESP-IDF projects use a partition table to maintain information about various regions of SPI flash memory (bootloader, various application binaries, data, filesystems). More information about partition tables can be found *here*.

This component provides APIs to enumerate partitions found in the partition table and perform operations on them. These functions are declared in `esp_partition.h`:

- `esp_partition_find` used to search partition table for entries with specific type, returns an opaque iterator
- `esp_partition_get` returns a structure describing the partition, for the given iterator
- `esp_partition_next` advances iterator to the next partition found
- `esp_partition_iterator_release` releases iterator returned by `esp_partition_find`
- `esp_partition_find_first` is a convenience function which returns structure describing the first partition found by esp_partition_find
- `esp_partition_read`, `esp_partition_write`, `esp_partition_erase_range` are equivalent to `spi_flash_read`, `spi_flash_write`, `spi_flash_erase_range`, but operate within partition boundaries

Most application code should use `esp_partition_*` APIs instead of lower level `spi_flash_*` APIs. Partition APIs do bounds checking and calculate correct offsets in flash based on data stored in partition table.

## SPI Flash Encryption

It is possible to encrypt SPI flash contents, and have it transparenlty decrypted by hardware.

Refer to the *Flash Encryption documentation* for more details.

## Memory mapping APIs

ESP32 features memory hardware which allows regions of flash memory to be mapped into instruction and data address spaces. This mapping works only for read operations, it is not possible to modify contents of flash memory by writing to mapped memory region. Mapping happens in 64KB pages. Memory mapping hardware can map up to 4 megabytes of flash into data address space, and up to 16 megabytes of flash into instruction address space. See the technical reference manual for more details about memory mapping hardware.

Note that some number of 64KB pages is used to map the application itself into memory, so the actual number of available 64KB pages may be less.

Reading data from flash using a memory mapped region is the only way to decrypt contents of flash when *flash encryption* is enabled. Decryption is performed at hardware level.

Memory mapping APIs are declared in `esp_spi_flash.h` and `esp_partition.h`:

- `spi_flash_mmap` maps a region of physical flash addresses into instruction space or data space of the CPU
- `spi_flash_munmap` unmaps previously mapped region
- `esp_partition_mmap` maps part of a partition into the instruction space or data space of the CPU

Differences between `spi_flash_mmap` and `esp_partition_mmap` are as follows:

- `spi_flash_mmap` must be given a 64KB aligned physical address
- `esp_partition_mmap` may be given an arbitrary offset within the partition, it will adjust returned pointer to mapped memory as necessary

Note that because memory mapping happens in 64KB blocks, it may be possible to read data outside of the partition provided to `esp_partition_mmap`.

## See also

- *Partition Table documentation*
- *Over The Air Update (OTA) API* provides high-level API for updating app firmware stored in flash.
- *Non-Volatile Storage (NVS) API* provides a structured API for storing small items of data in SPI flash.

## API Reference

### Header Files

- spi_flash/include/esp_spi_flash.h
- spi_flash/include/esp_partition.h
- bootloader_support/include/esp_flash_encrypt.h

### Macros

**ESP_ERR_FLASH_BASE** 0x10010

**ESP_ERR_FLASH_OP_FAIL** (ESP_ERR_FLASH_BASE + 1)

**ESP_ERR_FLASH_OP_TIMEOUT** (ESP_ERR_FLASH_BASE + 2)

**SPI_FLASH_SEC_SIZE** 4096
SPI Flash sector size

**SPI_FLASH_MMU_PAGE_SIZE** 0x10000
Flash cache MMU mapping page size

**ESP_PARTITION_SUBTYPE_OTA** (i) ((*esp_partition_subtype_t*)(*ESP_PARTITION_SUBTYPE_APP_OTA_MIN* + ((i) & 0xf)))
Convenience macro to get esp_partition_subtype_t value for the i-th OTA partition.

**SPI_FLASH_CACHE2PHYS_FAIL** UINT32_MAX /*<! Result from spi_flash_cache2phys() if flash cache address is invalid */

### Type Definitions

**typedef** uint32_t **spi_flash_mmap_handle_t**
Opaque handle for memory region obtained from spi_flash_mmap.

**typedef struct** esp_partition_iterator_opaque_ ***esp_partition_iterator_t**
Opaque partition iterator type.

### Enumerations

**enum spi_flash_mmap_memory_t**
Enumeration which specifies memory space requested in an mmap call.

*Values:*

**SPI_FLASH_MMAP_DATA**
map to data memory (Vaddr0), allows byte-aligned access, 4 MB total

**SPI_FLASH_MMAP_INST**
map to instruction memory (Vaddr1-3), allows only 4-byte-aligned access, 11 MB total

**enum esp_partition_type_t**
Partition type.

**Note** Keep this enum in sync with PartitionDefinition class gen_esp32part.py

*Values:*

**ESP_PARTITION_TYPE_APP** = 0x00
Application partition type.

**ESP_PARTITION_TYPE_DATA** = 0x01
Data partition type.

**enum esp_partition_subtype_t**
Partition subtype.

**Note** Keep this enum in sync with PartitionDefinition class gen_esp32part.py

*Values:*

**ESP_PARTITION_SUBTYPE_APP_FACTORY** = 0x00
Factory application partition.

**ESP_PARTITION_SUBTYPE_APP_OTA_MIN** = 0x10
Base for OTA partition subtypes.

**ESP_PARTITION_SUBTYPE_APP_OTA_0** = ESP_PARTITION_SUBTYPE_APP_OTA_MIN + 0
OTA partition 0.

**ESP_PARTITION_SUBTYPE_APP_OTA_1** = ESP_PARTITION_SUBTYPE_APP_OTA_MIN + 1
OTA partition 1.

**ESP_PARTITION_SUBTYPE_APP_OTA_2** = ESP_PARTITION_SUBTYPE_APP_OTA_MIN + 2
OTA partition 2.

**ESP_PARTITION_SUBTYPE_APP_OTA_3** = ESP_PARTITION_SUBTYPE_APP_OTA_MIN + 3
OTA partition 3.

**ESP_PARTITION_SUBTYPE_APP_OTA_4** = ESP_PARTITION_SUBTYPE_APP_OTA_MIN + 4
OTA partition 4.

**ESP_PARTITION_SUBTYPE_APP_OTA_5** = ESP_PARTITION_SUBTYPE_APP_OTA_MIN + 5
OTA partition 5.

**ESP_PARTITION_SUBTYPE_APP_OTA_6** = ESP_PARTITION_SUBTYPE_APP_OTA_MIN + 6
OTA partition 6.

**ESP_PARTITION_SUBTYPE_APP_OTA_7** = ESP_PARTITION_SUBTYPE_APP_OTA_MIN + 7
OTA partition 7.

**ESP_PARTITION_SUBTYPE_APP_OTA_8** = ESP_PARTITION_SUBTYPE_APP_OTA_MIN + 8
OTA partition 8.

**ESP_PARTITION_SUBTYPE_APP_OTA_9** = ESP_PARTITION_SUBTYPE_APP_OTA_MIN + 9
OTA partition 9.

**ESP_PARTITION_SUBTYPE_APP_OTA_10** = ESP_PARTITION_SUBTYPE_APP_OTA_MIN + 10
OTA partition 10.

**ESP_PARTITION_SUBTYPE_APP_OTA_11** = ESP_PARTITION_SUBTYPE_APP_OTA_MIN + 11
OTA partition 11.

**ESP_PARTITION_SUBTYPE_APP_OTA_12** = ESP_PARTITION_SUBTYPE_APP_OTA_MIN + 12
OTA partition 12.

**ESP_PARTITION_SUBTYPE_APP_OTA_13** = ESP_PARTITION_SUBTYPE_APP_OTA_MIN + 13
OTA partition 13.

**ESP_PARTITION_SUBTYPE_APP_OTA_14** = ESP_PARTITION_SUBTYPE_APP_OTA_MIN + 14
OTA partition 14.

**ESP_PARTITION_SUBTYPE_APP_OTA_15** = ESP_PARTITION_SUBTYPE_APP_OTA_MIN + 15
OTA partition 15.

**ESP_PARTITION_SUBTYPE_APP_OTA_MAX** = ESP_PARTITION_SUBTYPE_APP_OTA_MIN + 16
Max subtype of OTA partition.

**ESP_PARTITION_SUBTYPE_APP_TEST** = 0x20
Test application partition.

**ESP_PARTITION_SUBTYPE_DATA_OTA** = 0x00
OTA selection partition.

**ESP_PARTITION_SUBTYPE_DATA_PHY** = 0x01
PHY init data partition.

**ESP_PARTITION_SUBTYPE_DATA_NVS** = 0x02
NVS partition.

**ESP_PARTITION_SUBTYPE_DATA_COREDUMP** = 0x03
COREDUMP partition.

**ESP_PARTITION_SUBTYPE_DATA_ESPHTTPD** = 0x80
ESPHTTPD partition.

**ESP_PARTITION_SUBTYPE_DATA_FAT** = 0x81
FAT partition.

**ESP_PARTITION_SUBTYPE_DATA_SPIFFS** = 0x82
SPIFFS partition.

**ESP_PARTITION_SUBTYPE_ANY** = 0xff
Used to search for partitions with any subtype.

### Structures

**struct esp_partition_t**
partition information structure

This is not the format in flash, that format is esp_partition_info_t.

However, this is the format used by this API.

### Functions

void **spi_flash_init** ()
Initialize SPI flash access driver.

This function must be called exactly once, before any other spi_flash_* functions are called. Currently this function is called from startup code. There is no need to call it from application code.

size_t **spi_flash_get_chip_size**()

Get flash chip size, as set in binary image header.

**Note** This value does not necessarily match real flash size.

**Return** size of flash chip, in bytes

esp_err_t **spi_flash_erase_sector**(size_t *sector*)

Erase the Flash sector.

**Return** esp_err_t

**Parameters**

- `sector`: Sector number, the count starts at sector 0, 4KB per sector.

esp_err_t **spi_flash_erase_range**(size_t *start_address*, size_t *size*)

Erase a range of flash sectors.

**Return** esp_err_t

**Parameters**

- `start_address`: Address where erase operation has to start. Must be 4kB-aligned
- `size`: Size of erased range, in bytes. Must be divisible by 4kB.

esp_err_t **spi_flash_write**(size_t *dest_addr*, **const** void **src*, size_t *size*)

Write data to Flash.

**Note** If source address is in DROM, this function will return ESP_ERR_INVALID_ARG.

**Return** esp_err_t

**Parameters**

- `dest_addr`: destination address in Flash. Must be a multiple of 4 bytes.
- `src`: pointer to the source buffer.
- `size`: length of data, in bytes. Must be a multiple of 4 bytes.

esp_err_t **spi_flash_write_encrypted**(size_t *dest_addr*, **const** void **src*, size_t *size*)

Write data encrypted to Flash.

**Note** Flash encryption must be enabled for this function to work.

**Note** Flash encryption must be enabled when calling this function. If flash encryption is disabled, the function returns ESP_ERR_INVALID_STATE. Use esp_flash_encryption_enabled() function to determine if flash encryption is enabled.

**Note** Both dest_addr and size must be multiples of 16 bytes. For absolute best performance, both dest_addr and size arguments should be multiples of 32 bytes.

**Return** esp_err_t

**Parameters**

- `dest_addr`: destination address in Flash. Must be a multiple of 16 bytes.

- `src`: pointer to the source buffer.
- `size`: length of data, in bytes. Must be a multiple of 16 bytes.

esp_err_t **spi_flash_read** (size_t *src_addr*, void **dest*, size_t *size*)
Read data from Flash.

**Return** esp_err_t

**Parameters**

- `src_addr`: source address of the data in Flash.
- `dest`: pointer to the destination buffer
- `size`: length of data

esp_err_t **spi_flash_read_encrypted** (size_t *src*, void **dest*, size_t *size*)
Read data from Encrypted Flash.

If flash encryption is enabled, this function will transparently decrypt data as it is read. If flash encryption is not enabled, this function behaves the same as spi_flash_read().

See esp_flash_encryption_enabled() for a function to check if flash encryption is enabled.

**Return** esp_err_t

**Parameters**

- `src`: source address of the data in Flash.
- `dest`: pointer to the destination buffer
- `size`: length of data

esp_err_t **spi_flash_mmap** (size_t *src_addr*, size_t *size*, *spi_flash_mmap_memory_t* *memory*, **const** void ***out_ptr*, *spi_flash_mmap_handle_t* **out_handle*)
Map region of flash memory into data or instruction address space.

This function allocates sufficient number of 64k MMU pages and configures them to map request region of flash memory into data address space or into instruction address space. It may reuse MMU pages which already provide required mapping. As with any allocator, there is possibility of fragmentation of address space if mmap/munmap are heavily used. To troubleshoot issues with page allocation, use spi_flash_mmap_dump function.

**Return** ESP_OK on success, ESP_ERR_NO_MEM if pages can not be allocated

**Parameters**

- `src_addr`: Physical address in flash where requested region starts. This address *must* be aligned to 64kB boundary (SPI_FLASH_MMU_PAGE_SIZE).
- `size`: Size of region which has to be mapped. This size will be rounded up to a 64k boundary.
- `memory`: Memory space where the region should be mapped
- `out_ptr`: Output, pointer to the mapped memory region
- `out_handle`: Output, handle which should be used for spi_flash_munmap call

void **spi_flash_munmap** (*spi_flash_mmap_handle_t* *handle*)
Release region previously obtained using spi_flash_mmap.

**Note** Calling this function will not necessarily unmap memory region. Region will only be unmapped when there are no other handles which reference this region. In case of partially overlapping regions it is possible that memory will be unmapped partially.

**Parameters**

- `handle`: Handle obtained from spi_flash_mmap

void **`spi_flash_mmap_dump`**()

Display information about mapped regions.

This function lists handles obtained using spi_flash_mmap, along with range of pages allocated to each handle. It also lists all non-zero entries of MMU table and corresponding reference counts.

size_t **`spi_flash_cache2phys`**(**const** void **cached*)

Given a memory address where flash is mapped, return the corresponding physical flash offset.

Cache address does not have have been assigned via spi_flash_mmap(), any address in flash map space can be looked up.

**Return**

- SPI_FLASH_CACHE2PHYS_FAIL If cache address is outside flash cache region, or the address is not mapped.
- Otherwise, returns physical offset in flash

**Parameters**

- `cached`: Pointer to flashed cached memory.

**const** void ***`spi_flash_phys2cache`**(size_t *phys_offs*, *spi_flash_mmap_memory_t* *memory*)

Given a physical offset in flash, return the address where it is mapped in the memory space.

Physical address does not have to have been assigned via spi_flash_mmap(), any address in flash can be looked up.

**Note** Only the first matching cache address is returned. If MMU flash cache table is configured so multiple entries point to the same physical address, there may be more than one cache address corresponding to that physical address. It is also possible for a single physical address to be mapped to both the IROM and DROM regions.

**Note** This function doesn't impose any alignment constraints, but if memory argument is SPI_FLASH_MMAP_INST and phys_offs is not 4-byte aligned, then reading from the returned pointer will result in a crash.

**Return**

- NULL if the physical address is invalid or not mapped to flash cache of the specified memory type.
- Cached memory address (in IROM or DROM space) corresponding to phys_offs.

**Parameters**

- `phys_offs`: Physical offset in flash memory to look up.
- `memory`: Memory type to look up a flash cache address mapping for (IROM or DROM)

bool **`spi_flash_cache_enabled`**()

Check at runtime if flash cache is enabled on both CPUs.

**Return** true if both CPUs have flash cache enabled, false otherwise.

*esp_partition_iterator_t* **esp_partition_find**(*esp_partition_type_t type*, *esp_partition_subtype_t subtype*, **const** char **label*)

Find partition based on one or more parameters.

**Return** iterator which can be used to enumerate all the partitions found, or NULL if no partitions were found. Iterator obtained through this function has to be released using esp_partition_iterator_release when not used any more.

**Parameters**

- `type`: Partition type, one of esp_partition_type_t values
- `subtype`: Partition subtype, one of esp_partition_subtype_t values. To find all partitions of given type, use ESP_PARTITION_SUBTYPE_ANY.
- `label`: (optional) Partition label. Set this value if looking for partition with a specific name. Pass NULL otherwise.

**const** *esp_partition_t* ***esp_partition_find_first**(*esp_partition_type_t type*, *esp_partition_subtype_t subtype*, **const** char **label*)

Find first partition based on one or more parameters.

**Return** pointer to *esp_partition_t* structure, or NULL if no partition is found. This pointer is valid for the lifetime of the application.

**Parameters**

- `type`: Partition type, one of esp_partition_type_t values
- `subtype`: Partition subtype, one of esp_partition_subtype_t values. To find all partitions of given type, use ESP_PARTITION_SUBTYPE_ANY.
- `label`: (optional) Partition label. Set this value if looking for partition with a specific name. Pass NULL otherwise.

**const** *esp_partition_t* ***esp_partition_get**(*esp_partition_iterator_t iterator*)

Get *esp_partition_t* structure for given partition.

**Return** pointer to *esp_partition_t* structure. This pointer is valid for the lifetime of the application.

**Parameters**

- `iterator`: Iterator obtained using esp_partition_find. Must be non-NULL.

*esp_partition_iterator_t* **esp_partition_next**(*esp_partition_iterator_t iterator*)

Move partition iterator to the next partition found.

Any copies of the iterator will be invalid after this call.

**Return** NULL if no partition was found, valid esp_partition_iterator_t otherwise.

**Parameters**

- `iterator`: Iterator obtained using esp_partition_find. Must be non-NULL.

void **esp_partition_iterator_release**(*esp_partition_iterator_t iterator*)

Release partition iterator.

**Parameters**

- `iterator`: Iterator obtained using esp_partition_find. Must be non-NULL.

esp_err_t **esp_partition_read**(**const** *esp_partition_t* **partition*, size_t *src_offset*, void **dst*, size_t *size*)

Read data from the partition.

**Return** ESP_OK, if data was read successfully; ESP_ERR_INVALID_ARG, if src_offset exceeds partition size; ESP_ERR_INVALID_SIZE, if read would go out of bounds of the partition; or one of error codes from lower-level flash driver.

**Parameters**

- `partition`: Pointer to partition structure obtained using esp_partition_find_first or esp_partition_get. Must be non-NULL.
- `dst`: Pointer to the buffer where data should be stored. Pointer must be non-NULL and buffer must be at least 'size' bytes long.
- `src_offset`: Address of the data to be read, relative to the beginning of the partition.
- `size`: Size of data to be read, in bytes.

esp_err_t **esp_partition_write**(**const** *esp_partition_t* **partition*, size_t *dst_offset*, **const** void **src*, size_t *size*)

Write data to the partition.

Before writing data to flash, corresponding region of flash needs to be erased. This can be done using esp_partition_erase_range function.

Partitions marked with an encryption flag will automatically be written via the spi_flash_write_encrypted() function. If writing to an encrypted partition, all write offsets and lengths must be multiples of 16 bytes. See the spi_flash_write_encrypted() function for more details. Unencrypted partitions do not have this restriction.

**Note** Prior to writing to flash memory, make sure it has been erased with esp_partition_erase_range call.

**Return** ESP_OK, if data was written successfully; ESP_ERR_INVALID_ARG, if dst_offset exceeds partition size; ESP_ERR_INVALID_SIZE, if write would go out of bounds of the partition; or one of error codes from lower-level flash driver.

**Parameters**

- `partition`: Pointer to partition structure obtained using esp_partition_find_first or esp_partition_get. Must be non-NULL.
- `dst_offset`: Address where the data should be written, relative to the beginning of the partition.
- `src`: Pointer to the source buffer. Pointer must be non-NULL and buffer must be at least 'size' bytes long.
- `size`: Size of data to be written, in bytes.

esp_err_t **esp_partition_erase_range**(**const** *esp_partition_t* **partition*, uint32_t *start_addr*, uint32_t *size*)

Erase part of the partition.

**Return** ESP_OK, if the range was erased successfully; ESP_ERR_INVALID_ARG, if iterator or dst are NULL; ESP_ERR_INVALID_SIZE, if erase would go out of bounds of the partition; or one of error codes from lower-level flash driver.

**Parameters**

- `partition`: Pointer to partition structure obtained using esp_partition_find_first or esp_partition_get. Must be non-NULL.

- `start_addr`: Address where erase operation should start. Must be aligned to 4 kilobytes.
- `size`: Size of the range which should be erased, in bytes. Must be divisible by 4 kilobytes.

esp_err_t **esp_partition_mmap** (**const** *esp_partition_t* **partition*, uint32_t *offset*, uint32_t *size*, *spi_flash_mmap_memory_t* *memory*, **const** void ***out_ptr*, *spi_flash_mmap_handle_t* **out_handle*)

Configure MMU to map partition into data memory.

Unlike spi_flash_mmap function, which requires a 64kB aligned base address, this function doesn't impose such a requirement. If offset results in a flash address which is not aligned to 64kB boundary, address will be rounded to the lower 64kB boundary, so that mapped region includes requested range. Pointer returned via out_ptr argument will be adjusted to point to the requested offset (not necessarily to the beginning of mmap-ed region).

To release mapped memory, pass handle returned via out_handle argument to spi_flash_munmap function.

**Return** ESP_OK, if successful

**Parameters**

- `partition`: Pointer to partition structure obtained using esp_partition_find_first or esp_partition_get. Must be non-NULL.
- `offset`: Offset from the beginning of partition where mapping should start.
- `size`: Size of the area to be mapped.
- `memory`: Memory space where the region should be mapped
- `out_ptr`: Output, pointer to the mapped memory region
- `out_handle`: Output, handle which should be used for spi_flash_munmap call

**static** bool **esp_flash_encryption_enabled** (void)

Is flash encryption currently enabled in hardware?

Flash encryption is enabled if the FLASH_CRYPT_CNT efuse has an odd number of bits set.

**Return** true if flash encryption is enabled.

## Implementation details

In order to perform some flash operations, we need to make sure both CPUs are not running any code from flash for the duration of the flash operation. In a single-core setup this is easy: we disable interrupts/scheduler and do the flash operation. In the dual-core setup this is slightly more complicated. We need to make sure that the other CPU doesn't run any code from flash.

When SPI flash API is called on CPU A (can be PRO or APP), we start spi_flash_op_block_func function on CPU B using esp_ipc_call API. This API wakes up high priority task on CPU B and tells it to execute given function, in this case spi_flash_op_block_func. This function disables cache on CPU B and signals that cache is disabled by setting s_flash_op_can_start flag. Then the task on CPU A disables cache as well, and proceeds to execute flash operation.

While flash operation is running, interrupts can still run on CPUs A and B. We assume that all interrupt code is placed into RAM. Once interrupt allocation API is added, we should add a flag to request interrupt to be disabled for the duration of flash operations.

Once flash operation is complete, function on CPU A sets another flag, s_flash_op_complete, to let the task on CPU B know that it can re-enable cache and release the CPU. Then the function on CPU A re-enables the cache on CPU A as well and returns control to the calling code.

Additionally, all API functions are protected with a mutex (s_flash_op_mutex).

In a single core environment (CONFIG_FREERTOS_UNICORE enabled), we simply disable both caches, no inter-CPU communication takes place.

# Non-volatile storage library

## Introduction

Non-volatile storage (NVS) library is designed to store key-value pairs in flash. This sections introduces some concepts used by NVS.

### Underlying storage

Currently NVS uses a portion of main flash memory through `spi_flash_{read|write|erase}` APIs. The library uses the first partition with `data` type and `nvs` subtype.

Future versions of this library may add other storage backends to keep data in another flash chip (SPI or I2C), RTC, FRAM, etc.

---

**Note:** if an NVS partition is truncated (for example, when the partition table layout is changed), its contents should be erased. ESP-IDF build system provides a `make erase_flash` target to erase all contents of the flash chip.

---

### Keys and values

NVS operates on key-value pairs. Keys are ASCII strings, maximum key length is currently 15 characters. Values can have one of the following types:

- integer types: `uint8_t`, `int8_t`, `uint16_t`, `int16_t`, `uint32_t`, `int32_t`, `uint64_t`, `int64_t`
- zero-terminated string
- variable length binary data (blob)

Additional types, such as `float` and `double` may be added later.

Keys are required to be unique. Writing a value for a key which already exists behaves as follows:

- if the new value is of the same type as old one, value is updated
- if the new value has different data type, an error is returned

Data type check is also performed when reading a value. An error is returned if data type of read operation doesn't match the data type of the value.

### Namespaces

To mitigate potential conflicts in key names between different components, NVS assigns each key-value pair to one of namespaces. Namespace names follow the same rules as key names, i.e. 15 character maximum length. Namespace name is specified in the `nvs_open` call. This call returns an opaque handle, which is used in subsequent calls to `nvs_read_*`, `nvs_write_*`, and `nvs_commit` functions. This way, handle is associated with a namespace, and key names will not collide with same names in other namespaces.

### Security, tampering, and robustness

NVS library doesn't implement tamper prevention measures. It is possible for anyone with physical access to the flash chip to alter, erase, or add key-value pairs.

NVS is compatible with the ESP32 flash encryption system, and it can store key-value pairs in an encrypted form. Some metadata, like page state and write/erase flags of individual entries can not be encrypted as they are represented as bits of flash memory for efficient access and manipulation. Flash encryption can prevent some forms of modification:

- replacing keys or values with arbitrary data
- changing data types of values

The following forms of modification are still possible when flash encryption is used:

- erasing a page completely, removing all key-value pairs which were stored in that page
- corrupting data in a page, which will cause the page to be erased automatically when such condition is detected
- rolling back the contents of flash memory to an earlier snapshot
- merging two snapshots of flash memory, rolling back some key-value pairs to an earlier state (although this is possible to mitigate with the current design — TODO)

The library does try to recover from conditions when flash memory is in an inconsistent state. In particular, one should be able to power off the device at any point and time and then power it back on. This should not result in loss of data, expect for the new key-value pair if it was being written at the moment of power off. The library should also be able to initialize properly with any random data present in flash memory.

## Internals

### Log of key-value pairs

NVS stores key-value pairs sequentially, with new key-value pairs being added at the end. When a value of any given key has to be updated, new key-value pair is added at the end of the log and old key-value pair is marked as erased.

### Pages and entries

NVS library uses two main entities in its operation: pages and entries. Page is a logical structure which stores a portion of the overall log. Logical page corresponds to one physical sector of flash memory. Pages which are in use have a *sequence number* associated with them. Sequence numbers impose an ordering on pages. Higher sequence numbers correspond to pages which were created later. Each page can be in one of the following states:

**Empty/uninitialized** Flash storage for the page is empty (all bytes are `0xff`). Page isn't used to store any data at this point and doesn't have a sequence number.

**Active** Flash storage is initialized, page header has been written to flash, page has a valid sequence number. Page has some empty entries and data can be written there. At most one page can be in this state at any given moment.

**Full** Flash storage is in a consistent state and is filled with key-value pairs. Writing new key-value pairs into this page is not possible. It is still possible to mark some key-value pairs as erased.

**Erasing** Non-erased key-value pairs are being moved into another page so that the current page can be erased. This is a transient state, i.e. page should never stay in this state when any API call returns. In case of a sudden power off, move-and-erase process will be completed upon next power on.

**Corrupted** Page header contains invalid data, and further parsing of page data was canceled. Any items previously written into this page will not be accessible. Corresponding flash sector will not be erased immediately, and will be kept along with sectors in *uninitialized* state for later use. This may be useful for debugging.

Mapping from flash sectors to logical pages doesn't have any particular order. Library will inspect sequence numbers of pages found in each flash sector and organize pages in a list based on these numbers.

```
+--------+     +--------+     +--------+     +--------+
| Page 1 |     | Page 2 |     | Page 3 |     | Page 4 |
| Full   +---> | Full   +---> | Active |     | Empty  |   <- states
| #11    |     | #12    |     | #14    |     |        |   <- sequence numbers
+---+----+     +----+---+     +----+---+     +---+----+
    |               |              |             |
    |               |              |             |
    |               |              |             |
+---v------+  +-----v----+  +------v---+  +------v---+
| Sector 3 |  | Sector 0 |  | Sector 2 |  | Sector 1 |    <- physical sectors
+----------+  +----------+  +----------+  +----------+
```

### Structure of a page

For now we assume that flash sector size is 4096 bytes and that ESP32 flash encryption hardware operates on 32-byte blocks. It is possible to introduce some settings configurable at compile-time (e.g. via menuconfig) to accommodate flash chips with different sector sizes (although it is not clear if other components in the system, e.g. SPI flash driver and SPI flash cache can support these other sizes).

Page consists of three parts: header, entry state bitmap, and entries themselves. To be compatible with ESP32 flash encryption, entry size is 32 bytes. For integer types, entry holds one key-value pair. For strings and blobs, an entry holds part of key-value pair (more on that in the entry structure description).

The following diagram illustrates page structure. Numbers in parentheses indicate size of each part in bytes.

```
+-----------+--------------+-------------+-----------+
| State (4) | Seq. no. (4) | Unused (20) | CRC32 (4) | Header (32)
+-----------+--------------+-------------+-----------+
|                Entry state bitmap (32)             |
+----------------------------------------------------+
|                       Entry 0 (32)                 |
+----------------------------------------------------+
|                       Entry 1 (32)                 |
+----------------------------------------------------+
/                                                    /
/                                                    /
+----------------------------------------------------+
|                       Entry 125 (32)               |
+----------------------------------------------------+
```

Page header and entry state bitmap are always written to flash unencrypted. Entries are encrypted if flash encryption feature of the ESP32 is used.

Page state values are defined in such a way that changing state is possible by writing 0 into some of the bits. Therefore it not necessary to erase the page to change page state, unless that is a change to *erased* state.

CRC32 value in header is calculated over the part which doesn't include state value (bytes 4 to 28). Unused part is currently filled with `0xff` bytes. Future versions of the library may store format version there.

The following sections describe structure of entry state bitmap and entry itself.

### Entry and entry state bitmap

Each entry can be in one of the following three states. Each state is represented with two bits in the entry state bitmap. Final four bits in the bitmap (256 - 2 * 126) are unused.

**Empty (2'b11)** Nothing is written into the specific entry yet. It is in an uninitialized state (all bytes `0xff`).

**Written (2'b10)** A key-value pair (or part of key-value pair which spans multiple entries) has been written into the entry.

**Erased (2'b00)** A key-value pair in this entry has been discarded. Contents of this entry will not be parsed anymore.

### Structure of entry

For values of primitive types (currently integers from 1 to 8 bytes long), entry holds one key-value pair. For string and blob types, entry holds part of the whole key-value pair. In case when a key-value pair spans multiple entries, all entries are stored in the same page.

```
+--------+----------+----------+---------+-----------+---------------+----------+
| NS (1) | Type (1) | Span (1) | Rsv (1) | CRC32 (4) |    Key (16)   | Data (8) |
+--------+----------+----------+---------+-----------+---------------+----------+


                                               +--------------------------------+
                         +->    Fixed length:  | Data (8)                       |
                         |                     +--------------------------------+
          Data format ---+
                         |                     +----------+---------+-----------+
                         +-> Variable length:  | Size (2) | Rsv (2) | CRC32 (4) |
                                               +----------+---------+-----------+
```

Individual fields in entry structure have the following meanings:

**NS** Namespace index for this entry. See section on namespaces implementation for explanation of this value.

**Type** One byte indicating data type of value. See `ItemType` enumeration in `nvs_types.h` for possible values.

**Span** Number of entries used by this key-value pair. For integer types, this is equal to 1. For strings and blobs this depends on value length.

**Rsv** Unused field, should be `0xff`.

**CRC32** Checksum calculated over all the bytes in this entry, except for the CRC32 field itself.

**Key** Zero-terminated ASCII string containing key name. Maximum string length is 15 bytes, excluding zero terminator.

**Data** For integer types, this field contains the value itself. If the value itself is shorter than 8 bytes it is padded to the right, with unused bytes filled with `0xff`. For string and blob values, these 8 bytes hold additional data about the value, described next:

**Size** (Only for strings and blobs.) Size, in bytes, of actual data. For strings, this includes zero terminator.

**CRC32** (Only for strings and blobs.) Checksum calculated over all bytes of data.

Variable length values (strings and blobs) are written into subsequent entries, 32 bytes per entry. *Span* field of the first entry indicates how many entries are used.

### Namespaces

As mentioned above, each key-value pair belongs to one of the namespaces. Namespaces identifiers (strings) are stored as keys of key-value pairs in namespace with index 0. Values corresponding to these keys are indexes of these namespaces.

```
+-------------------------------------------+
| NS=0 Type=uint8_t Key="wifi" Value=1      |   Entry describing namespace "wifi"
+-------------------------------------------+
| NS=1 Type=uint32_t Key="channel" Value=6  |   Key "channel" in namespace "wifi"
+-------------------------------------------+
| NS=0 Type=uint8_t Key="pwm" Value=2       |   Entry describing namespace "pwm"
+-------------------------------------------+
| NS=2 Type=uint16_t Key="channel" Value=20 |   Key "channel" in namespace "pwm"
+-------------------------------------------+
```

### Item hash list

To reduce the number of reads performed from flash memory, each member of Page class maintains a list of pairs: (item index; item hash). This list makes searches much quicker. Instead of iterating over all entries, reading them from flash one at a time, `Page::findItem` first performs search for item hash in the hash list. This gives the item index within the page, if such an item exists. Due to a hash collision it is possible that a different item will be found. This is handled by falling back to iteration over items in flash.

Each node in hash list contains a 24-bit hash and 8-bit item index. Hash is calculated based on item namespace and key name. CRC32 is used for calculation, result is truncated to 24 bits. To reduce overhead of storing 32-bit entries in a linked list, list is implemented as a doubly-linked list of arrays. Each array holds 29 entries, for the total size of 128 bytes, together with linked list pointers and 32-bit count field. Minimal amount of extra RAM useage per page is therefore 128 bytes, maximum is 640 bytes.

## Application Example

Two examples are provided in storage directory of ESP-IDF examples:

storage/nvs_rw_value

Demonstrates how to read and write a single integer value using NVS.

The value holds the number of ESP32 module restarts. Since it is written to NVS, the value is preserved between restarts.

Example also shows how to check if read / write operation was successful, or certain value is not initialized in NVS. Diagnostic is provided in plain text to help track program flow and capture any issues on the way.

storage/nvs_rw_blob

Demonstrates how to read and write a single integer value and a blob (binary large object) using NVS to preserve them between ESP32 module restarts.

- value - tracks number of ESP32 module soft and hard restarts.
- blob - contains a table with module run times. The table is read from NVS to dynamically allocated RAM. New run time is added to the table on each manually triggered soft restart and written back to NVS. Triggering is done by pulling down GPIO0.

Example also shows how to implement diagnostics if read / write operation was successful.

## API Reference

### Header Files

- nvs_flash/include/nvs_flash.h
- nvs_flash/include/nvs.h

### Macros

**ESP_ERR_NVS_BASE** 0x1100
Starting number of error codes

**ESP_ERR_NVS_NOT_INITIALIZED** (ESP_ERR_NVS_BASE + 0x01)
The storage driver is not initialized

**ESP_ERR_NVS_NOT_FOUND** (ESP_ERR_NVS_BASE + 0x02)
Id namespace doesn't exist yet and mode is NVS_READONLY

**ESP_ERR_NVS_TYPE_MISMATCH** (ESP_ERR_NVS_BASE + 0x03)
The type of set or get operation doesn't match the type of value stored in NVS

**ESP_ERR_NVS_READ_ONLY** (ESP_ERR_NVS_BASE + 0x04)
Storage handle was opened as read only

**ESP_ERR_NVS_NOT_ENOUGH_SPACE** (ESP_ERR_NVS_BASE + 0x05)
There is not enough space in the underlying storage to save the value

**ESP_ERR_NVS_INVALID_NAME** (ESP_ERR_NVS_BASE + 0x06)
Namespace name doesn't satisfy constraints

**ESP_ERR_NVS_INVALID_HANDLE** (ESP_ERR_NVS_BASE + 0x07)
Handle has been closed or is NULL

**ESP_ERR_NVS_REMOVE_FAILED** (ESP_ERR_NVS_BASE + 0x08)
The value wasn't updated because flash write operation has failed. The value was written however, and update will be finished after re-initialization of nvs, provided that flash operation doesn't fail again.

**ESP_ERR_NVS_KEY_TOO_LONG** (ESP_ERR_NVS_BASE + 0x09)
Key name is too long

**ESP_ERR_NVS_PAGE_FULL** (ESP_ERR_NVS_BASE + 0x0a)
Internal error; never returned by nvs_ API functions

**ESP_ERR_NVS_INVALID_STATE** (ESP_ERR_NVS_BASE + 0x0b)
NVS is in an inconsistent state due to a previous error. Call nvs_flash_init and nvs_open again, then retry.

**ESP_ERR_NVS_INVALID_LENGTH** (ESP_ERR_NVS_BASE + 0x0c)
String or blob length is not sufficient to store data

**ESP_ERR_NVS_NO_FREE_PAGES** (ESP_ERR_NVS_BASE + 0x0d)
NVS partition doesn't contain any empty pages. This may happen if NVS partition was truncated. Erase the whole partition and call nvs_flash_init again.

### Type Definitions

**typedef** uint32_t **nvs_handle**
Opaque pointer type representing non-volatile storage handle

### Enumerations

**enum nvs_open_mode**

Mode of opening the non-volatile storage.

*Values:*

**NVS_READONLY**

Read only

**NVS_READWRITE**

Read and write

### Functions

esp_err_t **nvs_flash_init** (void)

Initialize NVS flash storage with layout given in the partition table.

**Return**

- ESP_OK if storage was successfully initialized.
- ESP_ERR_NVS_NO_FREE_PAGES if the NVS storage contains no empty pages (which may happen if NVS partition was truncated)
- one of the error codes from the underlying flash storage driver

esp_err_t **nvs_open** (**const** char **name*, *nvs_open_mode* *open_mode*, *nvs_handle* **out_handle*)

Open non-volatile storage with a given namespace.

Multiple internal ESP-IDF and third party application modules can store their key-value pairs in the NVS module. In order to reduce possible conflicts on key names, each module can use its own namespace.

**Return**

- ESP_OK if storage handle was opened successfully
- ESP_ERR_NVS_NOT_INITIALIZED if the storage driver is not initialized
- ESP_ERR_NVS_NOT_FOUND id namespace doesn't exist yet and mode is NVS_READONLY
- ESP_ERR_NVS_INVALID_NAME if namespace name doesn't satisfy constraints
- other error codes from the underlying storage driver

**Parameters**

- `name`: Namespace name. Maximal length is determined by the underlying implementation, but is guaranteed to be at least 16 characters. Shouldn't be empty.
- `open_mode`: NVS_READWRITE or NVS_READONLY. If NVS_READONLY, will open a handle for reading only. All write requests will be rejected for this handle.
- `out_handle`: If successful (return code is zero), handle will be returned in this argument.

esp_err_t **nvs_set_i8** (*nvs_handle* *handle*, **const** char **key*, int8_t *value*)

set value for given key

This family of functions set value for the key, given its name. Note that actual storage will not be updated until nvs_commit function is called.

**Return**

- ESP_OK if value was set successfully
- ESP_ERR_NVS_INVALID_HANDLE if handle has been closed or is NULL
- ESP_ERR_NVS_READ_ONLY if storage handle was opened as read only
- ESP_ERR_NVS_INVALID_NAME if key name doesn't satisfy constraints
- ESP_ERR_NVS_NOT_ENOUGH_SPACE if there is not enough space in the underlying storage to save the value
- ESP_ERR_NVS_REMOVE_FAILED if the value wasn't updated because flash write operation has failed. The value was written however, and update will be finished after re-initialization of nvs, provided that flash operation doesn't fail again.

**Parameters**

- `handle`: Handle obtained from nvs_open function. Handles that were opened read only cannot be used.
- `key`: Key name. Maximal length is determined by the underlying implementation, but is guaranteed to be at least 16 characters. Shouldn't be empty.
- `value`: The value to set.

esp_err_t **nvs_set_u8** (*nvs_handle handle*, **const** char **key*, uint8_t *value*)

esp_err_t **nvs_set_i16** (*nvs_handle handle*, **const** char **key*, int16_t *value*)

esp_err_t **nvs_set_u16** (*nvs_handle handle*, **const** char **key*, uint16_t *value*)

esp_err_t **nvs_set_i32** (*nvs_handle handle*, **const** char **key*, int32_t *value*)

esp_err_t **nvs_set_u32** (*nvs_handle handle*, **const** char **key*, uint32_t *value*)

esp_err_t **nvs_set_i64** (*nvs_handle handle*, **const** char **key*, int64_t *value*)

esp_err_t **nvs_set_u64** (*nvs_handle handle*, **const** char **key*, uint64_t *value*)

esp_err_t **nvs_set_str** (*nvs_handle handle*, **const** char **key*, **const** char **value*)

esp_err_t **nvs_set_blob** (*nvs_handle handle*, **const** char **key*, **const** void **value*, size_t *length*)

set variable length binary value for given key

This family of functions set value for the key, given its name. Note that actual storage will not be updated until nvs_commit function is called.

**Return**

- ESP_OK if value was set successfully
- ESP_ERR_NVS_INVALID_HANDLE if handle has been closed or is NULL
- ESP_ERR_NVS_READ_ONLY if storage handle was opened as read only
- ESP_ERR_NVS_INVALID_NAME if key name doesn't satisfy constraints
- ESP_ERR_NVS_NOT_ENOUGH_SPACE if there is not enough space in the underlying storage to save the value
- ESP_ERR_NVS_REMOVE_FAILED if the value wasn't updated because flash write operation has failed. The value was written however, and update will be finished after re-initialization of nvs, provided that flash operation doesn't fail again.

**Parameters**

- `handle`: Handle obtained from nvs_open function. Handles that were opened read only cannot be used.
- `key`: Key name. Maximal length is determined by the underlying implementation, but is guaranteed to be at least 16 characters. Shouldn't be empty.
- `value`: The value to set.
- `length`: length of binary value to set, in bytes.

esp_err_t **nvs_get_i8** (*nvs_handle handle*, **const** char **key*, int8_t **out_value*)

get value for given key

These functions retrieve value for the key, given its name. If key does not exist, or the requested variable type doesn't match the type which was used when setting a value, an error is returned.

In case of any error, out_value is not modified.

All functions expect out_value to be a pointer to an already allocated variable of the given type.

```
// Example of using nvs_get_i32:
int32_t max_buffer_size = 4096; // default value
esp_err_t err = nvs_get_i32(my_handle, "max_buffer_size", &max_buffer_size);
assert(err == ESP_OK || err == ESP_ERR_NVS_NOT_FOUND);
// if ESP_ERR_NVS_NOT_FOUND was returned, max_buffer_size will still
// have its default value.
```

**Return**

- ESP_OK if the value was retrieved successfully
- ESP_ERR_NVS_NOT_FOUND if the requested key doesn't exist
- ESP_ERR_NVS_INVALID_HANDLE if handle has been closed or is NULL
- ESP_ERR_NVS_INVALID_NAME if key name doesn't satisfy constraints
- ESP_ERR_NVS_INVALID_LENGTH if length is not sufficient to store data

**Parameters**

- `handle`: Handle obtained from nvs_open function.
- `key`: Key name. Maximal length is determined by the underlying implementation, but is guaranteed to be at least 16 characters. Shouldn't be empty.
- `out_value`: Pointer to the output value. May be NULL for nvs_get_str and nvs_get_blob, in this case required length will be returned in length argument.

esp_err_t **nvs_get_u8** (*nvs_handle handle*, **const** char **key*, uint8_t **out_value*)

esp_err_t **nvs_get_i16** (*nvs_handle handle*, **const** char **key*, int16_t **out_value*)

esp_err_t **nvs_get_u16** (*nvs_handle handle*, **const** char **key*, uint16_t **out_value*)

esp_err_t **nvs_get_i32** (*nvs_handle handle*, **const** char **key*, int32_t **out_value*)

esp_err_t **nvs_get_u32** (*nvs_handle handle*, **const** char **key*, uint32_t **out_value*)

esp_err_t **nvs_get_i64** (*nvs_handle handle*, **const** char **key*, int64_t **out_value*)

esp_err_t **nvs_get_u64** (*nvs_handle handle*, **const** char **key*, uint64_t **out_value*) esp_err_t **nvs_get_str** (*nvs_handle handle*, **const** char **key*, char **out_value*, size_t **length*)

get value for given key

These functions retrieve value for the key, given its name. If key does not exist, or the requested variable type doesn't match the type which was used when setting a value, an error is returned.

In case of any error, out_value is not modified.

All functions expect out_value to be a pointer to an already allocated variable of the given type.

nvs_get_str and nvs_get_blob functions support WinAPI-style length queries. To get the size necessary to store the value, call nvs_get_str or nvs_get_blob with zero out_value and non-zero pointer to length. Variable pointed to by length argument will be set to the required length. For nvs_get_str, this length includes the zero terminator. When calling nvs_get_str and nvs_get_blob with non-zero out_value, length has to be non-zero and has to point to the length available in out_value. It is suggested that nvs_get/set_str is used for zero-terminated C strings, and nvs_get/set_blob used for arbitrary data structures.

```
// Example (without error checking) of using nvs_get_str to get a string into␣
↪dynamic array:
size_t required_size;
nvs_get_str(my_handle, "server_name", NULL, &required_size);
char* server_name = malloc(required_size);
nvs_get_str(my_handle, "server_name", server_name, &required_size);

// Example (without error checking) of using nvs_get_blob to get a binary data
into a static array:
uint8_t mac_addr[6];
size_t size = sizeof(mac_addr);
nvs_get_blob(my_handle, "dst_mac_addr", mac_addr, &size);
```

**Return**

- ESP_OK if the value was retrieved successfully
- ESP_ERR_NVS_NOT_FOUND if the requested key doesn't exist
- ESP_ERR_NVS_INVALID_HANDLE if handle has been closed or is NULL
- ESP_ERR_NVS_INVALID_NAME if key name doesn't satisfy constraints
- ESP_ERR_NVS_INVALID_LENGTH if length is not sufficient to store data

**Parameters**

- `handle`: Handle obtained from nvs_open function.
- `key`: Key name. Maximal length is determined by the underlying implementation, but is guaranteed to be at least 16 characters. Shouldn't be empty.
- `out_value`: Pointer to the output value. May be NULL for nvs_get_str and nvs_get_blob, in this case required length will be returned in length argument.
- `length`: A non-zero pointer to the variable holding the length of out_value. In case out_value a zero, will be set to the length required to hold the value. In case out_value is not zero, will be set to the actual length of the value written. For nvs_get_str this includes zero terminator.

esp_err_t **nvs_get_blob** (*nvs_handle handle*, **const** char **key*, void **out_value*, size_t **length*)

esp_err_t **nvs_erase_key** (*nvs_handle handle*, **const** char **key*)

Erase key-value pair with given key name.

Note that actual storage may not be updated until nvs_commit function is called.

**Return**

- ESP_OK if erase operation was successful
- ESP_ERR_NVS_INVALID_HANDLE if handle has been closed or is NULL
- ESP_ERR_NVS_READ_ONLY if handle was opened as read only
- ESP_ERR_NVS_NOT_FOUND if the requested key doesn't exist
- other error codes from the underlying storage driver

**Parameters**

- `handle`: Storage handle obtained with nvs_open. Handles that were opened read only cannot be used.
- `key`: Key name. Maximal length is determined by the underlying implementation, but is guaranteed to be at least 16 characters. Shouldn't be empty.

esp_err_t **nvs_erase_all**(*nvs_handle handle*)

Erase all key-value pairs in a namespace.

Note that actual storage may not be updated until nvs_commit function is called.

**Return**

- ESP_OK if erase operation was successful
- ESP_ERR_NVS_INVALID_HANDLE if handle has been closed or is NULL
- ESP_ERR_NVS_READ_ONLY if handle was opened as read only
- other error codes from the underlying storage driver

**Parameters**

- `handle`: Storage handle obtained with nvs_open. Handles that were opened read only cannot be used.

esp_err_t **nvs_commit**(*nvs_handle handle*)

Write any pending changes to non-volatile storage.

After setting any values, nvs_commit() must be called to ensure changes are written to non-volatile storage. Individual implementations may write to storage at other times, but this is not guaranteed.

**Return**

- ESP_OK if the changes have been written successfully
- ESP_ERR_NVS_INVALID_HANDLE if handle has been closed or is NULL
- other error codes from the underlying storage driver

**Parameters**

- `handle`: Storage handle obtained with nvs_open. Handles that were opened read only cannot be used.

void **nvs_close**(*nvs_handle handle*)

Close the storage handle and free any allocated resources.

This function should be called for each handle opened with nvs_open once the handle is not in use any more. Closing the handle may not automatically write the changes to nonvolatile storage. This has to be done explicitly using nvs_commit function. Once this function is called on a handle, the handle should no longer be used.

**Parameters**

- `handle`: Storage handle to close

# Virtual filesystem component

## Overview

Virtual filesystem (VFS) component provides a unified interface for drivers which can perform operations on file-like objects. This can be a real filesystems (FAT, SPIFFS, etc.), or device drivers which exposes file-like interface.

This component allows C library functions, such as fopen and fprintf, to work with FS drivers. At high level, each FS driver is associated with some path prefix. When one of C library functions needs to open a file, VFS component searches for the FS driver associated with the file's path, and forwards the call to that driver. VFS also forwards read, write, and other calls for the given file to the same FS driver.

For example, one can register a FAT filesystem driver with `/fat` prefix, and call `fopen("/fat/file.txt", "w")`. VFS component will then call `open` function of FAT driver and pass `/file.txt` argument to it (and appropriate mode flags). All subsequent calls to C library functions for the returned `FILE*` stream will also be forwarded to the FAT driver.

## FS registration

To register an FS driver, application needs to define in instance of esp_vfs_t structure and populate it with function pointers to FS APIs:

```
esp_vfs_t myfs = {
    .fd_offset = 0,
    .flags = ESP_VFS_FLAG_DEFAULT,
    .write = &myfs_write,
    .open = &myfs_open,
    .fstat = &myfs_fstat,
    .close = &myfs_close,
    .read = &myfs_read,
};

ESP_ERROR_CHECK(esp_vfs_register("/data", &myfs, NULL));
```

Depending on the way FS driver declares its APIs, either `read`, `write`, etc., or `read_p`, `write_p`, etc. should be used.

Case 1: API functions are declared without an extra context pointer (FS driver is a singleton):

```
size_t myfs_write(int fd, const void * data, size_t size);

// In definition of esp_vfs_t:
    .flags = ESP_VFS_FLAG_DEFAULT,
    .write = &myfs_write,
// ... other members initialized

// When registering FS, context pointer (third argument) is NULL:
ESP_ERROR_CHECK(esp_vfs_register("/data", &myfs, NULL));
```

Case 2: API functions are declared with an extra context pointer (FS driver supports multiple instances):

```
size_t myfs_write(myfs_t* fs, int fd, const void * data, size_t size);

// In definition of esp_vfs_t:
    .flags = ESP_VFS_FLAG_CONTEXT_PTR,
    .write_p = &myfs_write,
// ... other members initialized

// When registering FS, pass the FS context pointer into the third argument
// (hypothetical myfs_mount function is used for illustrative purposes)
myfs_t* myfs_inst1 = myfs_mount(partition1->offset, partition1->size);
ESP_ERROR_CHECK(esp_vfs_register("/data1", &myfs, myfs_inst1));

// Can register another instance:
myfs_t* myfs_inst2 = myfs_mount(partition2->offset, partition2->size);
ESP_ERROR_CHECK(esp_vfs_register("/data2", &myfs, myfs_inst2));
```

## Paths

Each registered FS has a path prefix associated with it. This prefix may be considered a "mount point" of this partition.

Registering mount points which have another mount point as a prefix is not supported and results in undefined behavior. For instance, the following is correct and supported:

- FS 1 on /data/fs1
- FS 2 on /data/fs2

This **will not work** as expected:

- FS 1 on /data
- FS 2 on /data/fs2

When opening files, FS driver will only be given relative path to files. For example:

- `myfs` driver is registered with `/data` as path prefix
- and application calls `fopen("/data/config.json", ...)`
- then VFS component will call `myfs_open("/config.json", ...)`.
- `myfs` driver will open `/config.json` file

VFS doesn't impose a limit on total file path length, but it does limit FS path prefix to `ESP_VFS_PATH_MAX` characters. Individual FS drivers may have their own filename length limitations.

## File descriptors

It is suggested that filesystem drivers should use small positive integers as file descriptors. VFS component assumes that `CONFIG_MAX_FD_BITS` bits (12 by default) are sufficient to represent a file descriptor.

If filesystem is configured with an option to offset all file descriptors by a constant value, such value should be passed to `fd_offset` field of `esp_vfs_t` structure. VFS component will then remove this offset when working with FDs of that specific FS, bringing them into the range of small positive integers.

While file descriptors returned by VFS component to newlib library are rarely seen by the application, the following details may be useful for debugging purposes. File descriptors returned by VFS component are composed of two parts: FS driver ID, and the actual file descriptor. Because newlib stores file descriptors as 16-bit integers, VFS component is also limited by 16 bits to store both parts.

Lower `CONFIG_MAX_FD_BITS` bits are used to store zero-based file descriptor. If FS driver has a non-zero `fd_offset` field, this `fd_offset` is subtracted FDs obtained from the FS `open` call, and the result is stored in the lower bits of the FD. Higher bits are used to save the index of FS in the internal table of registered filesystems.

When VFS component receives a call from newlib which has a file descriptor, this file descriptor is translated back to the FS-specific file descriptor. First, higher bits of FD are used to identify the FS. Then `fd_offset` field of the FS is added to the lower `CONFIG_MAX_FD_BITS` bits of the fd, and resulting FD is passed to the FS driver.

```
   FD as seen by newlib                                    FD as seen by FS driver
                                                  +-----+
+-------+----------------+                        |     |    +------------------------+
| FS id | Zero--based FD |     +----------------> sum +---->                        |
+---+---+------+---------+     |                  |     |    +------------------------+
    |          |               |                  +--^--+
    |          +---------------+                     |
    |                                                |
    |       +-------------+                          |
    |       | Table of    |                          |
    |       | registered  |                          |
    |       | filesystems |                          |
    |       +-------------+    +-------------+       |
    +------->  entry      +----> esp_vfs_t   |       |
    index   +-------------+    | structure   |       |
            |             |    |             |       |
            |             |    | + fd_offset +-------+
            +-------------+    |             |
                               +-------------+
```

## Standard IO streams (stdin, stdout, stderr)

If "UART for console output" menuconfig option is not set to "None", then `stdin`, `stdout`, and `stderr` are configured to read from, and write to, a UART. It is possible to use UART0 or UART1 for standard IO. By default, UART0 is used, with 115200 baud rate, TX pin is GPIO1 and RX pin is GPIO3. These parameters can be changed in menuconfig.

Writing to `stdout` or `stderr` will send characters to the UART transmit FIFO. Reading from `stdin` will retrieve characters from the UART receive FIFO.

Note that while writing to `stdout` or `stderr` will block until all characters are put into the FIFO, reading from `stdin` is non-blocking. The function which reads from UART will get all the characters present in the FIFO (if any), and return. I.e. doing `fscanf("%d\n", &var);` may not have desired results. This is a temporary limitation which will be removed once `fcntl` is added to the VFS interface.

### Standard streams and FreeRTOS tasks

`FILE` objects for `stdin`, `stdout`, and `stderr` are shared between all FreeRTOS tasks, but the pointers to these objects are are stored in per-task `struct _reent`. The following code:

```
fprintf(stderr, "42\n");
```

actually is translated to to this (by the preprocessor):

fprintf(__getreent()->_stderr, "42n");

where the `__getreent()` function returns a per-task pointer to `struct _reent` (newlib/include/sys/reent.h#L370-L417>). This structure is allocated on the TCB of each task. When a task is initialized, `_stdin`, `_stdout` and `_stderr` members of `struct _reent` are set to the values of `_stdin`, `_stdout` and `_stderr` of `_GLOBAL_REENT` (i.e. the structure which is used before FreeRTOS is started).

Such a design has the following consequences:

- It is possible to set `stdin`, `stdout`, and `stderr` for any given task without affecting other tasks, e.g. by doing `stdin = fopen("/dev/uart/1", "r")`.
- Closing default `stdin`, `stdout`, or `stderr` using `fclose` will close the `FILE` stream object — this will affect all other tasks.
- To change the default `stdin`, `stdout`, `stderr` streams for new tasks, modify `_GLOBAL_REENT->_stdin` (`_stdout`, `_stderr`) before creating the task.

## Application Example

Instructions

## API Reference

### Header Files

- vfs/include/esp_vfs.h
- vfs/include/esp_vfs_dev.h

### Macros

**`ESP_VFS_PATH_MAX`** 15
Maximum length of path prefix (not including zero terminator)

**`ESP_VFS_FLAG_DEFAULT`** 0
Default value of flags member in *esp_vfs_t* structure.

**`ESP_VFS_FLAG_CONTEXT_PTR`** 1
Flag which indicates that FS needs extra context pointer in syscalls.

### Structures

**struct `esp_vfs_t`**
VFS definition structure.

This structure should be filled with pointers to corresponding FS driver functions.

If the FS implementation has an option to use certain offset for all file descriptors, this value should be passed into fd_offset field. Otherwise VFS component will translate all FDs to start at zero offset.

Some FS implementations expect some state (e.g. pointer to some structure) to be passed in as a first argument. For these implementations, populate the members of this structure which have _p suffix, set flags member to ESP_VFS_FLAG_CONTEXT_PTR and provide the context pointer to esp_vfs_register function. If the implementation doesn't use this extra argument, populate the members without _p suffix and set flags member to ESP_VFS_FLAG_DEFAULT.

If the FS driver doesn't provide some of the functions, set corresponding members to NULL.

### Public Members

int **fd_offset**
file descriptor offset, determined by the FS driver

int **flags**
ESP_VFS_FLAG_CONTEXT_PTR or ESP_VFS_FLAG_DEFAULT

## Functions

esp_err_t **esp_vfs_register** (**const** char **base_path*, **const** *esp_vfs_t* **vfs*, void **ctx*)
Register a virtual filesystem for given path prefix.

**Return** ESP_OK if successful, ESP_ERR_NO_MEM if too many VFSes are registered.

**Parameters**

- `base_path`: file path prefix associated with the filesystem. Must be a zero-terminated C string, up to ESP_VFS_PATH_MAX characters long, and at least 2 characters long. Name must start with a "/" and must not end with "/". For example, "/data" or "/dev/spi" are valid. These VFSes would then be called to handle file paths such as "/data/myfile.txt" or "/dev/spi/0".
- `vfs`: Pointer to *esp_vfs_t*, a structure which maps syscalls to the filesystem driver functions. VFS component doesn't assume ownership of this pointer.
- `ctx`: If vfs->flags has ESP_VFS_FLAG_CONTEXT_PTR set, a pointer which should be passed to VFS functions. Otherwise, NULL.

esp_err_t **esp_vfs_unregister** (**const** char **base_path*)
Unregister a virtual filesystem for given path prefix

**Return** ESP_OK if successful, ESP_ERR_INVALID_STATE if VFS for given prefix hasn't been registered

**Parameters**

- `base_path`: file prefix previously used in esp_vfs_register call

ssize_t **esp_vfs_write** (**struct** _reent **r*, int *fd*, **const** void **data*, size_t *size*)
These functions are to be used in newlib syscall table. They will be called by newlib when it needs to use any of the syscalls.

off_t **esp_vfs_lseek** (**struct** _reent **r*, int *fd*, off_t *size*, int *mode*)

ssize_t **esp_vfs_read** (**struct** _reent **r*, int *fd*, void **dst*, size_t *size*)

int **esp_vfs_open** (**struct** _reent **r*, **const** char **path*, int *flags*, int *mode*)

int **esp_vfs_close** (**struct** _reent **r*, int *fd*)

int **esp_vfs_fstat** (**struct** _reent **r*, int *fd*, **struct** stat **st*)

int **esp_vfs_stat** (**struct** _reent **r*, **const** char **path*, **struct** stat **st*)

int **esp_vfs_link** (**struct** _reent **r*, **const** char **n1*, **const** char **n2*)

int **esp_vfs_unlink** (**struct** _reent **r*, **const** char **path*)

int **esp_vfs_rename** (**struct** _reent **r*, **const** char **src*, **const** char **dst*)

void **esp_vfs_dev_uart_register**()
add /dev/uart virtual filesystem driver

This function is called from startup code to enable serial output

## FAT Filesystem Support

ESP-IDF uses FatFs library to work with FAT filesystems. FatFs library resides in `fatfs` component. Although it can be used directly, many of its features can be accessed via VFS using C standard library and POSIX APIs.

Additionally, FatFs has been modified to support run-time pluggable disk IO layer. This allows mapping of FatFs drives to physical disks at run-time.

### Using FatFs with VFS

`esp_vfs_fat.h` header file defines functions to connect FatFs with VFS. `esp_vfs_fat_register` function allocates a `FATFS` structure, and registers a given path prefix in VFS. Subsequent operations on files starting with this prefix are forwarded to FatFs APIs. `esp_vfs_fat_unregister_path` function deletes the registration with VFS, and frees the `FATFS` structure.

Most applications will use the following flow when working with `esp_vfs_fat_` functions:

1. Call `esp_vfs_fat_register`, specifying path prefix where the filesystem has to be mounted (e.g. `"/sdcard"`), FatFs drive number, and a variable which will receive a pointer to `FATFS` structure.
2. Call `ff_diskio_register` function to register disk IO driver for the drive number used in step 1.
3. Call `f_mount` function (and optionally `f_fdisk`, `f_mkfs`) to mount the filesystem using the same drive number which was passed to `esp_vfs_fat_register`. See FatFs documentation for more details.
4. Call POSIX and C standard library functions to open, read, write, erase, copy files, etc. Use paths starting with the prefix passed to `esp_vfs_register` (such as `"/sdcard/hello.txt"`).
5. Optionally, call FatFs library functions directly. Use paths without a VFS prefix in this case (`"/hello.txt"`).
6. Close all open files.
7. Call `f_mount` function for the same drive number, with NULL `FATFS*` argument, to unmount the filesystem.
8. Call `ff_diskio_register` with NULL `ff_diskio_impl_t*` argument and the same drive number.
9. Call `esp_vfs_fat_unregister_path` with the path where the file system is mounted to remove FatFs from VFS, and free the `FATFS` structure allocated on step 1.

Convenience functions, `esp_vfs_fat_sdmmc_mount` and `esp_vfs_fat_sdmmc_unmount`, which wrap these steps and also handle SD card initialization, are described in the next section.

esp_err_t **esp_vfs_fat_register**(**const** char **base_path*, **const** char **fat_drive*, size_t *max_files*, FATFS ***out_fs*)
Register FATFS with VFS component.

This function registers given FAT drive in VFS, at the specified base path. If only one drive is used, fat_drive argument can be an empty string. Refer to FATFS library documentation on how to specify FAT drive. This function also allocates FATFS structure which should be used for f_mount call.

**Note** This function doesn't mount the drive into FATFS, it just connects POSIX and C standard library IO function with FATFS. You need to mount desired drive into FATFS separately.

**Return**

- ESP_OK on success
- ESP_ERR_INVALID_STATE if esp_vfs_fat_register was already called
- ESP_ERR_NO_MEM if not enough memory or too many VFSes already registered

**Parameters**

- `base_path`: path prefix where FATFS should be registered
- `fat_drive`: FATFS drive specification; if only one drive is used, can be an empty string
- `max_files`: maximum number of files which can be open at the same time
- `out_fs`: pointer to FATFS structure which can be used for FATFS f_mount call is returned via this argument.

esp_err_t **esp_vfs_fat_unregister_path**(**const** char **base_path*)

Un-register FATFS from VFS.

**Note** FATFS structure returned by esp_vfs_fat_register is destroyed after this call. Make sure to call f_mount function to unmount it before calling esp_vfs_fat_unregister_ctx. Difference between this function and the one above is that this one will release the correct drive, while the one above will release the last registered one

**Return**

- ESP_OK on success
- ESP_ERR_INVALID_STATE if FATFS is not registered in VFS

**Parameters**

- `base_path`: path prefix where FATFS is registered. This is the same used when esp_vfs_fat_register was called

## Using FatFs with VFS and SD cards

`esp_vfs_fat.h` header file also provides a convenience function to perform steps 1–3 and 7–9, and also handle SD card initialization: `esp_vfs_fat_sdmmc_mount`. This function does only limited error handling. Developers are encouraged to look at its source code and incorporate more advanced versions into production applications. `esp_vfs_fat_sdmmc_unmount` function unmounts the filesystem and releases resources acquired by `esp_vfs_fat_sdmmc_mount`.

esp_err_t **esp_vfs_fat_sdmmc_mount**(**const** char **base_path*, **const** *sdmmc_host_t* **host_config*, **const** *sdmmc_slot_config_t* **slot_config*, **const** *esp_vfs_fat_sdmmc_mount_config_t* **mount_config*, *sdmmc_card_t* ***out_card*)

Convenience function to get FAT filesystem on SD card registered in VFS.

This is an all-in-one function which does the following:

- initializes SD/MMC peripheral with configuration in host_config
- initializes SD/MMC card with configuration in slot_config
- mounts FAT partition on SD/MMC card using FATFS library, with configuration in mount_config
- registers FATFS library with VFS, with prefix given by base_prefix variable

This function is intended to make example code more compact. For real world applications, developers should implement the logic of probing SD card, locating and mounting partition, and registering FATFS in VFS, with proper error checking and handling of exceptional conditions.

**Return**

- ESP_OK on success
- ESP_ERR_INVALID_STATE if esp_vfs_fat_sdmmc_mount was already called
- ESP_ERR_NO_MEM if memory can not be allocated
- ESP_FAIL if partition can not be mounted
- other error codes from SDMMC host, SDMMC protocol, or FATFS drivers

**Parameters**

- `base_path`: path where partition should be registered (e.g. "/sdcard")
- `host_config`: pointer to structure describing SDMMC host
- `slot_config`: pointer to structure with extra SDMMC slot configuration
- `mount_config`: pointer to structure with extra parameters for mounting FATFS
- `out_card`: if not NULL, pointer to the card information structure will be returned via this argument

**struct esp_vfs_fat_sdmmc_mount_config_t**

Configuration arguments for esp_vfs_fat_sdmmc_mount function.

### Public Members

bool **format_if_mount_failed**

If FAT partition can not be mounted, and this parameter is true, create partition table and format the filesystem.

int **max_files**

Max number of open files.

esp_err_t **esp_vfs_fat_sdmmc_unmount** ()

Unmount FAT filesystem and release resources acquired using esp_vfs_fat_sdmmc_mount.

**Return**

- ESP_OK on success
- ESP_ERR_INVALID_STATE if esp_vfs_fat_sdmmc_mount hasn't been called

## FatFS disk IO layer

FatFs has been extended with an API to register disk IO driver at runtime.

Implementation of disk IO functions for SD/MMC cards is provided. It can be registered for the given FatFs drive number using `ff_diskio_register_sdmmc` function.

void **ff_diskio_register** (BYTE *pdrv*, **const** *ff_diskio_impl_t* **discio_impl*)

Register or unregister diskio driver for given drive number.

When FATFS library calls one of disk_xxx functions for driver number pdrv, corresponding function in discio_impl for given pdrv will be called.

**Parameters**

- `pdrv`: drive number

- `discio_impl`: pointer to *ff_diskio_impl_t* structure with diskio functions or NULL to unregister and free previously registered drive

**struct ff_diskio_impl_t**

Structure of pointers to disk IO driver functions.

See FatFs documentation for details about these functions

### Public Members

DSTATUS (***init**) (BYTE pdrv)
disk initialization function

DSTATUS (***status**) (BYTE pdrv)
disk status check function

DRESULT (***read**) (BYTE pdrv, BYTE *buff, DWORD sector, UINT count)
sector read function

DRESULT (***write**) (BYTE pdrv, **const** BYTE *buff, DWORD sector, UINT count)
sector write function

DRESULT (***ioctl**) (BYTE pdrv, BYTE cmd, void *buff)
function to get info about disk and do some misc operations

void **ff_diskio_register_sdmmc** (BYTE *pdrv*, *sdmmc_card_t* **card*)
Register SD/MMC diskio driver

**Parameters**

- `pdrv`: drive number
- `card`: pointer to *sdmmc_card_t* structure describing a card; card should be initialized before calling f_mount.

Example code for this API section is provided in storage directory of ESP-IDF examples.

CHAPTER 23

# Protocols API

## mDNS Service

### Overview

mDNS is a multicast UDP service that is used to provide local network service and host discovery.

mDNS is installed by default on most operating systems or is available as separate package. On `Mac OS` it is installed by default and is called `Bonjour`. Apple releases an installer for `Windows` that can be found on Apple's support page. On `Linux`, mDNS is provided by avahi and is usually installed by default.

#### mDNS Properties

- `hostname`: the hostname that the device will respond to. If not set, the `hostname` will be read from the interface. Example: `my-esp32` will resolve to `my-esp32.local`
- `default_instance`: friendly name for your device, like `Jhon's ESP32 Thing`. If not set, `hostname` will be used.

Example method to start mDNS for the STA interface and set `hostname` and `default_instance`:

```
mdns_server_t * mdns = NULL;

void start_mdns_service()
{
    //initialize mDNS service on STA interface
    esp_err_t err = mdns_init(TCPIP_ADAPTER_IF_STA, &mdns);
    if (err) {
        printf("MDNS Init failed: %d\n", err);
        return;
    }

    //set hostname
    mdns_set_hostname(mdns, "my-esp32");
```

```
    //set default instance
    mdns_set_instance(mdns, "Jhon's ESP32 Thing");
}
```

### mDNS Services

mDNS can advertise information about network services that your device offers. Each service is defined by a few properties.

- `service`: (required) service type, prepended with underscore. Some common types can be found here.
- `proto`: (required) protocol that the service runs on, prepended with underscore. Example: `_tcp` or `_udp`
- `port`: (required) network port that the service runs on
- `instance`: friendly name for your service, like `Jhon's ESP32 Web Server`. If not defined, `default_instance` will be used.
- `txt`: `var=val` array of strings, used to define properties for your service

Example method to add a few services and different properties:

```
void add_mdns_services()
{
    //add our services
    mdns_service_add(mdns, "_http", "_tcp", 80);
    mdns_service_add(mdns, "_arduino", "_tcp", 3232);
    mdns_service_add(mdns, "_myservice", "_udp", 1234);

    //NOTE: services must be added before their properties can be set
    //use custom instance for the web server
    mdns_service_instance_set(mdns, "_http", "_tcp", "Jhon's ESP32 Web Server
↪");

    const char * arduTxtData[4] = {
            "board=esp32",
            "tcp_check=no",
            "ssh_upload=no",
            "auth_upload=no"
    };
    //set txt data for service (will free and replace current data)
    mdns_service_txt_set(mdns, "_arduino", "_tcp", 4, arduTxtData);

    //change service port
    mdns_service_port_set(mdns, "_myservice", "_udp", 4321);
}
```

### mDNS Query

**mDNS provides methods for browsing for services and resolving host's IP/IPv6 addresses.** Results are returned as a linked list of `mdns_result_t` objects. If the result is from host query, it will contain only `addr` and `addrv6` if found. Service queries will populate all fields in a result that were found.

Example method to resolve host IPs:

```
void resolve_mdns_host(const char * hostname)
{
```

```
    printf("mDNS Host Lookup: %s.local\n", hostname);
    //run search for 1000 ms
    if (mdns_query(mdns, hostname, NULL, 1000)) {
        //results were found
        const mdns_result_t * results = mdns_result_get(mdns, 0);
        //itterate through all results
        size_t i = 1;
        while(results) {
            //print result information
            printf("  %u: IP:" IPSTR ", IPv6:" IPV6STR "\n", i++
                IP2STR(&results->addr), IPV62STR(results->addrv6));
            //load next result. Will be NULL if this was the last one
            results = results->next;
        }
        //free the results from memory
        mdns_result_free(mdns);
    } else {
        //host was not found
        printf("  Host Not Found\n");
    }
}
```

Example method to resolve local services:

```
void find_mdns_service(const char * service, const char * proto)
{
    printf("mDNS Service Lookup: %s.%s\n", service, proto);
    //run search for 1000 ms
    if (mdns_query(mdns, service, proto, 1000)) {
        //results were found
        const mdns_result_t * results = mdns_result_get(mdns, 0);
        //itterate through all results
        size_t i = 1;
        while(results) {
            //print result information
            printf("  %u: hostname:%s, instance:\"%s\", IP:" IPSTR ", IPv6:"
↪IPV6STR ", port:%u, txt:%s\n", i++,
                (results->host)?results->host:"NULL", (results->instance)?
↪results->instance:"NULL",
                IP2STR(&results->addr), IPV62STR(results->addrv6),
                results->port, (results->txt)?results->txt:"\r");
            //load next result. Will be NULL if this was the last one
            results = results->next;
        }
        //free the results from memory
        mdns_result_free(mdns);
    } else {
        //service was not found
        printf("  Service Not Found\n");
    }
}
```

Example of using the methods above:

```
void my_app_some_method(){
    //search for esp32-mdns.local
    resolve_mdns_host("esp32-mdns");
```

```
    //search for HTTP servers
    find_mdns_service("_http", "_tcp");
    //or file servers
    find_mdns_service("_smb", "_tcp"); //windows sharing
    find_mdns_service("_afpovertcp", "_tcp"); //apple sharing
    find_mdns_service("_nfs", "_tcp"); //NFS server
    find_mdns_service("_ftp", "_tcp"); //FTP server
    //or networked printer
    find_mdns_service("_printer", "_tcp");
    find_mdns_service("_ipp", "_tcp");
}
```

## Application Example

mDNS server/scanner example: protocols/mdns.

## API Reference

### Header Files

- mdns/include/mdns.h

### Macros

### Type Definitions

**typedef struct** mdns_server_s **`mdns_server_t`**

**typedef struct** *mdns_result_s* **`mdns_result_t`**
mDNS query result structure

### Enumerations

### Structures

**struct `mdns_result_s`**
mDNS query result structure

#### Public Members

**const** char ***`host`**
hostname

**const** char ***`instance`**
instance

**const** char ***`txt`**
txt data

uint16_t **`priority`**
service priority

uint16_t **weight**
service weight

uint16_t **port**
service port

**struct** ip4_addr **addr**
ip4 address

**struct** ip6_addr **addrv6**
ip6 address

**const struct** *mdns_result_s* ***next**
next result, or NULL for the last result in the list

## Functions

esp_err_t **mdns_init** (tcpip_adapter_if_t *tcpip_if*, *mdns_server_t* ***server*)
Initialize mDNS on given interface.

**Return**

- ESP_OK on success
- ESP_ERR_INVALID_ARG when bad tcpip_if is given
- ESP_ERR_INVALID_STATE when the network returned error
- ESP_ERR_NO_MEM on memory error
- ESP_ERR_WIFI_NOT_INIT when WiFi is not initialized by eps_wifi_init

**Parameters**

- `tcpip_if`: Interface that the server will listen on
- `server`: Server pointer to populate on success

void **mdns_free** (*mdns_server_t* **server*)
Stop and free mDNS server.

**Parameters**

- `server`: mDNS Server to free

esp_err_t **mdns_set_hostname** (*mdns_server_t* **server*, **const** char **hostname*)
Set the hostname for mDNS server.

**Return**

- ESP_OK success
- ESP_ERR_INVALID_ARG Parameter error
- ESP_ERR_NO_MEM memory error

**Parameters**

- `server`: mDNS Server
- `hostname`: Hostname to set

esp_err_t **mdns_set_instance** (*mdns_server_t* **server*, **const** char **instance*)

Set the default instance name for mDNS server.

**Return**

- ESP_OK success
- ESP_ERR_INVALID_ARG Parameter error
- ESP_ERR_NO_MEM memory error

**Parameters**

- `server`: mDNS Server
- `instance`: Instance name to set

esp_err_t **mdns_service_add** (*mdns_server_t* **server*, **const** char **service*, **const** char **proto*, uint16_t *port*)

Add service to mDNS server.

**Return**

- ESP_OK success
- ESP_ERR_INVALID_ARG Parameter error
- ESP_ERR_NO_MEM memory error

**Parameters**

- `server`: mDNS Server
- `service`: service type (_http, _ftp, etc)
- `proto`: service protocol (_tcp, _udp)
- `port`: service port

esp_err_t **mdns_service_remove** (*mdns_server_t* **server*, **const** char **service*, **const** char **proto*)

Remove service from mDNS server.

**Return**

- ESP_OK success
- ESP_ERR_INVALID_ARG Parameter error
- ESP_ERR_NOT_FOUND Service not found
- ESP_FAIL unknown error

**Parameters**

- `server`: mDNS Server
- `service`: service type (_http, _ftp, etc)
- `proto`: service protocol (_tcp, _udp)

esp_err_t **mdns_service_instance_set** (*mdns_server_t* **server*, **const** char **service*, **const** char **proto*, **const** char **instance*)

Set instance name for service.

**Return**

- ESP_OK success
- ESP_ERR_INVALID_ARG Parameter error
- ESP_ERR_NOT_FOUND Service not found
- ESP_ERR_NO_MEM memory error

**Parameters**

- `server`: mDNS Server
- `service`: service type (_http, _ftp, etc)
- `proto`: service protocol (_tcp, _udp)
- `instance`: instance name to set

esp_err_t **mdns_service_txt_set** (*mdns_server_t* **server*, **const** char **service*, **const** char **proto*, uint8_t *num_items*, **const** char ***txt*)

Set TXT data for service.

**Return**

- ESP_OK success
- ESP_ERR_INVALID_ARG Parameter error
- ESP_ERR_NOT_FOUND Service not found
- ESP_ERR_NO_MEM memory error

**Parameters**

- `server`: mDNS Server
- `service`: service type (_http, _ftp, etc)
- `proto`: service protocol (_tcp, _udp)
- `num_items`: number of items in TXT data
- `txt`: string array of TXT data (eg. {"var=val","other=2"})

esp_err_t **mdns_service_port_set** (*mdns_server_t* **server*, **const** char **service*, **const** char **proto*, uint16_t *port*)

Set service port.

**Return**

- ESP_OK success
- ESP_ERR_INVALID_ARG Parameter error
- ESP_ERR_NOT_FOUND Service not found

**Parameters**

- `server`: mDNS Server
- `service`: service type (_http, _ftp, etc)
- `proto`: service protocol (_tcp, _udp)
- `port`: service port

esp_err_t **mdns_service_remove_all** (*mdns_server_t *server*)

Remove and free all services from mDNS server.

**Return**

- ESP_OK success
- ESP_ERR_INVALID_ARG Parameter error

**Parameters**

- `server`: mDNS Server

size_t **mdns_query** (*mdns_server_t *server*, **const** char **service*, **const** char **proto*, uint32_t *timeout*)

Query mDNS for host or service.

**Return** the number of results found

**Parameters**

- `server`: mDNS Server
- `service`: service type or host name
- `proto`: service protocol or NULL if searching for host
- `timeout`: time to wait for answers. If 0, mdns_query_end MUST be called to end the search

size_t **mdns_query_end** (*mdns_server_t *server*)

Stop mDNS Query started with timeout = 0.

**Return** the number of results found

**Parameters**

- `server`: mDNS Server

size_t **mdns_result_get_count** (*mdns_server_t *server*)

get the number of results currently in memoty

**Return** the number of results

**Parameters**

- `server`: mDNS Server

**const** *mdns_result_t* ***mdns_result_get** (*mdns_server_t *server*, size_t *num*)

Get mDNS Search result with given index.

**Return** the result or NULL if error

**Parameters**

- `server`: mDNS Server
- `num`: the index of the result

esp_err_t **mdns_result_free** (*mdns_server_t *server*)

Remove and free all search results from mDNS server.

**Return**

- ESP_OK success
- ESP_ERR_INVALID_ARG Parameter error

**Parameters**

- `server`: mDNS Server

Example code for this API section is provided in protocols directory of ESP-IDF examples.

CHAPTER 24

# ESP32 Modules and Boards

Espressif designed and manufactured several development modules and boards to help users evaluate functionality of ESP32 chip. Development boards, depending on intended functionality, have exposed GPIO pins headers, provide USB programming interface, JTAG interface as well as peripherals like touch pads, LCD screen, SD card slot, camera module header, etc.

For details please refer to documentation below, provided together with description of particular boards.

## ESP-WROOM-32

The smallest module intended for installation in final products. Can be also used for evaluation after adding extra components like programming interface, boot strapping resistors and break out headers.

- Schematic (PDF)
- Datasheet (PDF)
- ESP32 Module Reference Design (ZIP) containing OrCAD schematic, PCB layout, gerbers and BOM

## ESP32 Core Board V2 / ESP32 DevKitC

Small and convenient development board with break out pin headers and minimum additional components. Includes USB to serial programming interface, that also provides power supply for the board. Has press buttons to reset the board and put it in upload mode.

- Schematic (PDF)
- ESP32 Development Board Reference Design (ZIP) containing OrCAD schematic, PCB layout, gerbers and BOM
- ESP32-DevKitC Getting Started Guide (PDF)
- CP210x USB to UART Bridge VCP Drivers

## ESP32 Demo Board V2

One of first feature rich evaluation boards that contains several pin headers, dip switches, USB to serial programming interface, reset and boot mode press buttons, power switch, 10 touch pads and separate header to connect LCD screen.

- Schematic (PDF)
- FTDI Virtual COM Port Drivers Note: Drivers install automatically on most of OS / there is no need to install them manually

## ESP32 WROVER KIT V1 / ESP32 DevKitJ V1

Development board that has dual port USB to serial converter for programming and JTAG interface for debugging. Power supply is provided by USB interface or from standard 5 mm power supply jack. Power supply selection is done with a jumper and may be put on/off with a separate switch. Has SD card slot, 3.2" SPI LCD screen and dedicated header to connect a camera. Provides RGB diode for diagnostics. Also includes 32.768KHz XTAL for internal RTC to operate it in low power modes.

- Schematic (PDF)
- FTDI Virtual COM Port Drivers Note: Drivers install automatically on most of OS / there is no need to install them manually
- JTAG Debugging for ESP32 (PDF)

## ESP32 WROVER KIT V2

This is an updated version of ESP32 DevKitJ V1 described above with design improvements identified when DevKitJ was in use. Both V1 and V2 versions of this board are ready to accommodate existing ESP-WROOM-32 or the new ESP32-WROVER module.

- Schematic (PDF)
- ESP-WROVER-KIT Getting Started Guide (PDF)
- FTDI Virtual COM Port Drivers Note: Drivers install automatically on most of OS / there is no need to install them manually
- JTAG Debugging for ESP32 (PDF)

CHAPTER 25

# Contributions Guide

We welcome contributions to the esp-idf project!

## How to Contribute

Contributions to esp-idf - fixing bugs, adding features, adding documentation - are welcome. We accept contributions via Github Pull Requests.

## Before Contributing

Before sending us a Pull Request, please consider this list of points:

- Is the contribution entirely your own work, or already licensed under an Apache License 2.0 compatible Open Source License? If not then we unfortunately cannot accept it.
- Does any new code conform to the esp-idf *Style Guide*?
- Does the code documentation follow requirements in *Documenting Code*?
- Is the code adequately commented for people to understand how it is structured?
- Is there documentation or examples that go with code contributions? There are additional suggestions for writing good examples in examples readme.
- Are comments and documentation written in clear English, with no spelling or grammar errors?
- If the contribution contains multiple commits, are they grouped together into logical changes (one major change per pull request)? Are any commits with names like "fixed typo" squashed into previous commits?
- If you're unsure about any of these points, please open the Pull Request anyhow and then ask us for feedback.

## Pull Request Process

After you open the Pull Request, there will probably be some discussion in the comments field of the request itself.

Once the Pull Request is ready to merge, it will first be merged into our internal git system for in-house automated testing.

If this process passes, it will be merged onto the public github repository.

## Legal Part

Before a contribution can be accepted, you will need to sign our *Contributor Agreement*. You will be prompted for this automatically as part of the Pull Request process.

CHAPTER 26

# Espressif IoT Development Framework Style Guide

## About this guide

Purpose of this style guide is to encourage use of common coding practices within the ESP-IDF.

Style guide is a set of rules which are aimed to help create readable, maintainable, and robust code. By writing code which looks the same way across the code base we help others read and comprehend the code. By using same conventions for spaces and newlines we reduce chances that future changes will produce huge unreadable diffs. By following common patterns for module structure and by using language features consistently we help others understand code behavior.

We try to keep rules simple enough, which means that they can not cover all potential cases. In some cases one has to bend these simple rules to achieve readability, maintainability, or robustness.

When doing modifications to third-party code used in ESP-IDF, follow the way that particular project is written. That will help propose useful changes for merging into upstream project.

## C code formatting

### Indentation

Use 4 spaces for each indentation level. Don't use tabs for indentation. Configure the editor to emit 4 spaces each time you press tab key.

### Vertical space

Place one empty line between functions. Don't begin or end a function with an empty line.

```
void function1()
{
    do_one_thing();
```

```
    do_another_thing();
                                // INCORRECT, don't place empty line here
}
                                // place empty line here
void function2()
{
                                // INCORRECT, don't use an empty line here
    int var = 0;
    while (var < SOME_CONSTANT) {
        do_stuff(&var);
    }
}
```

### Horizontal space

Always add single space after conditional and loop keywords:

```
if (condition) {    // correct
    // ...
}

switch (n) {        // correct
    case 0:
        // ...
}

for(int i = 0; i < CONST; ++i) {    // INCORRECT
    // ...
}
```

Add single space around binary operators. No space is necessary for unary operators. It is okay to drop space around multiply and divide operators:

```
const int y = y0 + (x - x0) * (y1 - y0) / (x1 - x0);    // correct

const int y = y0 + (x - x0)*(y1 - y0)/(x1 - x0);        // also okay

int y_cur = -y;                                          // correct
++y_cur;

const int y = y0+(x-x0)*(y1-y0)/(x1-x0);                // INCORRECT
```

No space is necessary around `.` and `->` operators.

Sometimes adding horizontal space within a line can help make code more readable. For example, you can add space to align function arguments:

```
gpio_matrix_in(PIN_CAM_D6,   I2S0I_DATA_IN14_IDX, false);
gpio_matrix_in(PIN_CAM_D7,   I2S0I_DATA_IN15_IDX, false);
gpio_matrix_in(PIN_CAM_HREF, I2S0I_H_ENABLE_IDX,  false);
gpio_matrix_in(PIN_CAM_PCLK, I2S0I_DATA_IN15_IDX, false);
```

Note however that if someone goes to add new line with a longer identifier as first argument (e.g. `PIN_CAM_VSYNC`), it will not fit. So other lines would have to be realigned, adding meaningless changes to the commit.

Therefore, use horizontal alignment sparingly, especially if you expect new lines to be added to the list later.

Never use TAB characters for horizontal alignment.

Never add trailing whitespace at the end of the line.

## Braces

- Function definition should have a brace on a separate line:

```
// This is correct:
void function(int arg)
{

}

// NOT like this:
void function(int arg) {

}
```

- Within a function, place opening brace on the same line with conditional and loop statements:

```
if (condition) {
    do_one();
} else if (other_condition) {
    do_two();
}
```

## Comments

Use `//` for single line comments. For multi-line comments it is okay to use either `//` on each line or a `/* */` block.

Although not directly related to formatting, here are a few notes about using comments effectively.

- Don't use single comments to disable some functionality:

```
void init_something()
{
    setup_dma();
    // load_resources();                // WHY is this thing commented, asks the␣
↪reader?
    start_timer();
}
```

- If some code is no longer required, remove it completely. If you need it you can always look it up in git history of this file. If you disable some call because of temporary reasons, with an intention to restore it in the future, add explanation on the adjacent line:

```
void init_something()
{
    setup_dma();
    // TODO: we should load resources here, but loader is not fully integrated␣
↪yet.
    // load_resources();
    start_timer();
}
```

- Same goes for `#if 0 ... #endif` blocks. Remove code block completely if it is not used. Otherwise, add comment explaining why the block is disabled. Don't use `#if 0 ... #endif` or comments to store code snippets which you may need in the future.
- Don't add trivial comments about authorship and change date. You can always look up who modified any given line using git. E.g. this comment adds clutter to the code without adding any useful information:

```
void init_something()
{
    setup_dma();
    // XXX add 2016-09-01
    init_dma_list();
    fill_dma_item(0);
    // end XXX add
    start_timer();
}
```

### Formatting your code

You can use `astyle` program to format your code according to the above recommendations.

If you are writing a file from scratch, or doing a complete rewrite, feel free to re-format the entire file. If you are changing a small portion of file, don't re-format the code you didn't change. This will help others when they review your changes.

To re-format a file, run:

```
tools/format.sh components/my_component/file.c
```

## Documenting code

Please see the guide here: *Documenting Code*.

## Structure and naming

## Language features

To be written.

CHAPTER 27

# Documenting Code

The purpose of this description is to provide quick summary on documentation style used in espressif/esp-idf repository and how to add new documentation.

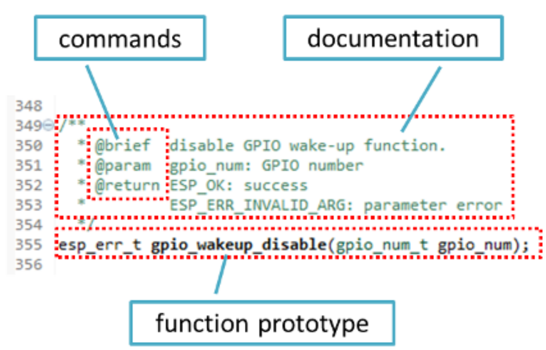
## Introduction

When documenting code for this repository, please follow Doxygen style. You are doing it by inserting special commands, for instance @param, into standard comments blocks, for example:

```
/**
 * @param ratio this is oxygen to air ratio
 */
```

Doxygen is phrasing the code, extracting the commands together with subsequent text, and building documentation out of it.

Typical comment block, that contains documentation of a function, looks like below.

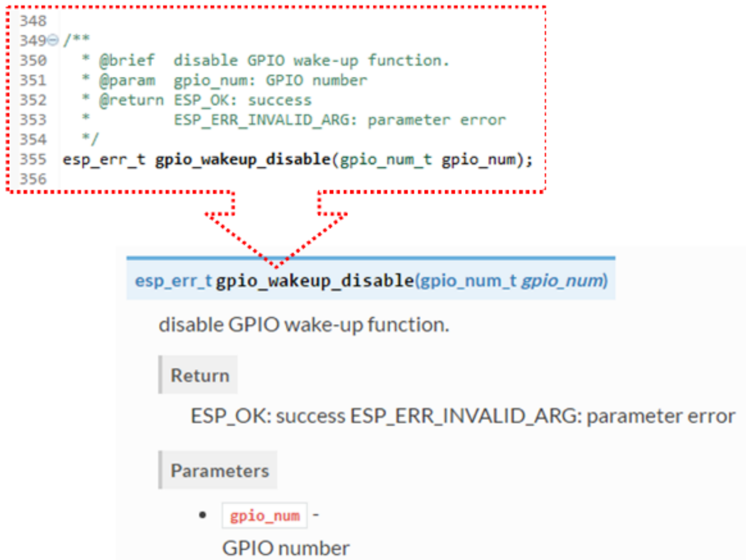



Doxygen supports couple of formatting styles. It also gives you great flexibility on level of details to include in documentation. To get familiar with available features, please check data reach and very well organized Doxygen Manual.

## Why we need it?

The ultimate goal is to ensure that all the code is consistently documented, so we can use tools like Sphinx and Breathe to aid preparation and automatic updates of API documentation when the code changes.

With these tools the above piece of code renders like below:



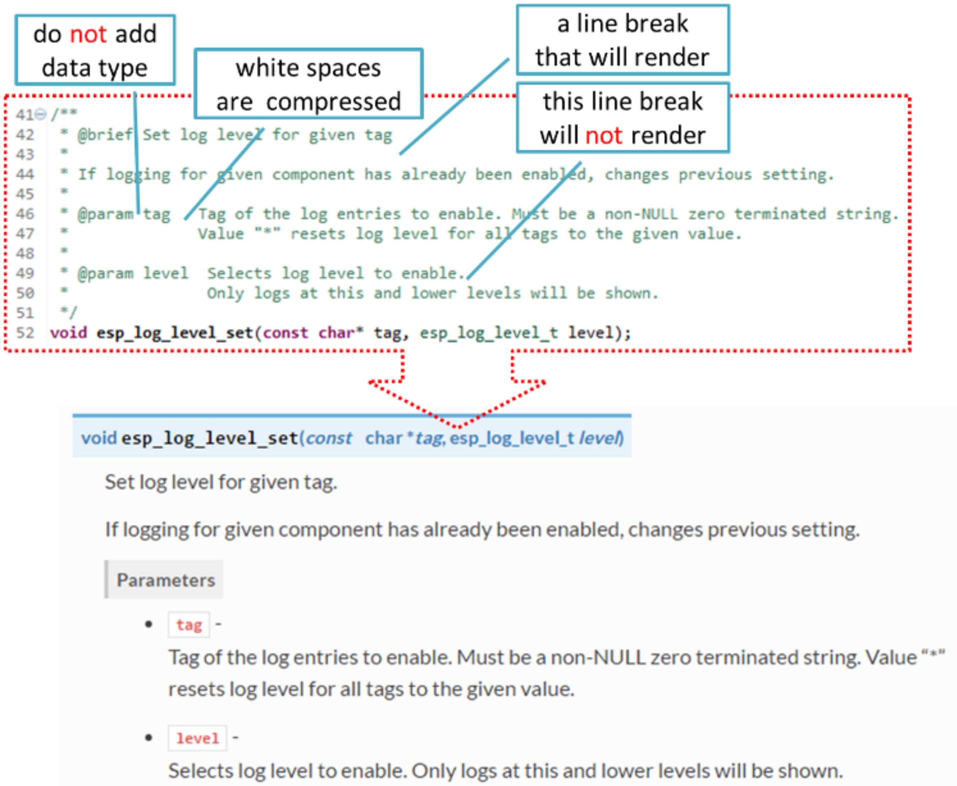

## Go for it!

When writing code for this repository, please follow guidelines below.

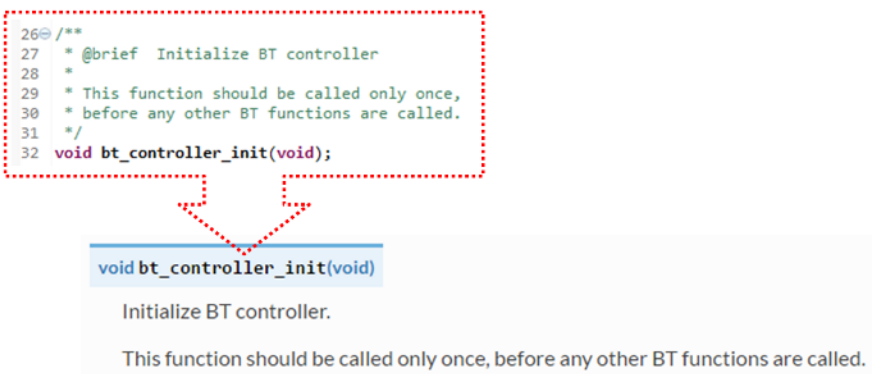
1. Document all building blocks of code: functions, structs, typedefs, enums, macros, etc. Provide enough information on purpose, functionality and limitations of documented items, as you would like to see them documented when reading the code by others.

2. Documentation of function should describe what this function does. If it accepts input parameters and returns some value, all of them should be explained.

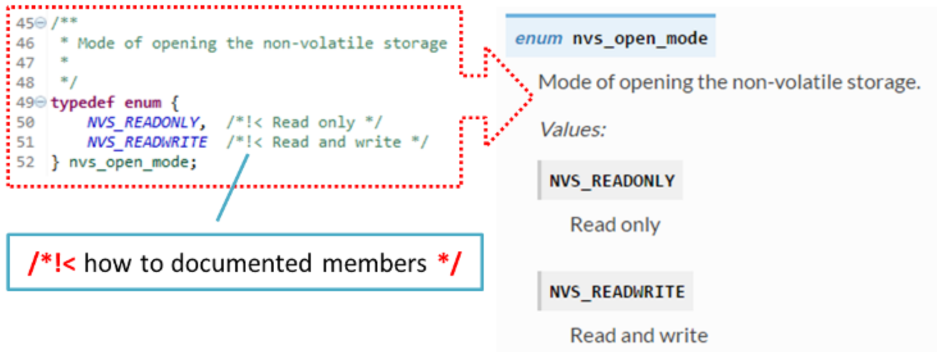
3. Do not add a data type before parameter or any other characters besides spaces. All spaces and line breaks are compressed into a single space. If you like to break a line, then break it twice.




4. If function has void input or does not return any value, then skip `@param` or `@return`




5. When documenting a `define` as well as members of a `struct` or `enum`, place specific comment like below after each member.




6. To provide well formatted lists, break the line after command (like `@return` in example below).

```
*
* @return
*     - ESP_OK if erase operation was successful
*     - ESP_ERR_NVS_INVALID_HANDLE if handle has been closed or is NULL
*     - ESP_ERR_NVS_READ_ONLY if handle was opened as read only
*     - ESP_ERR_NVS_NOT_FOUND if the requested key doesn't exist
*     - other error codes from the underlying storage driver
*
```

7. Overview of functionality of documented header file, or group of files that make a library, should be placed in the same directory in a separate `README.rst` file. If directory contains header files for different APIs, then the file name should be `apiname-readme.rst`.

## Go one extra mile

There is couple of tips, how you can make your documentation even better and more useful to the reader.

1. Add code snippets to illustrate implementation. To do so, enclose snippet using `@code{c}` and `@endcode` commands.

```
*
* @code{c}
* // Example of using nvs_get_i32:
* int32_t max_buffer_size = 4096; // default value
* esp_err_t err = nvs_get_i32(my_handle, "max_buffer_size", &max_buffer_
↪size);
* assert(err == ESP_OK || err == ESP_ERR_NVS_NOT_FOUND);
* // if ESP_ERR_NVS_NOT_FOUND was returned, max_buffer_size will still
* // have its default value.
* @endcode
*
```

The code snippet should be enclosed in a comment block of the function that it illustrates.

2. To highlight some important information use command `@attention` or `@note`.

```
*
* @attention
*     1. This API only impact WIFI_MODE_STA or WIFI_MODE_APSTA mode
*     2. If the ESP32 is connected to an AP, call esp_wifi_disconnect to␣
↪disconnect.
*
```

```
```

Above example also shows how to use a numbered list.

3. Use markdown to make your documentation even more readable. You will add headers, links, tables and more.

```
*
* [ESP32 Technical Reference](http://espressif.com/sites/default/files/
↪documentation/esp32_technical_reference_manual_en.pdf)
*
```

**Note:** Code snippets, notes, links, etc. will not make it to the documentation, if not enclosed in a comment block associated with one of documented objects.

5. Prepare one or more complete code examples together with description. Place them in a separate file `example.rst` in the same directory as the API header files. If directory contains header files for different APIs, then the file name should be `apiname-example.rst`.

## Put it all together

Once all the above steps are complete, follow instruction in *Template* and create a single file, that will merge all individual pieces of prepared documentation. Finally add a link to this file to respective `.. toctree::` in `index.rst` file located in `/docs` folder.

## OK, but I am new to Sphinx!

1. No worries. All the software you need is well documented. It is also open source and free. Start by checking Sphinx documentation. If you are not clear how to write using rst markup language, see reStructuredText Primer.
2. Check the source files of this documentation to understand what is behind of what you see now on the screen. Sources are maintained on GitHub in espressif/esp-idf repository in docs folder. You can go directly to the source file of this page by scrolling up and clicking the link in the top right corner. When on GitHub, see what's really inside, open source files by clicking `Raw` button.
3. You will likely want to see how documentation builds and looks like before posting it on the GitHub. There are two options to do so:

- Install Sphinx, Breathe and Doxygen to build it locally. You would need a Linux machine for that.
- Set up an account on Read the Docs and build documentation in the cloud. Read the Docs provides document building and hosting for free and their service works really quick and great.

## Wrap up

We love good code that is doing cool things. We love it even better, if it is well documented, so we can quickly make it run and also do the cool things.

Go ahead, contribute your code and documentation!

# CHAPTER 28

# Template

**Note:** *INSTRUCTIONS*

1. Use this file as a template to document API.
2. Change the file name to the name of the header file that represents documented API.
3. Include respective files with descriptions from the API folder using `..include::`

- README.rst
- example.rst

4. Optionally provide description right in this file.
5. Once done, remove all instructions like this one and any superfluous headers.

## Overview

**Note:** *INSTRUCTIONS*

1. Provide overview where and how this API may be used.
2. Where applicable include code snippets to illustrate functionality of particular functions.
3. To distinguish between sections, use the following heading levels:

- # with overline, for parts
- * with overline, for chapters
- =, for sections
- -, for subsections
- ^, for subsubsections

- `"`, for paragraphs

## Application Example

**Note:** *INSTRUCTIONS*

1. Prepare one or more practical examples to demonstrate functionality of this API.
2. Each example should follow pattern of projects located in `esp-idf/examples/` folder.
3. Place example in this folder complete with `README.md` file.
4. Provide overview of demonstrated functionality in `README.md`.
5. With good overview reader should be able to understand what example does without opening the source code.
6. Depending on complexity of example, break down description of code into parts and provide overview of functionality of each part.
7. Include flow diagram and screenshots of application output if applicable.
8. Finally add in this section synopsis of each example together with link to respective folder in `esp-idf/examples/`.

## API Reference

**Note:** *INSTRUCTIONS*

1. Specify the names of header files used to generate this reference. Each name should be linked to the source on espressif/esp-idf repository.
2. Provide list of API members divided into sections.
3. Use corresponding `.. doxygen..` directives, so member documentation is auto updated.
   - Data Structures -`.. doxygenstruct::` together with `:members:`
   - Macros - `.. doxygendefine::`
   - Type Definitions - `.. doxygentypedef::`
   - Enumerations - `.. doxygenenum::`
   - Functions - `.. doxygenfunction::`

   See Breathe documentation for additional information.
4. Once done remove superfluous headers.
5. When changes are committed and documentation is build, check how this section rendered. *Correct annotations* in respective header files, if required.

## Header Files

- *path/header-file.h*

## Data Structures

```
.. doxygenstruct:: name_of_structure
   :members:
```

## Macros

```
.. doxygendefine:: name_of_macro
```

## Type Definitions

```
.. doxygentypedef:: name_of_type
```

## Enumerations

```
.. doxygenenum:: name_of_enumeration
```

## Functions

```
.. doxygenfunction:: name_of_function
```

# CHAPTER 29

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# CHAPTER 30

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# CHAPTER 31

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