Remote Control Transceiver (RMT)

[中文]

Introduction

The RMT (Remote Control Transceiver) peripheral was designed to act as an infrared transceiver. However, due to the flexibility of its data format, RMT can be extended to a versatile and general-purpose transceiver, transmitting or receiving many other types of signals. From the perspective of network layering, the RMT hardware contains both physical and data link layers. The physical layer defines the communication media and bit signal representation. The data link layer defines the format of an RMT frame. The minimal data unit in the frame is called the **RMT symbol**, which is represented by `rmt_symbol_word_t` in the driver.

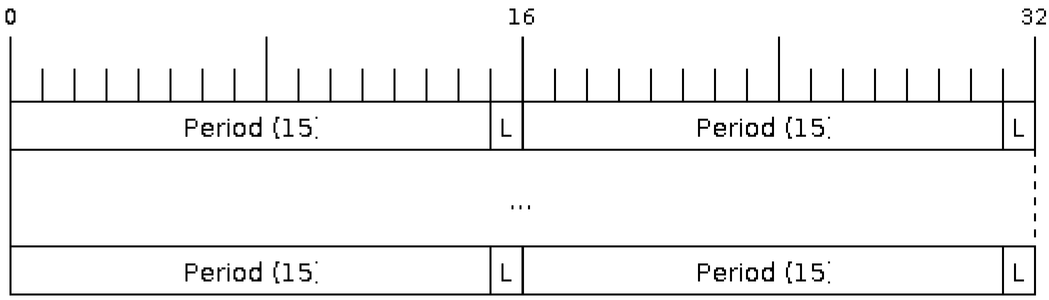
ESP32-S3 contains multiple channels in the RMT peripheral [1]. Each channel can be independently configured as either transmitter or receiver.

Typically, the RMT peripheral can be used in the following scenarios:

- Transmit or receive infrared signals, with any IR protocols, e.g., NEC
- General-purpose sequence generator
- Transmit signals in a hardware-controlled loop, with a finite or infinite number of times
- Multi-channel simultaneous transmission
- Modulate the carrier to the output signal or demodulate the carrier from the input signal

Layout of RMT Symbols

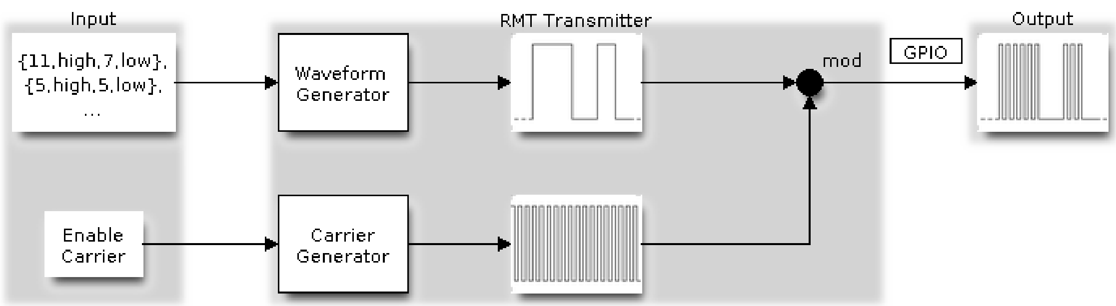
The RMT hardware defines data in its own pattern -- the **RMT symbol**. The diagram below illustrates the bit fields of an RMT symbol. Each symbol consists of two pairs of two values. The first value in the pair is a 15-bit value representing the signal's duration in units of RMT ticks. The second in the pair is a 1-bit value representing the signal's logic level, i.e., high or low.



Structure of RMT symbols (L - signal level)

RMT Transmitter Overview

The data path and control path of an RMT TX channel is illustrated in the figure below:

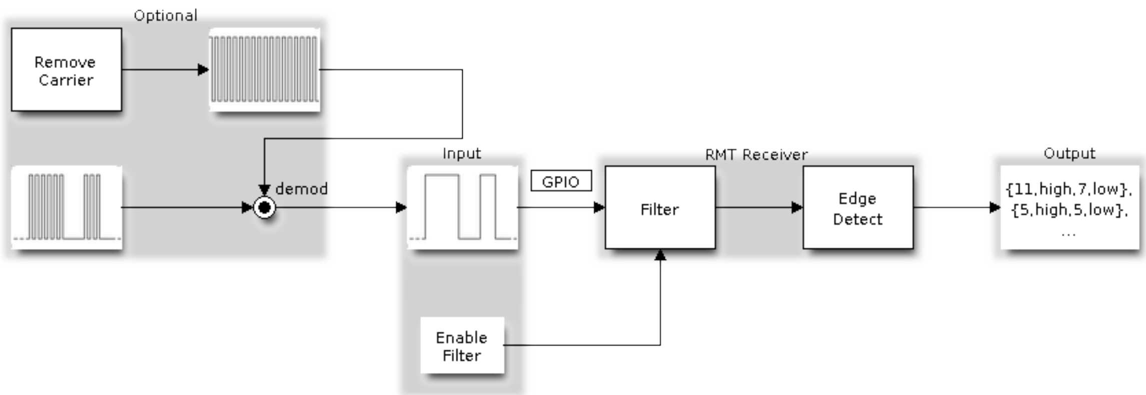


RMT Transmitter Overview

The driver encodes the user's data into RMT data format, then the RMT transmitter can generate the waveforms according to the encoding artifacts. It is also possible to modulate a high-frequency carrier signal before being routed to a GPIO pad.

RMT Receiver Overview

The data path and control path of an RMT RX channel is illustrated in the figure below:



RMT Receiver Overview

The RMT receiver can sample incoming signals into RMT data format, and store the data in memory. It is also possible to tell the receiver the basic characteristics of the incoming signal, so that the signal's stop condition can be recognized, and signal glitches and noise can be filtered out. The RMT peripheral also supports demodulating the high-frequency carrier from the base signal.

Functional Overview

The description of the RMT functionality is divided into the following sections:

- Resource Allocation - covers how to allocate and properly configure RMT channels. It also covers how to recycle channels and other resources when they are no longer used.
- Carrier Modulation and Demodulation - describes how to modulate and demodulate the carrier signals for TX and RX channels respectively.
- Register Event Callbacks - covers how to register user-provided event callbacks to receive RMT channel events.
- Enable and Disable Channel - shows how to enable and disable the RMT channel.
- Initiate TX Transaction - describes the steps to initiate a transaction for a TX channel.
- Initiate RX Transaction - describes the steps to initiate a transaction for an RX channel.
- Multiple Channels Simultaneous Transmission - describes how to collect multiple channels into a sync group so that their transmissions can be started simultaneously.
- RMT Encoder - focuses on how to write a customized encoder by combining multiple primitive encoders that are provided by the driver.
- Power Management - describes how different clock sources affects power consumption.
- IRAM Safe - describes how disabling the cache affects the RMT driver, and tips to mitigate it.
- Thread Safety - lists which APIs are guaranteed to be thread-safe by the driver.
- Kconfig Options - describes the various Kconfig options supported by the RMT driver.

Resource Allocation

Both RMT TX and RX channels are represented by `rmt_channel_handle_t` in the driver. The driver internally manages which channels are available and hands out a free channel on request.

Install RMT TX Channel

To install an RMT TX channel, there is a configuration structure that needs to be given in advance `rmt_tx_channel_config_t`. The following list describes each member of the configuration structure.

- `rmt_tx_channel_config_t::gpio_num` sets the GPIO number used by the transmitter.
- `rmt_tx_channel_config_t::clk_src` selects the source clock for the RMT channel. The available clocks are listed in `rmt_clock_source_t`. Note that, the selected clock is also used by other channels, which means the user should ensure this configuration is the same

when allocating other channels, regardless of TX or RX. For the effect on the power consumption of different clock sources, please refer to the Power Management section.

- `rmt_tx_channel_config_t::resolution_hz` sets the resolution of the internal tick counter. The timing parameter of the RMT signal is calculated based on this **tick**.
- `rmt_tx_channel_config_t::mem_block_symbols` has a slightly different meaning based on if the DMA backend is enabled or not.
  - If the DMA is enabled via `rmt_tx_channel_config_t::with_dma`, then this field controls the size of the internal DMA buffer. To achieve a better throughput and smaller CPU overhead, you can set a larger value, e.g., `1024`.
  - If DMA is not used, this field controls the size of the dedicated memory block owned by the channel, which should be at least 48.
- `rmt_tx_channel_config_t::trans_queue_depth` sets the depth of the internal transaction queue, the deeper the queue, the more transactions can be prepared in the backlog.
- `rmt_tx_channel_config_t::invert_out` is used to decide whether to invert the RMT signal before sending it to the GPIO pad.
- `rmt_tx_channel_config_t::with_dma` enables the DMA backend for the channel. Using the DMA allows a significant amount of the channel's workload to be offloaded from the CPU. However, the DMA backend is not available on all ESP chips, please refer to [TRM] before you enable this option. Or you might encounter a `ESP_ERR_NOT_SUPPORTED` error.
- `rmt_tx_channel_config_t::intr_priority` Set the priority of the interrupt. If set to `0` , then the driver will use a interrupt with low or medium priority (priority level may be one of 1,2 or 3), otherwise use the priority indicated by `rmt_tx_channel_config_t::intr_priority`. Please use the number form (1,2,3) , not the bitmask form ((1<<1),(1<<2),(1<<3)). Please pay attention that once the interrupt priority is set, it cannot be changed until `rmt_del_channel()` is called.
- `rmt_tx_channel_config_t::allow_pd` configures if the driver allows the system to power down the peripheral in light sleep mode. Before entering sleep, the system will backup the RMT register context, which will be restored later when the system exit the sleep mode. Powering down the peripheral can save more power, but at the cost of more memory consumed to save the register context. It's a tradeoff between power consumption and memory consumption. This configuration option relies on specific hardware feature, if you enable it on an unsupported chip, you will see error message like `not able to power down in light sleep`.

Once the `rmt_tx_channel_config_t` structure is populated with mandatory parameters, users can call `rmt_new_tx_channel()` to allocate and initialize a TX channel. This function returns an RMT channel handle if it runs correctly. Specifically, when there are no more free channels in the RMT resource pool, this function returns `ESP_ERR_NOT_FOUND` error. If some feature (e.g., DMA backend) is not supported by the hardware, it returns `ESP_ERR_NOT_SUPPORTED` error.

```
rmt_channel_handle_t tx_chan = NULL;
rmt_tx_channel_config_t tx_chan_config = {
    .clk_src = RMT_CLK_SRC_DEFAULT,   // select source clock
    .gpio_num = 0,                    // GPIO number
    .mem_block_symbols = 64,          // memory block size, 64 * 4 = 256 Bytes
    .resolution_hz = 1 * 1000 * 1000, // 1 MHz tick resolution, i.e., 1 tick = 1 µs
    .trans_queue_depth = 4,           // set the number of transactions that can pend in the background
    .flags.invert_out = false,        // do not invert output signal
    .flags.with_dma = false,          // do not need DMA backend
};
ESP_ERROR_CHECK(rmt_new_tx_channel(&tx_chan_config, &tx_chan));
```

Install RMT RX Channel

To install an RMT RX channel, there is a configuration structure that needs to be given in advance `rmt_rx_channel_config_t`. The following list describes each member of the configuration structure.

- `rmt_rx_channel_config_t::gpio_num` sets the GPIO number used by the receiver.
- `rmt_rx_channel_config_t::clk_src` selects the source clock for the RMT channel. The available clocks are listed in `rmt_clock_source_t`. Note that, the selected clock is also used by other channels, which means the user should ensure this configuration is the same when allocating other channels, regardless of TX or RX. For the effect on the power consumption of different clock sources, please refer to the Power Management section.
- `rmt_rx_channel_config_t::resolution_hz` sets the resolution of the internal tick counter. The timing parameter of the RMT signal is calculated based on this **tick**.
- `rmt_rx_channel_config_t::mem_block_symbols` has a slightly different meaning based on whether the DMA backend is enabled.
    - If the DMA is enabled via `rmt_rx_channel_config_t::with_dma`, this field controls the maximum size of the DMA buffer.
    - If DMA is not used, this field controls the size of the dedicated memory block owned by the channel, which should be at least 48.
- `rmt_rx_channel_config_t::invert_in` is used to invert the input signals before it is passed to the RMT receiver. The inversion is done by the GPIO matrix instead of by the RMT peripheral.
- `rmt_rx_channel_config_t::with_dma` enables the DMA backend for the channel. Using the DMA allows a significant amount of the channel's workload to be offloaded from the CPU. However, the DMA backend is not available on all ESP chips, please refer to [TRM] before you enable this option. Or you might encounter a `ESP_ERR_NOT_SUPPORTED` error.
- `rmt_rx_channel_config_t::intr_priority` Set the priority of the interrupt. If set to `0` , then the driver will use a interrupt with low or medium priority (priority level may be one of 1,2 or 3), otherwise use the priority indicated by `rmt_rx_channel_config_t::intr_priority`. Please use the number form (1,2,3) , not the bitmask form ((1<<1),(1<<2),(1<<3)). Please pay attention that once the interrupt priority is set, it cannot be changed until `rmt_del_channel()` is called.

- `rmt_rx_channel_config_t::allow_pd` configures if the driver allows the system to power down the peripheral in light sleep mode. Before entering sleep, the system will backup the RMT register context, which will be restored later when the system exit the sleep mode. Powering down the peripheral can save more power, but at the cost of more memory consumed to save the register context. It's a tradeoff between power consumption and memory consumption. This configuration option relies on specific hardware feature, if you enable it on an unsupported chip, you will see error message like `not able to power down in light sleep`.

Once the `rmt_rx_channel_config_t` structure is populated with mandatory parameters, users can call `rmt_new_rx_channel()` to allocate and initialize an RX channel. This function returns an RMT channel handle if it runs correctly. Specifically, when there are no more free channels in the RMT resource pool, this function returns `ESP_ERR_NOT_FOUND` error. If some feature (e.g., DMA backend) is not supported by the hardware, it returns `ESP_ERR_NOT_SUPPORTED` error.

```
rmt_channel_handle_t rx_chan = NULL;
rmt_rx_channel_config_t rx_chan_config = {
    .clk_src = RMT_CLK_SRC_DEFAULT,   // select source clock
    .resolution_hz = 1 * 1000 * 1000, // 1 MHz tick resolution, i.e., 1 tick = 1 µs
    .mem_block_symbols = 64,          // memory block size, 64 * 4 = 256 Bytes
    .gpio_num = 2,                    // GPIO number
    .flags.invert_in = false,         // do not invert input signal
    .flags.with_dma = false,          // do not need DMA backend
};
ESP_ERROR_CHECK(rmt_new_rx_channel(&rx_chan_config, &rx_chan));
```

Note

Due to a software limitation in the GPIO driver, when both TX and RX channels are bound to the same GPIO, ensure the RX Channel is initialized before the TX Channel. If the TX Channel was set up first, then during the RX Channel setup, the previous RMT TX Channel signal will be overridden by the GPIO control signal.

Uninstall RMT Channel

If a previously installed RMT channel is no longer needed, it is recommended to recycle the resources by calling `rmt_del_channel()`, which in return allows the underlying software and hardware resources to be reused for other purposes.

Carrier Modulation and Demodulation

The RMT transmitter can generate a carrier wave and modulate it onto the message signal. Compared to the message signal, the carrier signal's frequency is significantly higher. In addition, the user can only set the frequency and duty cycle for the carrier signal. The RMT receiver can demodulate the carrier signal from the incoming signal. Note that, carrier modulation and demodulation are not supported on all ESP chips, please refer to [TRM] before configuring the carrier, or you might encounter a `ESP_ERR_NOT_SUPPORTED` error.

Carrier-related configurations lie in `rmt_carrier_config_t`:

- `rmt_carrier_config_t::frequency_hz` sets the carrier frequency, in Hz.
- `rmt_carrier_config_t::duty_cycle` sets the carrier duty cycle.
- `rmt_carrier_config_t::polarity_active_low` sets the carrier polarity, i.e., on which level the carrier is applied.
- `rmt_carrier_config_t::always_on` sets whether to output the carrier even when the data transmission has finished. This configuration is only valid for the TX channel.

> **Note**
>
> For the RX channel, we should not set the carrier frequency exactly to the theoretical value. It is recommended to leave a tolerance for the carrier frequency. For example, in the snippet below, we set the frequency to 25 KHz, instead of the 38 KHz configured on the TX side. The reason is that reflection and refraction occur when a signal travels through the air, leading to distortion on the receiver side.

```
rmt_carrier_config_t tx_carrier_cfg = {
    .duty_cycle = 0.33,                 // duty cycle 33%
    .frequency_hz = 38000,              // 38 KHz
    .flags.polarity_active_low = false, // carrier should be modulated to high level
};
// modulate carrier to TX channel
ESP_ERROR_CHECK(rmt_apply_carrier(tx_chan, &tx_carrier_cfg));

rmt_carrier_config_t rx_carrier_cfg = {
    .duty_cycle = 0.33,                 // duty cycle 33%
    .frequency_hz = 25000,              // 25 KHz carrier, should be smaller than the
transmitter's carrier frequency
    .flags.polarity_active_low = false, // the carrier is modulated to high level
};
// demodulate carrier from RX channel
ESP_ERROR_CHECK(rmt_apply_carrier(rx_chan, &rx_carrier_cfg));
```

Register Event Callbacks

When an event occurs on an RMT channel (e.g., transmission or receiving is completed), the CPU is notified of this event via an interrupt. If you have some function that needs to be called when a particular events occur, you can register a callback for that event to the RMT driver's ISR (Interrupt Service Routine) by calling `rmt_tx_register_event_callbacks()` and `rmt_rx_register_event_callbacks()` for TX and RX channel respectively. Since the registered callback functions are called in the interrupt context, the user should ensure the callback function does not block, e.g., by making sure that only FreeRTOS APIs with the `FromISR` suffix are called from within the function. The callback function has a boolean return value used to indicate whether a higher priority task has been unblocked by the callback.

The TX channel-supported event callbacks are listed in the `rmt_tx_event_callbacks_t`:

- `rmt_tx_event_callbacks_t::on_trans_done` sets a callback function for the "trans-done" event. The function prototype is declared in `rmt_tx_done_callback_t`.

The RX channel-supported event callbacks are listed in the `rmt_rx_event_callbacks_t`:

- `rmt_rx_event_callbacks_t::on_recv_done` sets a callback function for "receive-done" event. The function prototype is declared in `rmt_rx_done_callback_t`.

> **Note**
>
> The "receive-done" is not equivalent to "receive-finished". This callback can also be called at a "partial-receive-done" time, for many times during one receive transaction.

Users can save their own context in `rmt_tx_register_event_callbacks()` and `rmt_rx_register_event_callbacks()` as well, via the parameter `user_data`. The user data is directly passed to each callback function.

In the callback function, users can fetch the event-specific data that is filled by the driver in the `edata`. Note that the `edata` pointer is **only** valid during the callback, please do not try to save this pointer and use that outside of the callback function.

The TX-done event data is defined in `rmt_tx_done_event_data_t`:

- `rmt_tx_done_event_data_t::num_symbols` indicates the number of transmitted RMT symbols. This also reflects the size of the encoding artifacts. Please note, this value accounts for the `EOF` symbol as well, which is appended by the driver to mark the end of one transaction.

The RX-complete event data is defined in `rmt_rx_done_event_data_t`:

- `rmt_rx_done_event_data_t::received_symbols` points to the received RMT symbols. These symbols are saved in the `buffer` parameter of the `rmt_receive()` function. Users should not free this receive buffer before the callback returns. If you also enabled the partial receive feature, then the user buffer will be used as a "second level buffer", where its content can be overwritten by data comes in afterwards. In this case, you should copy the received data to another place if you want to keep it or process it later.
- `rmt_rx_done_event_data_t::num_symbols` indicates the number of received RMT symbols. This value is not larger than the `buffer_size` parameter of `rmt_receive()` function. If the `buffer_size` is not sufficient to accommodate all the received RMT symbols, the driver only keeps the maximum number of symbols that the buffer can hold, and excess symbols are discarded or ignored.
- `rmt_rx_done_event_data_t::is_last` indicates whether the current received buffer is the last one in the transaction. This is useful when you enable the partial reception feature by `rmt_receive_config_t::extra_rmt_receive_flags::en_partial_rx`.

Enable and Disable Channel

`rmt_enable()` must be called in advance before transmitting or receiving RMT symbols. For TX channels, enabling a channel enables a specific interrupt and prepares the hardware to dispatch transactions. For RX channels, enabling a channel enables an interrupt, but the receiver is not started during this time, as the characteristics of the incoming signal have yet to be specified. The receiver is started in `rmt_receive()`.

`rmt_disable()` does the opposite by disabling the interrupt and clearing any pending interrupts. The transmitter and receiver are disabled as well.

```
ESP_ERROR_CHECK(rmt_enable(tx_chan));
ESP_ERROR_CHECK(rmt_enable(rx_chan));
```

Initiate TX Transaction

RMT is a special communication peripheral, as it is unable to transmit raw byte streams like SPI and I2C. RMT can only send data in its own format `rmt_symbol_word_t`. However, the hardware does not help to convert the user data into RMT symbols, this can only be done in software by the so-called **RMT Encoder**. The encoder is responsible for encoding user data into RMT symbols and then writing to the RMT memory block or the DMA buffer. For how to create an RMT encoder, please refer to RMT Encoder.

Once you created an encoder, you can initiate a TX transaction by calling `rmt_transmit()`. This function takes several positional parameters like channel handle, encoder handle, and payload buffer. Besides, you also need to provide a transmission-specific configuration in `rmt_transmit_config_t`:

- `rmt_transmit_config_t::loop_count` sets the number of transmission loops. After the transmitter has finished one round of transmission, it can restart the same transmission again if this value is not set to zero. As the loop is controlled by hardware, the RMT channel can be used to generate many periodic sequences with minimal CPU intervention.

- Setting `rmt_transmit_config_t::loop_count` to *-1* means an infinite loop transmission. In this case, the channel does not stop until `rmt_disable()` is called. The "trans-done" event is not generated as well.
- Setting `rmt_transmit_config_t::loop_count` to a positive number means finite number of iterations. In this case, the "trans-done" event is when the specified number of iterations have completed.

> **Note**
>
> The **loop transmit** feature is not supported on all ESP chips, please refer to [TRM] before you configure this option, or you might encounter `ESP_ERR_NOT_SUPPORTED` error.

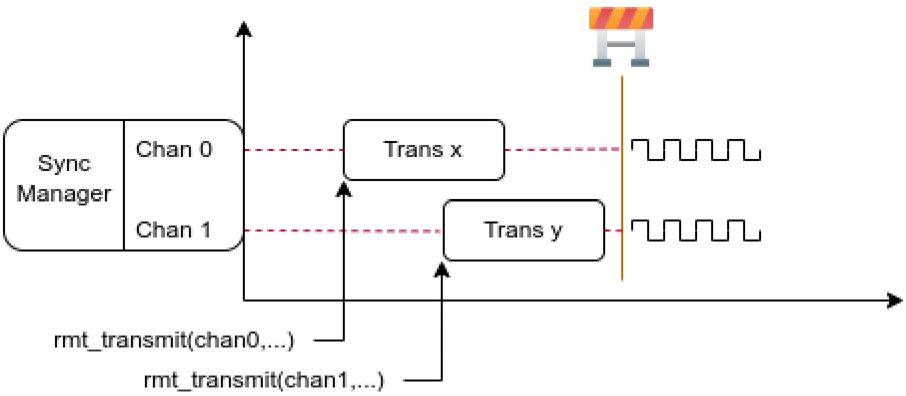
- `rmt_transmit_config_t::eot_level` sets the output level when the transmitter finishes working or stops working by calling `rmt_disable()`.
- `rmt_transmit_config_t::queue_nonblocking` sets whether to wait for a free slot in the transaction queue when it is full. If this value is set to `true`, then the function will return with an error code `ESP_ERR_INVALID_STATE` when the queue is full. Otherwise, the function will block until a free slot is available in the queue.

> **Note**
>
> There is a limitation in the transmission size if the `rmt_transmit_config_t::loop_count` is set to non-zero, i.e., to enable the loop feature. The encoded RMT symbols should not exceed the capacity of the RMT hardware memory block size, or you might see an error message like `encoding artifacts can't exceed hw memory block for loop transmission`. If you have to start a large transaction by loop, you can try either of the following methods.
>
> - Increase the `rmt_tx_channel_config_t::mem_block_symbols`. This approach does not work if the DMA backend is also enabled.
> - Customize an encoder and construct an infinite loop in the encoding function. See also RMT Encoder.

Internally, `rmt_transmit()` constructs a transaction descriptor and sends it to a job queue, which is dispatched in the ISR. So it is possible that the transaction is not started yet when `rmt_transmit()` returns. You cannot recycle or modify the payload buffer until the transaction is finished. You can get the transaction completion event by registering a callback function via `rmt_tx_register_event_callbacks()`. To ensure all pending transactions to complete, you can also use `rmt_tx_wait_all_done()`.

Multiple Channels Simultaneous Transmission

In some real-time control applications (e.g., to make two robotic arms move simultaneously), you do not want any time drift between different channels. The RMT driver can help to manage this by creating a so-called **Sync Manager**. The sync manager is represented by `rmt_sync_manager_handle_t` in the driver. The procedure of RMT sync transmission is shown as follows:



RMT TX Sync

Install RMT Sync Manager

To create a sync manager, the user needs to tell which channels are going to be managed in the `rmt_sync_manager_config_t`:

- `rmt_sync_manager_config_t::tx_channel_array` points to the array of TX channels to be managed.
- `rmt_sync_manager_config_t::array_size` sets the number of channels to be managed.

`rmt_new_sync_manager()` can return a manager handle on success. This function could also fail due to various errors such as invalid arguments, etc. Especially, when the sync manager has been installed before, and there are no hardware resources to create another manager, this function reports `ESP_ERR_NOT_FOUND` error. In addition, if the sync manager is not supported by the hardware, it reports a `ESP_ERR_NOT_SUPPORTED` error. Please refer to [TRM] before using the sync manager feature.

Start Transmission Simultaneously

For any managed TX channel, it does not start the machine until `rmt_transmit()` has been called on all channels in `rmt_sync_manager_config_t::tx_channel_array`. Before that, the channel is just put in a waiting state. TX channels will usually complete their transactions at different times due to differing transactions, thus resulting in a loss of sync. So before restarting a simultaneous transmission, the user needs to call `rmt_sync_reset()` to synchronize all channels again.

Calling `rmt_del_sync_manager()` can recycle the sync manager and enable the channels to initiate transactions independently afterward.

```
rmt_channel_handle_t tx_channels[2] = {NULL}; // declare two channels
int tx_gpio_number[2] = {0, 2};
// install channels one by one
for (int i = 0; i < 2; i++) {
    rmt_tx_channel_config_t tx_chan_config = {
        .clk_src = RMT_CLK_SRC_DEFAULT,       // select source clock
        .gpio_num = tx_gpio_number[i],    // GPIO number
        .mem_block_symbols = 64,          // memory block size, 64 * 4 = 256 Bytes
        .resolution_hz = 1 * 1000 * 1000, // 1 MHz resolution
        .trans_queue_depth = 1,           // set the number of transactions that can pend in
the background
    };
    ESP_ERROR_CHECK(rmt_new_tx_channel(&tx_chan_config, &tx_channels[i]));
}
// enable the channels
for (int i = 0; i < 2; i++) {
    ESP_ERROR_CHECK(rmt_enable(tx_channels[i]));
}
// install sync manager
rmt_sync_manager_handle_t synchro = NULL;
rmt_sync_manager_config_t synchro_config = {
    .tx_channel_array = tx_channels,
    .array_size = sizeof(tx_channels) / sizeof(tx_channels[0]),
};
ESP_ERROR_CHECK(rmt_new_sync_manager(&synchro_config, &synchro));

ESP_ERROR_CHECK(rmt_transmit(tx_channels[0], led_strip_encoders[0], led_data, led_num * 3,
&transmit_config));
// tx_channels[0] does not start transmission until call of `rmt_transmit()` for
tx_channels[1] returns
ESP_ERROR_CHECK(rmt_transmit(tx_channels[1], led_strip_encoders[1], led_data, led_num * 3,
&transmit_config));
```

Initiate RX Transaction

As also discussed in the Enable and Disable Channel, calling `rmt_enable()` does not prepare an RX to receive RMT symbols. The user needs to specify the basic characteristics of the incoming signals in `rmt_receive_config_t`:

- `rmt_receive_config_t::signal_range_min_ns` specifies the minimal valid pulse duration in either high or low logic levels. A pulse width that is smaller than this value is treated as a glitch, and ignored by the hardware.
- `rmt_receive_config_t::signal_range_max_ns` specifies the maximum valid pulse duration in either high or low logic levels. A pulse width that is bigger than this value is treated as **Stop Signal**, and the receiver generates receive-complete event immediately.
- If the incoming packet is long, that they cannot be stored in the user buffer at once, you can enable the partial reception feature by setting `rmt_receive_config_t::extra_rmt_receive_flags::en_partial_rx` to `true`. In this case, the driver invokes `rmt_rx_event_callbacks_t::on_recv_done` callback multiple times during one transaction, when the user buffer is **almost full**. You can check the value of :cpp:member::*rmt_rx_done_event_data_t::is_last* to know if the transaction is about to finish. Please note this features is not supported on all ESP series chips because it relies on hardware abilities like "ping-pong receive" or "DMA receive".

The RMT receiver starts the RX machine after the user calls `rmt_receive()` with the provided configuration above. Note that, this configuration is transaction specific, which means, to start a new round of reception, the user needs to set the `rmt_receive_config_t` again. The receiver saves the incoming signals into its internal memory block or DMA buffer, in the format of `rmt_symbol_word_t`.

Due to the limited size of the memory block, the RMT receiver notifies the driver to copy away the accumulated symbols in a ping-pong way.

The copy destination should be provided in the `buffer` parameter of `rmt_receive()` function. If this buffer overflows due to an insufficient buffer size, the receiver can continue to work, but overflowed symbols are dropped and the following error message is reported: `user buffer too small, received symbols truncated`. Please take care of the lifecycle of the `buffer` parameter, ensuring that the buffer is not recycled before the receiver is finished or stopped.

The receiver is stopped by the driver when it finishes working, i.e., receive a signal whose duration is bigger than `rmt_receive_config_t::signal_range_max_ns`. The user needs to call `rmt_receive()` again to restart the receiver, if necessary. The user can get the received data in the `rmt_rx_event_callbacks_t::on_recv_done` callback. See also Register Event Callbacks for more information.

```c
static bool example_rmt_rx_done_callback(rmt_channel_handle_t channel, const
rmt_rx_done_event_data_t *edata, void *user_data)
{
    BaseType_t high_task_wakeup = pdFALSE;
    QueueHandle_t receive_queue = (QueueHandle_t)user_data;
    // send the received RMT symbols to the parser task
    xQueueSendFromISR(receive_queue, edata, &high_task_wakeup);
    // return whether any task is woken up
    return high_task_wakeup == pdTRUE;
}

QueueHandle_t receive_queue = xQueueCreate(1, sizeof(rmt_rx_done_event_data_t));
rmt_rx_event_callbacks_t cbs = {
    .on_recv_done = example_rmt_rx_done_callback,
};
ESP_ERROR_CHECK(rmt_rx_register_event_callbacks(rx_channel, &cbs, receive_queue));

// the following timing requirement is based on NEC protocol
rmt_receive_config_t receive_config = {
    .signal_range_min_ns = 1250,     // the shortest duration for NEC signal is 560 µs, 1250
ns < 560 µs, valid signal is not treated as noise
    .signal_range_max_ns = 12000000, // the longest duration for NEC signal is 9000 µs,
12000000 ns > 9000 µs, the receive does not stop early
};

rmt_symbol_word_t raw_symbols[64]; // 64 symbols should be sufficient for a standard NEC frame
// ready to receive
ESP_ERROR_CHECK(rmt_receive(rx_channel, raw_symbols, sizeof(raw_symbols), &receive_config));
// wait for the RX-done signal
rmt_rx_done_event_data_t rx_data;
xQueueReceive(receive_queue, &rx_data, portMAX_DELAY);
// parse the received symbols
example_parse_nec_frame(rx_data.received_symbols, rx_data.num_symbols);
```

RMT Encoder

An RMT encoder is part of the RMT TX transaction, whose responsibility is to generate and write the correct RMT symbols into hardware memory or DMA buffer at a specific time. There are some special restrictions for an encoding function:

- During a single transaction, the encoding function may be called multiple times. This is necessary because the target RMT memory block cannot hold all the artifacts at once. To overcome this limitation, the driver utilizes a **ping-pong** approach, where the encoding session is divided into multiple parts. This means that the encoder needs to **keep track of its state** to continue encoding from where it left off in the previous part.
- The encoding function is running in the ISR context. To speed up the encoding session, it is highly recommended to put the encoding function into IRAM. This can also avoid the cache miss during encoding.

To help get started with the RMT driver faster, some commonly used encoders are provided out-of-the-box. They can either work alone or be chained together into a new encoder. See also Composite Pattern for the principle behind it. The driver has defined the encoder interface in `rmt_encoder_t`, it contains the following functions:

- `rmt_encoder_t::encode` is the fundamental function of an encoder. This is where the encoding session happens.
    - The function might be called multiple times within a single transaction. The encode function should return the state of the current encoding session.
    - The supported states are listed in the `rmt_encode_state_t`. If the result contains `RMT_ENCODING_COMPLETE`, it means the current encoder has finished work.
    - If the result contains `RMT_ENCODING_MEM_FULL`, the program needs to yield from the current session, as there is no space to save more encoding artifacts.
- `rmt_encoder_t::reset` should reset the encoder state back to the initial state (the RMT encoder is stateful).
    - If the RMT transmitter is manually stopped without resetting its corresponding encoder, subsequent encoding session can be erroneous.
    - This function is also called implicitly in `rmt_disable()`.
- `rmt_encoder_t::del` should free the resources allocated by the encoder.

Copy Encoder

A copy encoder is created by calling `rmt_new_copy_encoder()`. A copy encoder's main functionality is to copy the RMT symbols from user space into the driver layer. It is usually used to encode `const` data, i.e., data does not change at runtime after initialization such as the leading code in the IR protocol.

A configuration structure `rmt_copy_encoder_config_t` should be provided in advance before calling `rmt_new_copy_encoder()`. Currently, this configuration is reserved for future expansion, and has no specific use or setting items for now.

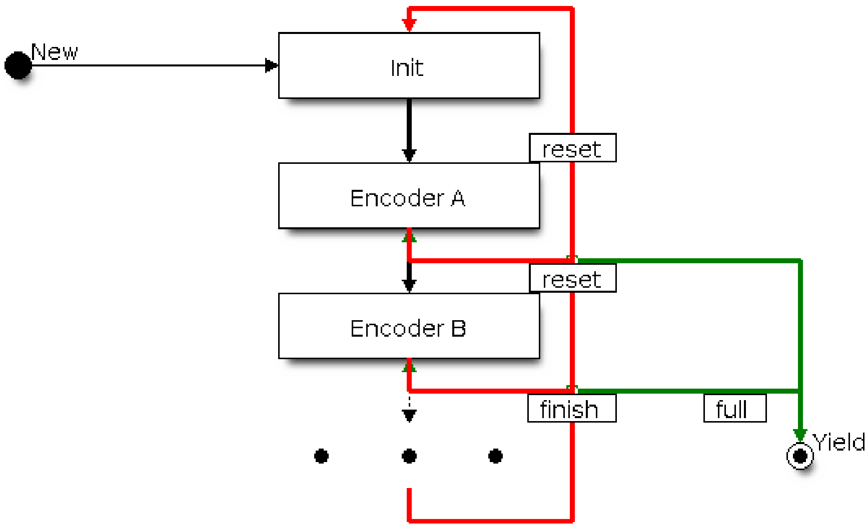
Bytes Encoder

A bytes encoder is created by calling `rmt_new_bytes_encoder()`. The bytes encoder's main functionality is to convert the user space byte stream into RMT symbols dynamically. It is usually used to encode dynamic data, e.g., the address and command fields in the IR protocol.

A configuration structure `rmt_bytes_encoder_config_t` should be provided in advance before calling `rmt_new_bytes_encoder()`:

- `rmt_bytes_encoder_config_t::bit0` and `rmt_bytes_encoder_config_t::bit1` are necessary to specify the encoder how to represent bit zero and bit one in the format of `rmt_symbol_word_t`.
- `rmt_bytes_encoder_config_t::msb_first` sets the bit endianness of each byte. If it is set to true, the encoder encodes the **Most Significant Bit** first. Otherwise, it encodes the **Least Significant Bit** first.

Besides the primitive encoders provided by the driver, the user can implement his own encoder by chaining the existing encoders together. A common encoder chain is shown as follows:



RMT Encoder Chain

Simple Callback Encoder

A simple callback encoder is created by calling `rmt_new_simple_encoder()`. The simple callback encoder allows you to provide a callback that reads data from userspace and writes symbols to the output stream without having to chain other encoders. The callback itself gets a pointer to the data passed to `rmt_transmit()`, a counter indicating the amount of symbols already written by the callback in this transmission, and a pointer where to write the encoded RMT symbols as well as the free space there. If the space is not enough for the callback to encode something, it can return 0 and the RMT will wait for previous symbols to be transmitted and call the callback again, now with more space available. If the callback successfully writes RMT symbols, it should return the number of symbols written.

A configuration structure `rmt_simple_encoder_config_t` should be provided in advance before calling `rmt_new_simple_encoder()`:

- `rmt_simple_encoder_config_t::callback` and `rmt_simple_encoder_config_t::arg` provide the callback function and an opaque argument that will be passed to that function.
- `rmt_simple_encoder_config_t::min_chunk_size` specifies the minimum amount of free space, in symbols, the encoder will be always be able to write some data to. In other words, when this amount of free space is passed to the encoder, it should never return 0 (except when the encoder is done encoding symbols).

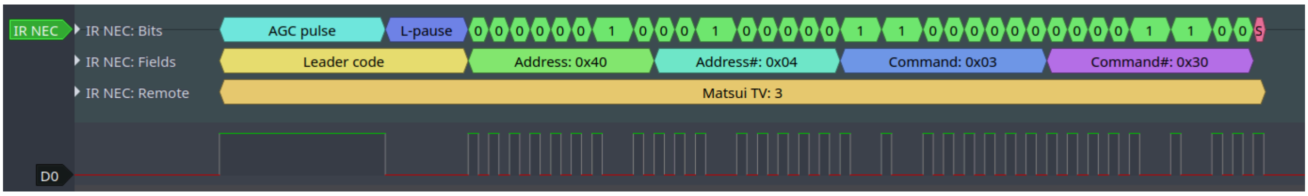
While the functionality of an encoding process using the simple callback encoder can usually also realized by chaining other encoders, the simple callback can be more easy to understand and maintain than an encoder chain.

Customize RMT Encoder for NEC Protocol

This section demonstrates how to write an NEC encoder. The NEC IR protocol uses pulse distance encoding of the message bits. Each pulse burst is `562.5 µs` in length, logical bits are transmitted as follows. It is worth mentioning that the least significant bit of each byte is sent first.

- Logical `0`: a `562.5 µs` pulse burst followed by a `562.5 µs` space, with a total transmit time of `1.125 ms`
- Logical `1`: a `562.5 µs` pulse burst followed by a `1.6875 ms` space, with a total transmit time of `2.25 ms`

When a key is pressed on the remote controller, the transmitted message includes the following elements in the specified order:



IR NEC Frame

- `9 ms` leading pulse burst, also called the "AGC pulse"
- `4.5 ms` space
- 8-bit address for the receiving device
- 8-bit logical inverse of the address
- 8-bit command
- 8-bit logical inverse of the command
- a final `562.5 µs` pulse burst to signify the end of message transmission

Then you can construct the NEC `rmt_encoder_t::encode` function in the same order, for example:

```
// IR NEC scan code representation
typedef struct {
    uint16_t address;
    uint16_t command;
} ir_nec_scan_code_t;

// construct an encoder by combining primitive encoders
typedef struct {
    rmt_encoder_t base;           // the base "class" declares the standard encoder interface
    rmt_encoder_t *copy_encoder;  // use the copy_encoder to encode the leading and ending
pulse
    rmt_encoder_t *bytes_encoder; // use the bytes_encoder to encode the address and command
data
    rmt_symbol_word_t nec_leading_symbol; // NEC leading code with RMT representation
    rmt_symbol_word_t nec_ending_symbol;  // NEC ending code with RMT representation
    int state; // record the current encoding state, i.e., we are in which encoding phase
} rmt_ir_nec_encoder_t;

static size_t rmt_encode_ir_nec(rmt_encoder_t *encoder, rmt_channel_handle_t channel, const
void *primary_data, size_t data_size, rmt_encode_state_t *ret_state)
{
    rmt_ir_nec_encoder_t *nec_encoder = __containerof(encoder, rmt_ir_nec_encoder_t, base);
    rmt_encode_state_t session_state = RMT_ENCODING_RESET;
    rmt_encode_state_t state = RMT_ENCODING_RESET;
    size_t encoded_symbols = 0;
    ir_nec_scan_code_t *scan_code = (ir_nec_scan_code_t *)primary_data;
    rmt_encoder_handle_t copy_encoder = nec_encoder->copy_encoder;
    rmt_encoder_handle_t bytes_encoder = nec_encoder->bytes_encoder;
    switch (nec_encoder->state) {
    case 0: // send leading code
        encoded_symbols += copy_encoder->encode(copy_encoder, channel, &nec_encoder-
>nec_leading_symbol,
                                                sizeof(rmt_symbol_word_t), &session_state);
        if (session_state & RMT_ENCODING_COMPLETE) {
            nec_encoder->state = 1; // we can only switch to the next state when the current
encoder finished
        }
        if (session_state & RMT_ENCODING_MEM_FULL) {
            state |= RMT_ENCODING_MEM_FULL;
            goto out; // yield if there is no free space to put other encoding artifacts
        }
    // fall-through
    case 1: // send address
        encoded_symbols += bytes_encoder->encode(bytes_encoder, channel, &scan_code->address,
sizeof(uint16_t), &session_state);
        if (session_state & RMT_ENCODING_COMPLETE) {
            nec_encoder->state = 2; // we can only switch to the next state when the current
encoder finished
        }
        if (session_state & RMT_ENCODING_MEM_FULL) {
            state |= RMT_ENCODING_MEM_FULL;
            goto out; // yield if there is no free space to put other encoding artifacts
        }
    // fall-through
    case 2: // send command
        encoded_symbols += bytes_encoder->encode(bytes_encoder, channel, &scan_code->command,
sizeof(uint16_t), &session_state);
        if (session_state & RMT_ENCODING_COMPLETE) {
            nec_encoder->state = 3; // we can only switch to the next state when the current
encoder finished
        }
        if (session_state & RMT_ENCODING_MEM_FULL) {
            state |= RMT_ENCODING_MEM_FULL;
```

```
            goto out; // yield if there is no free space to put other encoding artifacts
        }
    // fall-through
    case 3: // send ending code
        encoded_symbols += copy_encoder->encode(copy_encoder, channel, &nec_encoder-
>nec_ending_symbol,
                                                sizeof(rmt_symbol_word_t), &session_state);
        if (session_state & RMT_ENCODING_COMPLETE) {
            nec_encoder->state = RMT_ENCODING_RESET; // back to the initial encoding session
            state |= RMT_ENCODING_COMPLETE; // telling the caller the NEC encoding has
finished
        }
        if (session_state & RMT_ENCODING_MEM_FULL) {
            state |= RMT_ENCODING_MEM_FULL;
            goto out; // yield if there is no free space to put other encoding artifacts
        }
    }
out:
    *ret_state = state;
    return encoded_symbols;
}
```

A full sample code can be found in peripherals/rmt/ir_nec_transceiver. In the above snippet, we use a `switch-case` and several `goto` statements to implement a Finite-state machine . With this pattern, users can construct much more complex IR protocols.

Power Management

When power management is enabled, i.e., CONFIG_PM_ENABLE is on, the system may adjust or disable the clock source before going to sleep. As a result, the time base inside the RMT can't work as expected.

The driver can prevent the above issue by creating a power management lock. The lock type is set based on different clock sources. The driver will acquire the lock in `rmt_enable()`, and release it in `rmt_disable()`. That means, any RMT transactions in between these two functions are guaranteed to work correctly and stable.

IRAM Safe

By default, the RMT interrupt is deferred when the Cache is disabled for reasons like writing or erasing the main Flash. Thus the transaction-done interrupt does not get handled in time, which is not acceptable in a real-time application. What is worse, when the RMT transaction relies on **ping-pong** interrupt to successively encode or copy RMT symbols, a delayed interrupt can lead to an unpredictable result.

There is a Kconfig option CONFIG_RMT_ISR_IRAM_SAFE that has the following features:

1. Enable the interrupt being serviced even when the cache is disabled
2. Place all functions used by the ISR into IRAM [2]
3. Place the driver object into DRAM in case it is mapped to PSRAM by accident

This Kconfig option allows the interrupt handler to run while the cache is disabled but comes at the cost of increased IRAM consumption.

Another Kconfig option CONFIG_RMT_RECV_FUNC_IN_IRAM can place `rmt_receive()` into the IRAM as well. So that the receive function can be used even when the flash cache is disabled.

Thread Safety

The factory function `rmt_new_tx_channel()`, `rmt_new_rx_channel()` and `rmt_new_sync_manager()` are guaranteed to be thread-safe by the driver, which means, user can call them from different RTOS tasks without protection by extra locks. Other functions that take the `rmt_channel_handle_t` and `rmt_sync_manager_handle_t` as the first positional parameter, are not thread-safe. which means the user should avoid calling them from multiple tasks.

The following functions are allowed to use under ISR context as well.

- `rmt_receive()`

Kconfig Options

- CONFIG_RMT_ISR_IRAM_SAFE controls whether the default ISR handler can work when cache is disabled, see also IRAM Safe for more information.
- CONFIG_RMT_ENABLE_DEBUG_LOG is used to enable the debug log at the cost of increased firmware binary size.
- CONFIG_RMT_RECV_FUNC_IN_IRAM controls where to place the RMT receive function (IRAM or Flash), see IRAM Safe for more information.

Application Examples

- peripherals/rmt/led_strip demonstrates how to use the RMT peripheral to drive a WS2812 LED strip, which is able to change the number of LEDs and the chasing effect.
- peripherals/rmt/led_strip_simple_encoder demonstrates how to use the RMT peripheral to drive a WS2812 LED strip by implementing a callback that converts RGB pixels into a format recognized by the hardware.
- peripherals/rmt/ir_nec_transceiver demonstrates how to use the RMT peripheral to implement the encoding and decoding of remote IR NEC protocol.
- peripherals/rmt/dshot_esc demonstrates how to use the RMT TX channel to achieve infinite loop transmission. It constructs an RMT encoder for the DShot digital protocol. This protocol is primarily used for communication between flight controllers and electronic speed controllers, offering greater resistance to electrical noise compared to traditional analog protocols.
- peripherals/rmt/onewire demonstrates how to simulate the 1-wire hardware protocol by using the *onewire_bus* library, and read data from multiple DS18B20 temperature sensors on the bus. This library is built upon a pair of transmit and receive channels of the RMT peripheral.

- peripherals/rmt/musical_buzzer demonstrates how to use the RMT TX channel to drive a passive buzzer to play simple music. Each musical note is represented by a constant frequency of PWM signal with a fixed duration.
- peripherals/rmt/stepper_motor demonstrates how to use the RMT peripheral to drive a STEP/DIR interfaced stepper motor controller (such as DRV8825). After programming the RMT encoder, S-curve profile can be implemented for desired acceleration, constant speed, and deceleration phases, thereby smoothly driving the stepper motor.

FAQ

- Why the RMT transmits more data than expected?

  The encoding for the RMT transmission is carried out within the ISR context. Should the RMT encoding process be prolonged (for example, through logging or tracing the procedure) or if it is delayed due to interrupt latency and preemptive interrupts, the hardware transmitter might read from the memory before the encoder has written to it. Consequently, the transmitter would end up sending outdated data. Although it's not possible to instruct the transmitter to pause and wait, this issue can be mitigated by employing a combination of the following strategies:

  - Increase the `rmt_tx_channel_config_t::mem_block_symbols`, in steps of 48.
  - Place the encoding function in the IRAM with `IRAM_ATTR` attribute.
  - Enable the `rmt_tx_channel_config_t::with_dma` if DMA is available.
  - Install the RMT driver on a separate CPU core to avoid competing for the same CPU resources with other interrupt heavy peripherals (e.g. WiFi, Bluetooth).

API Reference

Header File

- components/esp_driver_rmt/include/driver/rmt_tx.h
- This header file can be included with:

```
#include "driver/rmt_tx.h"
```

- This header file is a part of the API provided by the `esp_driver_rmt` component. To declare that your component depends on `esp_driver_rmt`, add the following to your CMakeLists.txt:

```
REQUIRES esp_driver_rmt
```

or

```
PRIV_REQUIRES esp_driver_rmt
```

Functions

esp_err_t **`rmt_new_tx_channel`**(*const* rmt_tx_channel_config_t *config, rmt_channel_handle_t *ret_chan)

Create a RMT TX channel.

Parameters:

- **config** -- **[in]** TX channel configurations
- **ret_chan** -- **[out]** Returned generic RMT channel handle

Returns:

- ESP_OK: Create RMT TX channel successfully
- ESP_ERR_INVALID_ARG: Create RMT TX channel failed because of invalid argument
- ESP_ERR_NO_MEM: Create RMT TX channel failed because out of memory
- ESP_ERR_NOT_FOUND: Create RMT TX channel failed because all RMT channels are used up and no more free one
- ESP_ERR_NOT_SUPPORTED: Create RMT TX channel failed because some feature is not supported by hardware, e.g. DMA feature is not supported by hardware
- ESP_FAIL: Create RMT TX channel failed because of other error

esp_err_t **`rmt_transmit`**(rmt_channel_handle_t tx_channel, rmt_encoder_handle_t encoder, *const* void *payload, size_t payload_bytes, *const* rmt_transmit_config_t *config)

Transmit data by RMT TX channel.

> **Note**
>
> This function constructs a transaction descriptor then pushes to a queue. The transaction will not start immediately if there's another one under processing. Based on the setting of `rmt_transmit_config_t::queue_nonblocking`, if there're too many transactions pending in the queue, this function can block until it has free slot, otherwise just return quickly.

> **Note**

The payload data to be transmitted will be encoded into RMT symbols by the specific `encoder`.

> **Note**
>
> You CAN'T modify the `payload` during the transmission, it should be kept valid until the transmission is finished.

Parameters:

- **tx_channel** -- **[in]** RMT TX channel that created by `rmt_new_tx_channel()`
- **encoder** -- **[in]** RMT encoder that created by various factory APIs like `rmt_new_bytes_encoder()`
- **payload** -- **[in]** The raw data to be encoded into RMT symbols
- **payload_bytes** -- **[in]** Size of the `payload` in bytes
- **config** -- **[in]** Transmission specific configuration

Returns:

- ESP_OK: Transmit data successfully
- ESP_ERR_INVALID_ARG: Transmit data failed because of invalid argument
- ESP_ERR_INVALID_STATE: Transmit data failed because channel is not enabled
- ESP_ERR_NOT_SUPPORTED: Transmit data failed because some feature is not supported by hardware, e.g. unsupported loop count
- ESP_FAIL: Transmit data failed because of other error

esp_err_t **`rmt_tx_wait_all_done`**(rmt_channel_handle_t tx_channel, int timeout_ms)

Wait for all pending TX transactions done.

> **Note**
>
> This function will block forever if the pending transaction can't be finished within a limited time (e.g. an infinite loop transaction). See also `rmt_disable()` for how to terminate a working channel.

Parameters:

- **tx_channel** -- **[in]** RMT TX channel that created by `rmt_new_tx_channel()`
- **timeout_ms** -- **[in]** Wait timeout, in ms. Specially, -1 means to wait forever.

Returns:

- ESP_OK: Flush transactions successfully
- ESP_ERR_INVALID_ARG: Flush transactions failed because of invalid argument
- ESP_ERR_TIMEOUT: Flush transactions failed because of timeout

- ESP_FAIL: Flush transactions failed because of other error

esp_err_t **`rmt_tx_register_event_callbacks`**(rmt_channel_handle_t tx_channel, *const* rmt_tx_event_callbacks_t *cbs, void *user_data)

Set event callbacks for RMT TX channel.

> **Note**
>
> User can deregister a previously registered callback by calling this function and setting the callback member in the `cbs` structure to NULL.

> **Note**
>
> When CONFIG_RMT_ISR_IRAM_SAFE is enabled, the callback itself and functions called by it should be placed in IRAM. The variables used in the function should be in the SRAM as well. The `user_data` should also reside in SRAM.

Parameters:

- **tx_channel** -- **[in]** RMT generic channel that created by `rmt_new_tx_channel()`
- **cbs** -- **[in]** Group of callback functions
- **user_data** -- **[in]** User data, which will be passed to callback functions directly

Returns:

- ESP_OK: Set event callbacks successfully
- ESP_ERR_INVALID_ARG: Set event callbacks failed because of invalid argument
- ESP_FAIL: Set event callbacks failed because of other error

esp_err_t **`rmt_new_sync_manager`**(*const* rmt_sync_manager_config_t *config, rmt_sync_manager_handle_t *ret_synchro)

Create a synchronization manager for multiple TX channels, so that the managed channel can start transmitting at the same time.

> **Note**
>
> All the channels to be managed should be enabled by `rmt_enable()` before put them into sync manager.

Parameters:

- **config** -- **[in]** Synchronization manager configuration
- **ret_synchro** -- **[out]** Returned synchronization manager handle

Returns:

- ESP_OK: Create sync manager successfully

- ESP_ERR_INVALID_ARG: Create sync manager failed because of invalid argument
- ESP_ERR_NOT_SUPPORTED: Create sync manager failed because it is not supported by hardware
- ESP_ERR_INVALID_STATE: Create sync manager failed because not all channels are enabled
- ESP_ERR_NO_MEM: Create sync manager failed because out of memory
- ESP_ERR_NOT_FOUND: Create sync manager failed because all sync controllers are used up and no more free one
- ESP_FAIL: Create sync manager failed because of other error

esp_err_t **`rmt_del_sync_manager`**(rmt_sync_manager_handle_t synchro)

Delete synchronization manager.

Parameters: **synchro** -- **[in]** Synchronization manager handle returned from `rmt_new_sync_manager()`

Returns:

- ESP_OK: Delete the synchronization manager successfully
- ESP_ERR_INVALID_ARG: Delete the synchronization manager failed because of invalid argument
- ESP_FAIL: Delete the synchronization manager failed because of other error

esp_err_t **`rmt_sync_reset`**(rmt_sync_manager_handle_t synchro)

Reset synchronization manager.

Parameters: **synchro** -- **[in]** Synchronization manager handle returned from `rmt_new_sync_manager()`

Returns:

- ESP_OK: Reset the synchronization manager successfully
- ESP_ERR_INVALID_ARG: Reset the synchronization manager failed because of invalid argument
- ESP_FAIL: Reset the synchronization manager failed because of other error

Structures

struct **`rmt_tx_event_callbacks_t`**

Group of RMT TX callbacks.

Note

The callbacks are all running under ISR environment

Note

When CONFIG_RMT_ISR_IRAM_SAFE is enabled, the callback itself and functions called by it should be placed in IRAM. The variables used in the function should be in the SRAM as well.

Public Members

rmt_tx_done_callback_t **`on_trans_done`**

Event callback, invoked when transmission is finished

struct `rmt_tx_channel_config_t`

RMT TX channel specific configuration.

Public Members

gpio_num_t **`gpio_num`**

GPIO number used by RMT TX channel. Set to -1 if unused

rmt_clock_source_t **`clk_src`**

Clock source of RMT TX channel, channels in the same group must use the same clock source

uint32_t **`resolution_hz`**

Channel clock resolution, in Hz

size_t **`mem_block_symbols`**

Size of memory block, in number of `rmt_symbol_word_t`, must be an even. In the DMA mode, this field controls the DMA buffer size, it can be set to a large value; In the normal mode, this field controls the number of RMT memory block that will be used by the channel.

size_t **`trans_queue_depth`**

Depth of internal transfer queue, increase this value can support more transfers pending in the background

int **`intr_priority`**

RMT interrupt priority, if set to 0, the driver will try to allocate an interrupt with a relative low priority (1,2,3) uint32_t **invert_out**

Whether to invert the RMT channel signal before output to GPIO pad

uint32_t **with_dma**

If set, the driver will allocate an RMT channel with DMA capability

uint32_t **io_loop_back**

The signal output from the GPIO will be fed to the input path as well

uint32_t **io_od_mode**

Configure the GPIO as open-drain mode

uint32_t **allow_pd**

If set, driver allows the power domain to be powered off when system enters sleep mode. This can save power, but at the expense of more RAM being consumed to save register context.

struct rmt_tx_channel_config_t::[anonymous] **flags**

TX channel config flags

struct **rmt_transmit_config_t**

RMT transmit specific configuration.

Public Members

int **loop_count**

Specify the times of transmission in a loop, -1 means transmitting in an infinite loop

uint32_t **eot_level**

Set the output level for the "End Of Transmission"

uint32_t **queue_nonblocking**

If set, when the transaction queue is full, driver will not block the thread but return directly

struct rmt_transmit_config_t::[anonymous] **flags**

Transmit specific config flags

struct **rmt_sync_manager_config_t**

Synchronous manager configuration.

Public Members

const rmt_channel_handle_t ***tx_channel_array**

Array of TX channels that are about to be managed by a synchronous controller

size_t **array_size**

Size of the `tx_channel_array`

Header File

- components/esp_driver_rmt/include/driver/rmt_rx.h
- This header file can be included with:

```
#include "driver/rmt_rx.h"
```

- This header file is a part of the API provided by the `esp_driver_rmt` component. To declare that your component depends on `esp_driver_rmt`, add the following to your CMakeLists.txt:

```
REQUIRES esp_driver_rmt
```

or

```
PRIV_REQUIRES esp_driver_rmt
```

Functions

esp_err_t **rmt_new_rx_channel**(*const* rmt_rx_channel_config_t *config, rmt_channel_handle_t *ret_chan)

Create a RMT RX channel.

Parameters:

- **config** -- **[in]** RX channel configurations
- **ret_chan** -- **[out]** Returned generic RMT channel handle

Returns:

- ESP_OK: Create RMT RX channel successfully
- ESP_ERR_INVALID_ARG: Create RMT RX channel failed because of invalid argument
- ESP_ERR_NO_MEM: Create RMT RX channel failed because out of memory

- ESP_ERR_NOT_FOUND: Create RMT RX channel failed because all RMT channels are used up and no more free one
- ESP_ERR_NOT_SUPPORTED: Create RMT RX channel failed because some feature is not supported by hardware, e.g. DMA feature is not supported by hardware
- ESP_FAIL: Create RMT RX channel failed because of other error

esp_err_t **rmt_receive**(rmt_channel_handle_t rx_channel, void *buffer, size_t buffer_size, *const* rmt_receive_config_t *config)

Initiate a receive job for RMT RX channel.

> **Note**
>
> This function is non-blocking, it initiates a new receive job and then returns. User should check the received data from the `on_recv_done` callback that registered by `rmt_rx_register_event_callbacks()`.

> **Note**
>
> This function can also be called in ISR context.

> **Note**
>
> If you want this function to work even when the flash cache is disabled, please enable the `CONFIG_RMT_RECV_FUNC_IN_IRAM` option.

Parameters:

- **rx_channel** -- **[in]** RMT RX channel that created by `rmt_new_rx_channel()`
- **buffer** -- **[in]** The buffer to store the received RMT symbols
- **buffer_size** -- **[in]** size of the `buffer`, in bytes
- **config** -- **[in]** Receive specific configurations

Returns:

- ESP_OK: Initiate receive job successfully
- ESP_ERR_INVALID_ARG: Initiate receive job failed because of invalid argument
- ESP_ERR_INVALID_STATE: Initiate receive job failed because channel is not enabled
- ESP_FAIL: Initiate receive job failed because of other error

esp_err_t **rmt_rx_register_event_callbacks**(rmt_channel_handle_t rx_channel, *const* rmt_rx_event_callbacks_t *cbs, void *user_data)

Set callbacks for RMT RX channel.

Note

User can deregister a previously registered callback by calling this function and setting the callback member in the `cbs` structure to NULL.

Note

When CONFIG_RMT_ISR_IRAM_SAFE is enabled, the callback itself and functions called by it should be placed in IRAM. The variables used in the function should be in the SRAM as well. The `user_data` should also reside in SRAM.

Parameters:

- **rx_channel** -- **[in]** RMT generic channel that created by `rmt_new_rx_channel()`
- **cbs** -- **[in]** Group of callback functions
- **user_data** -- **[in]** User data, which will be passed to callback functions directly

Returns:

- ESP_OK: Set event callbacks successfully
- ESP_ERR_INVALID_ARG: Set event callbacks failed because of invalid argument
- ESP_FAIL: Set event callbacks failed because of other error

Structures

struct **`rmt_rx_event_callbacks_t`**

Group of RMT RX callbacks.

Note

The callbacks are all running under ISR environment

Note

When CONFIG_RMT_ISR_IRAM_SAFE is enabled, the callback itself and functions called by it should be placed in IRAM. The variables used in the function should be in the SRAM as well.

Public Members

rmt_rx_done_callback_t **`on_recv_done`**

Event callback, invoked when the RMT channel reception is finished or partial data is received

struct **`rmt_rx_channel_config_t`**

RMT RX channel specific configuration.

Public Members

gpio_num_t **`gpio_num`**

GPIO number used by RMT RX channel. Set to -1 if unused

rmt_clock_source_t **`clk_src`**

Clock source of RMT RX channel, channels in the same group must use the same clock source

uint32_t **`resolution_hz`**

Channel clock resolution, in Hz

size_t **`mem_block_symbols`**

Size of memory block, in number of `rmt_symbol_word_t`, must be an even. In the DMA mode, this field controls the DMA buffer size, it can be set to a large value (e.g. 1024); In the normal mode, this field controls the number of RMT memory block that will be used by the channel.

int **`intr_priority`**

RMT interrupt priority, if set to 0, the driver will try to allocate an interrupt with a relative low priority (1,2,3)

uint32_t **`invert_in`**

Whether to invert the incoming RMT channel signal

uint32_t **`with_dma`**

If set, the driver will allocate an RMT channel with DMA capability

uint32_t **`io_loop_back`**

For debug/test, the signal output from the GPIO will be fed to the input path as well

uint32_t **`allow_pd`**

If set, driver allows the power domain to be powered off when system enters sleep mode. This can save power, but at the expense of more RAM being consumed to save register context.

struct rmt_rx_channel_config_t::[anonymous] **`flags`**

RX channel config flags

struct **rmt_receive_config_t**

RMT receive specific configuration.

Public Members

uint32_t **signal_range_min_ns**

A pulse whose width is smaller than this threshold will be treated as glitch and ignored

uint32_t **signal_range_max_ns**

RMT will stop receiving if one symbol level has kept more than `signal_range_max_ns`

struct rmt_receive_config_t::extra_rmt_receive_flags **flags**

Receive specific config flags

struct **extra_rmt_receive_flags**

Receive specific flags.

Public Members

uint32_t **en_partial_rx**

Set this flag if the incoming data is very long, and the driver can only receive the data piece by piece, because the user buffer is not sufficient to save all the data.

Header File

- components/esp_driver_rmt/include/driver/rmt_common.h
- This header file can be included with:

```
#include "driver/rmt_common.h"
```

- This header file is a part of the API provided by the `esp_driver_rmt` component. To declare that your component depends on `esp_driver_rmt`, add the following to your CMakeLists.txt:

```
REQUIRES esp_driver_rmt
```

or

```
PRIV_REQUIRES esp_driver_rmt
```

Functions

esp_err_t `rmt_del_channel`(rmt_channel_handle_t channel)

Delete an RMT channel.

Parameters: **channel** -- **[in]** RMT generic channel that created by `rmt_new_tx_channel()` or `rmt_new_rx_channel()`

Returns:

- ESP_OK: Delete RMT channel successfully
- ESP_ERR_INVALID_ARG: Delete RMT channel failed because of invalid argument
- ESP_ERR_INVALID_STATE: Delete RMT channel failed because it is still in working
- ESP_FAIL: Delete RMT channel failed because of other error

esp_err_t `rmt_apply_carrier`(rmt_channel_handle_t channel, *const* rmt_carrier_config_t *config)

Apply modulation feature for TX channel or demodulation feature for RX channel.

Parameters:

- **channel** -- **[in]** RMT generic channel that created by `rmt_new_tx_channel()` or `rmt_new_rx_channel()`
- **config** -- **[in]** Carrier configuration. Specially, a NULL config means to disable the carrier modulation or demodulation feature

Returns:

- ESP_OK: Apply carrier configuration successfully
- ESP_ERR_INVALID_ARG: Apply carrier configuration failed because of invalid argument
- ESP_FAIL: Apply carrier configuration failed because of other error

esp_err_t `rmt_enable`(rmt_channel_handle_t channel)

Enable the RMT channel.

> **Note**
>
> This function will acquire a PM lock that might be installed during channel allocation

Parameters: **channel** -- **[in]** RMT generic channel that created by `rmt_new_tx_channel()` or `rmt_new_rx_channel()`

Returns:

- ESP_OK: Enable RMT channel successfully
- ESP_ERR_INVALID_ARG: Enable RMT channel failed because of invalid argument

- ESP_ERR_INVALID_STATE: Enable RMT channel failed because it's enabled already
- ESP_FAIL: Enable RMT channel failed because of other error

esp_err_t **rmt_disable**(rmt_channel_handle_t channel)

Disable the RMT channel.

> **Note**
>
> This function will release a PM lock that might be installed during channel allocation

Parameters: **channel** -- **[in]** RMT generic channel that created by `rmt_new_tx_channel()` or `rmt_new_rx_channel()`

Returns:

- ESP_OK: Disable RMT channel successfully
- ESP_ERR_INVALID_ARG: Disable RMT channel failed because of invalid argument
- ESP_ERR_INVALID_STATE: Disable RMT channel failed because it's not enabled yet
- ESP_FAIL: Disable RMT channel failed because of other error

Structures

struct **rmt_carrier_config_t**

RMT carrier wave configuration (for either modulation or demodulation)

Public Members

uint32_t **frequency_hz**

Carrier wave frequency, in Hz, 0 means disabling the carrier

float **duty_cycle**

Carrier wave duty cycle (0~100%)

uint32_t **polarity_active_low**

Specify the polarity of carrier, by default it's modulated to base signal's high level

uint32_t **always_on**

If set, the carrier can always exist even there's not transfer undergoing

struct rmt_carrier_config_t::[anonymous] **flags**

Carrier config flags

Header File

- components/esp_driver_rmt/include/driver/rmt_encoder.h
- This header file can be included with:

```
#include "driver/rmt_encoder.h"
```

- This header file is a part of the API provided by the `esp_driver_rmt` component. To declare that your component depends on `esp_driver_rmt`, add the following to your CMakeLists.txt:

```
REQUIRES esp_driver_rmt
```

or

```
PRIV_REQUIRES esp_driver_rmt
```

Functions

esp_err_t **rmt_new_bytes_encoder**(*const* rmt_bytes_encoder_config_t *config, rmt_encoder_handle_t *ret_encoder)

Create RMT bytes encoder, which can encode byte stream into RMT symbols.

Parameters:

- **config** -- **[in]** Bytes encoder configuration
- **ret_encoder** -- **[out]** Returned encoder handle

Returns:

- ESP_OK: Create RMT bytes encoder successfully
- ESP_ERR_INVALID_ARG: Create RMT bytes encoder failed because of invalid argument
- ESP_ERR_NO_MEM: Create RMT bytes encoder failed because out of memory
- ESP_FAIL: Create RMT bytes encoder failed because of other error

esp_err_t **rmt_bytes_encoder_update_config**(rmt_encoder_handle_t bytes_encoder, *const* rmt_bytes_encoder_config_t *config)

Update the configuration of the bytes encoder.

Note

The configurations of the bytes encoder is also set up by `rmt_new_bytes_encoder()`. This function is used to update the configuration of the bytes encoder at runtime.

Parameters:

- **bytes_encoder** -- **[in]** Bytes encoder handle, created by e.g `rmt_new_bytes_encoder()`
- **config** -- **[in]** Bytes encoder configuration

Returns:

- ESP_OK: Update RMT bytes encoder successfully
- ESP_ERR_INVALID_ARG: Update RMT bytes encoder failed because of invalid argument
- ESP_FAIL: Update RMT bytes encoder failed because of other error

esp_err_t **rmt_new_copy_encoder**(*const* rmt_copy_encoder_config_t *config, rmt_encoder_handle_t *ret_encoder)

Create RMT copy encoder, which copies the given RMT symbols into RMT memory.

Parameters:

- **config** -- **[in]** Copy encoder configuration
- **ret_encoder** -- **[out]** Returned encoder handle

Returns:

- ESP_OK: Create RMT copy encoder successfully
- ESP_ERR_INVALID_ARG: Create RMT copy encoder failed because of invalid argument
- ESP_ERR_NO_MEM: Create RMT copy encoder failed because out of memory
- ESP_FAIL: Create RMT copy encoder failed because of other error

esp_err_t **rmt_new_simple_encoder**(*const* rmt_simple_encoder_config_t *config, rmt_encoder_handle_t *ret_encoder)

Create RMT simple callback encoder, which uses a callback to convert incoming data into RMT symbols.

Parameters:

- **config** -- **[in]** Simple callback encoder configuration
- **ret_encoder** -- **[out]** Returned encoder handle

Returns:

- ESP_OK: Create RMT simple callback encoder successfully
- ESP_ERR_INVALID_ARG: Create RMT simple callback encoder failed because of invalid argument
- ESP_ERR_NO_MEM: Create RMT simple callback encoder failed because out of memory
- ESP_FAIL: Create RMT simple callback encoder failed because of other error

esp_err_t **rmt_del_encoder**(rmt_encoder_handle_t encoder)

Delete RMT encoder.

Parameters: **encoder** -- **[in]** RMT encoder handle, created by e.g `rmt_new_bytes_encoder()`

Returns:

- ESP_OK: Delete RMT encoder successfully
- ESP_ERR_INVALID_ARG: Delete RMT encoder failed because of invalid argument
- ESP_FAIL: Delete RMT encoder failed because of other error

esp_err_t **`rmt_encoder_reset`**(rmt_encoder_handle_t encoder)

Reset RMT encoder.

Parameters: **encoder** -- **[in]** RMT encoder handle, created by e.g `rmt_new_bytes_encoder()`

Returns:

- ESP_OK: Reset RMT encoder successfully
- ESP_ERR_INVALID_ARG: Reset RMT encoder failed because of invalid argument
- ESP_FAIL: Reset RMT encoder failed because of other error

void ***`rmt_alloc_encoder_mem`**(size_t size)

A helper function to allocate a proper memory for RMT encoder.

Parameters: **size** -- Size of memory to be allocated

Returns: Pointer to the allocated memory if the allocation is successful, NULL otherwise

Structures

struct **`rmt_encoder_t`**

Interface of RMT encoder.

Public Members

size_t (***encode**)(rmt_encoder_t *encoder, rmt_channel_handle_t tx_channel, *const* void *primary_data, size_t data_size, rmt_encode_state_t *ret_state)

Encode the user data into RMT symbols and write into RMT memory.

> **Note**
>
> The encoding function will also be called from an ISR context, thus the function must not call any blocking API.

Note

It's recommended to put this function implementation in the IRAM, to achieve a high performance and less interrupt latency.

Param encoder: [in] Encoder handle

Param tx_channel: [in] RMT TX channel handle, returned from `rmt_new_tx_channel()`

Param primary_data: [in] App data to be encoded into RMT symbols

Param data_size: [in] Size of primary_data, in bytes

Param ret_state: [out] Returned current encoder's state

Return: Number of RMT symbols that the primary data has been encoded into

esp_err_t (*reset)(rmt_encoder_t *encoder)

Reset encoding state.

Param encoder: [in] Encoder handle

Return:

- ESP_OK: reset encoder successfully
- ESP_FAIL: reset encoder failed

esp_err_t (*del)(rmt_encoder_t *encoder)

Delete encoder object.

Param encoder: [in] Encoder handle

Return:

- ESP_OK: delete encoder successfully
- ESP_FAIL: delete encoder failed

struct **rmt_bytes_encoder_config_t**

Bytes encoder configuration.

Public Members

rmt_symbol_word_t **bit0**

How to represent BIT0 in RMT symbol

rmt_symbol_word_t **bit1**

How to represent BIT1 in RMT symbol

uint32_t **msb_first**

Whether to encode MSB bit first

struct rmt_bytes_encoder_config_t::[anonymous] **flags**

Encoder config flag

struct **rmt_copy_encoder_config_t**

Copy encoder configuration.

struct **rmt_simple_encoder_config_t**

Simple callback encoder configuration.

Public Members

rmt_encode_simple_cb_t **callback**

Callback to call for encoding data into RMT items

void *__arg__

Opaque user-supplied argument for callback

size_t **min_chunk_size**

Minimum amount of free space, in RMT symbols, the encoder needs in order to guarantee it always returns non-zero. Defaults to 64 if zero / not given.

Type Definitions

typedef size_t (***rmt_encode_simple_cb_t**)(*const* void *data, size_t data_size, size_t symbols_written, size_t symbols_free, rmt_symbol_word_t *symbols, bool *done, void *arg)

Callback for simple callback encoder.

This will get called to encode the data stream of given length (as passed to rmt_transmit by the user) into symbols to be sent by the hardware.

The callback will be initially called with symbol_pos=0. If the callback encodes N symbols and finishes, the next callback will always be with symbols_written=N. If the callback then encodes M symbols, the next callback will always be with symbol_pos=N+M, etc. The only exception is when the encoder is reset (e.g. to begin a new transaction) in which case symbol_pos will always restart at 0.

If the amount of free space in the symbol buffer (as indicated by symbols_free) is too low, the function can return 0 as result and the RMT will call the function again once there is more space available. Note that the callback should eventually return non-0 if called with free space of rmt_simple_encoder_config_t::min_chunk_size or more. It is acceptable to return 0 for a given free space N, then on the next call (possibly with a larger free buffer space) return less or more than N symbols.

When the transaction is done (all data_size data is encoded), the callback can indicate this by setting *done to true. This can either happen on the last callback call that returns an amount of symbols encoded, or on a callback that returns zero. In either case, the callback will not be called again for this transaction.

Param data:	**[in]** Data pointer, as passed to rmt_transmit()
Param data_size:	**[in]** Size of the data, as passed to rmt_transmit()
Param symbols_written:	**[in]** Current position in encoded stream, in symbols
Param symbols_free:	**[in]** The maximum amount of symbols that can be written into the `symbols` buffer
Param symbols:	**[out]** Symbols to be sent to the RMT hardware
Param done:	**[out]** Setting this to true marks this transaction as finished
Param arg:	Opaque argument
Return:	Amount of symbols encoded in this callback round. 0 if more space is needed.

Enumerations

enum **`rmt_encode_state_t`**

RMT encoding state.

Values:

enumerator **`RMT_ENCODING_RESET`**

The encoding session is in reset state

enumerator **`RMT_ENCODING_COMPLETE`**

The encoding session is finished, the caller can continue with subsequent encoding

enumerator **`RMT_ENCODING_MEM_FULL`**

The encoding artifact memory is full, the caller should return from current encoding session

Header File

- components/esp_driver_rmt/include/driver/rmt_types.h
- This header file can be included with:

```
#include "driver/rmt_types.h"
```

- This header file is a part of the API provided by the `esp_driver_rmt` component. To declare that your component depends on `esp_driver_rmt`, add the following to your CMakeLists.txt:

```
REQUIRES esp_driver_rmt
```

or

```
PRIV_REQUIRES esp_driver_rmt
```

Structures

struct **rmt_tx_done_event_data_t**

Type of RMT TX done event data.

Public Members

size_t **num_symbols**

The number of transmitted RMT symbols, including one EOF symbol, which is appended by the driver to mark the end of a transmission. For a loop transmission, this value only counts for one round.

struct **rmt_rx_done_event_data_t**

Type of RMT RX done event data.

Public Members

rmt_symbol_word_t ***received_symbols**

Point to the received RMT symbols

size_t **num_symbols**

The number of received RMT symbols

uint32_t **is_last**

Indicating if the current received data are the last part of the transaction

struct rmt_rx_done_event_data_t::[anonymous] **flags**

Extra flags

Type Definitions

typedef struct rmt_channel_t ***rmt_channel_handle_t***

Type of RMT channel handle.

typedef struct rmt_sync_manager_t ***rmt_sync_manager_handle_t***

Type of RMT synchronization manager handle.

typedef struct rmt_encoder_t ***rmt_encoder_handle_t***

Type of RMT encoder handle.

typedef bool (***rmt_tx_done_callback_t**)(rmt_channel_handle_t tx_chan, *const* rmt_tx_done_event_data_t *edata, void *user_ctx)

Prototype of RMT event callback.

Param tx_chan: **[in]** RMT channel handle, created from `rmt_new_tx_channel()`

Param edata: **[in]** Point to RMT event data. The lifecycle of this pointer memory is inside this function, user should copy it into static memory if used outside this function.

Param user_ctx: **[in]** User registered context, passed from `rmt_tx_register_event_callbacks()`

Return: Whether a high priority task has been waken up by this callback function

typedef bool (***rmt_rx_done_callback_t**)(rmt_channel_handle_t rx_chan, *const* rmt_rx_done_event_data_t *edata, void *user_ctx)

Prototype of RMT event callback.

Param rx_chan: **[in]** RMT channel handle, created from `rmt_new_rx_channel()`

Param edata: **[in]** Point to RMT event data. The lifecycle of this pointer memory is inside this function, user should copy it into static memory if used outside this function.

Param user_ctx: **[in]** User registered context, passed from `rmt_rx_register_event_callbacks()`

Return: Whether a high priority task has been waken up by this function

Header File

- components/hal/include/hal/rmt_types.h

- This header file can be included with:

```
#include "hal/rmt_types.h"
```

Unions

union **rmt_symbol_word_t**

#include <rmt_types.h>

The layout of RMT symbol stored in memory, which is decided by the hardware design.

Public Members

uint16_t **duration0**

Duration of level0

uint16_t **level0**

Level of the first part

uint16_t **duration1**

Duration of level1

uint16_t **level1**

Level of the second part

struct rmt_symbol_word_t::[anonymous] **[anonymous]**

uint32_t **val**

Equivalent unsigned value for the RMT symbol

Type Definitions

typedef soc_periph_rmt_clk_src_t **rmt_clock_source_t**

RMT group clock source.

> **Note**
>
> User should select the clock source based on the power and resolution requirement

[1] : Different ESP chip series might have different numbers of RMT channels. Please refer to [TRM] for details. The driver does not forbid you from applying for more RMT channels, but it returns an error when there are no hardware resources available. Please always check the return value when doing Resource Allocation.

[2] : The callback function, e.g., `rmt_tx_event_callbacks_t::on_trans_done`, and the functions invoked by itself should also reside in IRAM, users need to take care of this by themselves.

Was this page helpful?