

RYZ014

Module System Integration Guide

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1. Hardware Control

1.1 Generic Rules

Throughout this document, it is assumed that the product uses an RYZ014 module connected to an external host MCU. The application runs on the external host MCU, which is the master of the system. The RYZ014 module functions as a slave.

The RYZ014-based module behaves like a DCE. There are several possible ways to connect the RYZ014 to an external host MCU using the UART interface (the physical UART port usually used is UART0):

Host		Hardware Flow control	
		Supported	Not supported
Low power	Supported	Type 1: section 1.1.1	Type 3: section 1.1.3
	Not supported	Type 2: section 1.1.2	Type 4: section 1.1.4

1.1.1 Type 1: Hardware Flow Control Supported and Low Power Supported

Figure 1 is the recommended design.

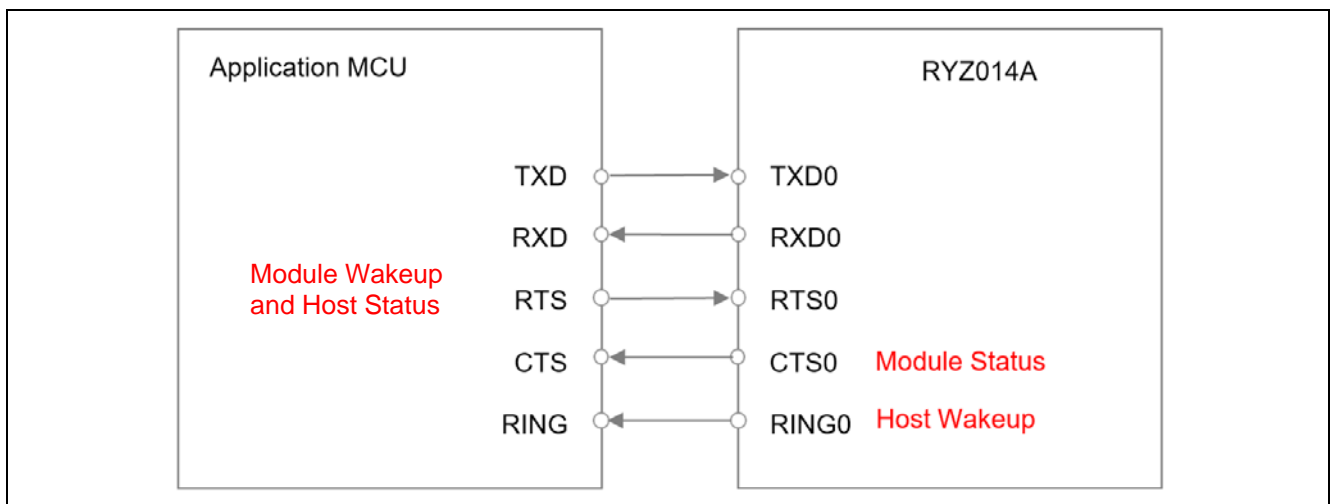


Figure 1. UART With Hardware Flow Control and Low Power

The `AT+SQNRICFG` command can be used to configure the RING function. By default, RING activation mirrors general URC events and data. The RYZ014 wakes the host up whenever Unsolicited Response Codes (URCs) are pending on UART 0, or data are received from the network. In this configuration, enter the following commands:

```

AT+CFUN=5
AT+SQNIPSCFG=2,100 //Set UART timeout to 100 ms
AT+SQNHWCFG="uart0","enable","rtscts" //Enable flow control on UART0
//((default configuration))
AT+SQNHWCFG="wakeRTS0","enable" //Set RTS0 as a wake source
//((default configuration))
AT+SQNRICFG=1,3,100 //Reduce RING timeout to 100 ms
AT^RESET
    
```

Refer to the *RYZ014A Module Integration Guide* for the values of the pull-ups or pull-downs to be tied to the physical signals.

1.1.2 Type 2: Hardware Flow Control Supported and Low Power Not Supported

In this configuration, monitoring the RING line is not needed, provided the MCU does not use PPP or socket online mode. Hardwiring is simpler:

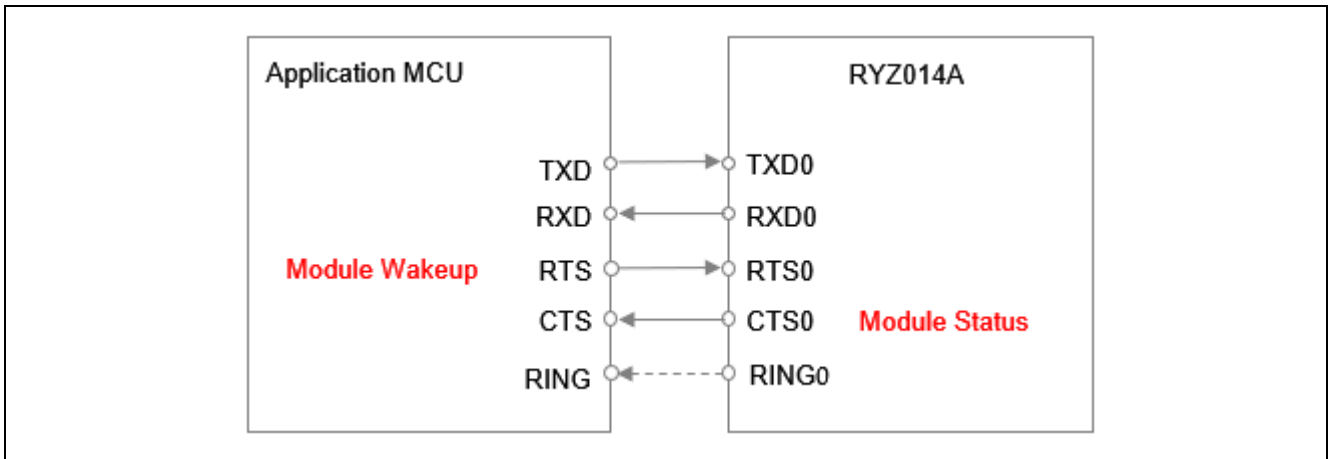


Figure 2. UART With Hardware Flow Control, Without Low Power

Enter the following commands:

```
AT+CFUN=5
AT+SQNIPSCFG=2,100 //Set UART timeout to 100 ms
AT+SQNHWCFG="uart0","enable","rtscts" //Enable flow control on UART0
//((default configuration)
AT+SQNHWCFG="wakeRTS0","enable" //Set RTS0 as a wake source
//((default configuration)
AT+SQNRICFG=1,3,100 //Reduce RING timeout to 100 ms
//((optional)
AT^RESET
```

If the MCU uses PPP or socket online mode, the RING line toggles to warn of pending URCs or SMSes, prompting the MCU to resume command mode.

Refer to the *RYZ014A Module Integration Guide* for the values of the pull-ups or pull-downs to be tied to the physical signals.

1.1.3 Type 3: Hardware Flow Control Not Supported and Low Power Supported

If the MCU does not support hardware flow control but does support low-power modes, the recommended approach is to write a few software lines to emulate hardware flow control using two of the host MCU's GPIOs:

- As RTS0 wakes up the modem, the host MCU software must handle this pin according to UART flow control protocol.
- The host MCU must also handle the CTS0 pin, as the modem toggles it when sending data to the host MCU.

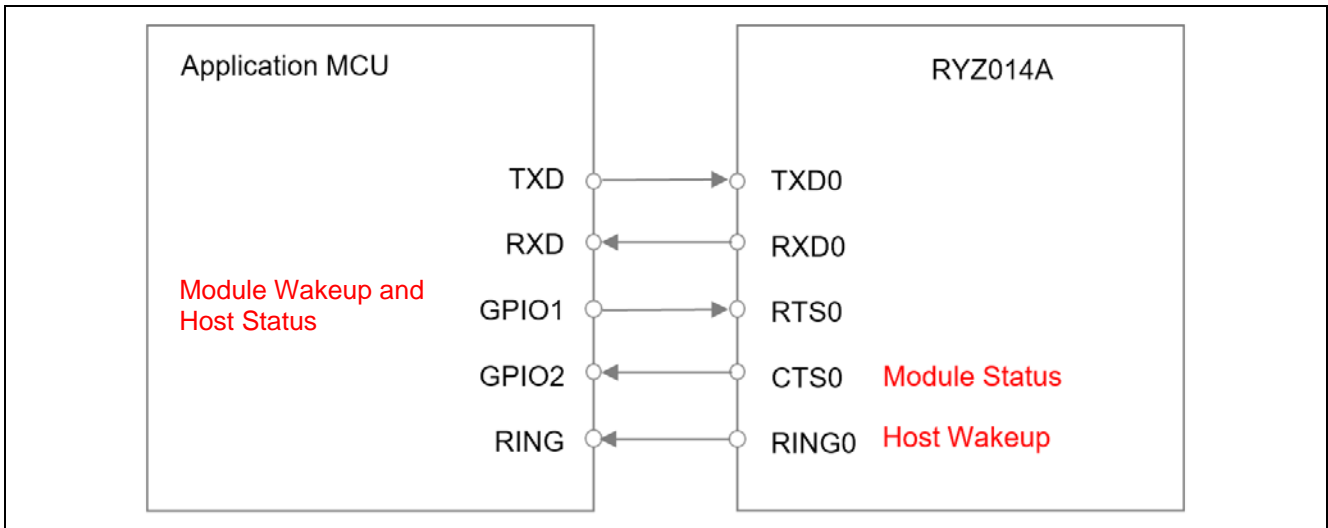


Figure 3. UART Without Hardware Flow Control, With Low Power

The `AT+SQNRICFG` command can be used to configure the RING function. By default, RING activation is triggered by general URC events and data. The modem wakes the host up whenever URCs are generated on UART0, or data are received from the network. In this configuration, enter the following commands:

```

AT+CFUN=5
AT+SQNIPSCFG=2,100 //Set UART timeout to 100 ms
AT+SQNHWCFG="uart0","enable","rtscts" //Enable flow control on UART0
// (default configuration)
AT+SQNHWCFG="wakeRTS0","enable" //Set RTS0 as a wake source
// (default configuration)
AT+SQNRICFG=1,3,100 //Reduce RING timeout to 100 ms
AT^RESET

```

Refer to the *RYZ014A Module Integration Guide* for the values of the pull-ups or pull-downs to be tied to the physical signals.

1.1.4 Type 4: Hardware Flow Control and Low Power Not Supported

If the MCU supports neither hardware flow control nor low power modes, then a simplified wiring can be implemented:

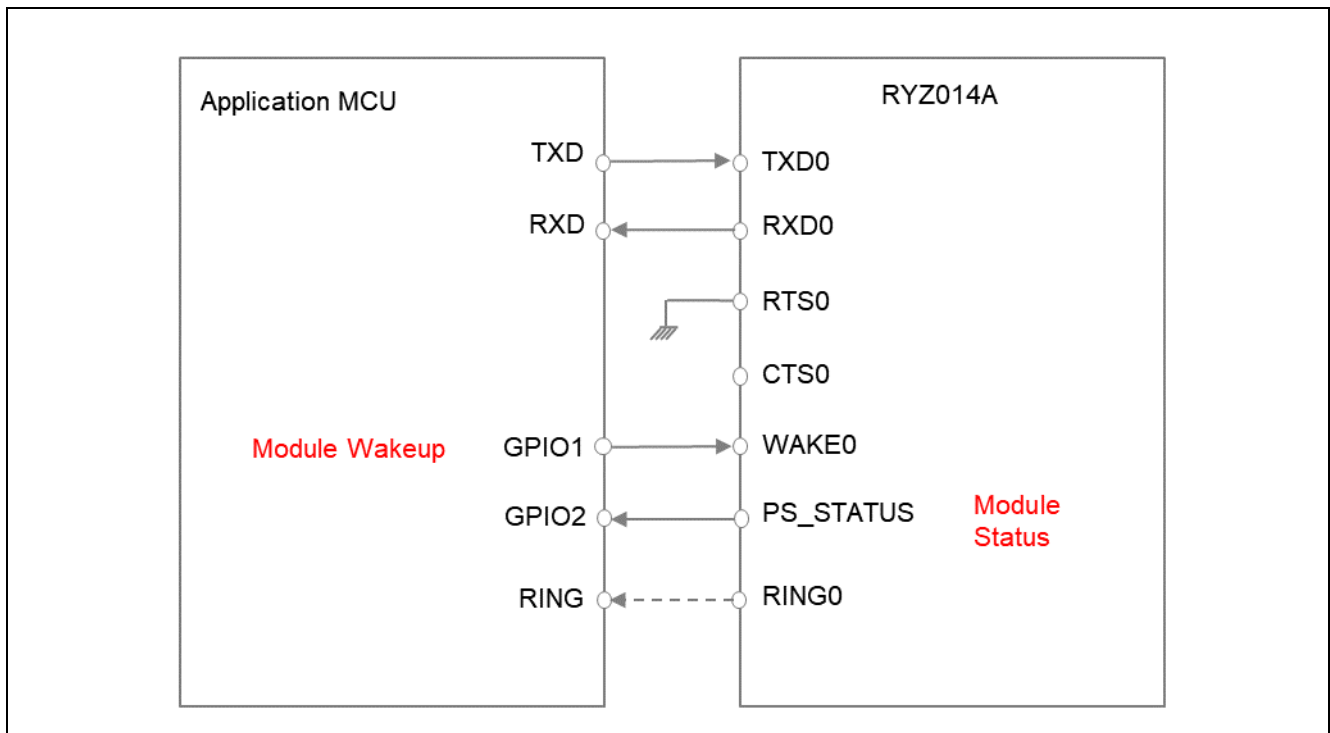


Figure 4. UART Without Hardware Flow Control and No Support for Low Power Modes

The PS_STATUS line must be connected to the MCU, which monitors it to know whether the modem is awake or needs to be woken up.

Wiring the RING line is optional if the MCU does not use PPP or socket online mode.

As explained in section 1.2.3, the PS_STATUS signal only tells if the modem is awake or asleep, not if it is ready to receive AT commands. The host MCU must use AT polling by sending **AT+CFUN?** and wait for the **OK** response before sending any other command. It is recommended to pull down RTS0 to make sure that UART communication will not be interrupted and to leave the CTS0 line unconnected.

The following commands must be entered to properly configure the modem in this mode:

```

AT+CFUN=5
AT+SQNIPSCFG=2,100 //Set UART timeout to 100ms
AT+SQNHWCFG="uart0","enable","none" //Disable flow control on UART0
AT+SQNHWCFG="wakeRTS0","disable" //Unset RTS0 as wake source
AT+SQNHWCFG="wake0","enable" //Set wake0 as a wake source
AT+SQNHWCFG="ps_status","enable" //Enable ps_status function
//default configuration
AT+SQNRICFG=1,3,100 //Reduce RING timeout to 100 ms (optional)
AT^RESET

```

Refer to the *RYZ014A Module Integration Guide* for the values of the pull-ups or pull-downs to be tied to the physical signals.

In this configuration, baud rates higher than 115200 bps on the UART connected to the MCU are not recommended. At high speeds, without flow control, it is not possible to guarantee data integrity. The MCU application should therefore handle potential data loss. The UARTs Rx/Tx FIFOs are 64 bytes deep.

1.2 Signals

The host application running on the external MCU has access to the following physical interfaces of the modem:

- The UART: Used to send AT commands to turn the network connectivity on or off. The UART can be used to perform software resets or shutdowns.
- The RESETN pin of the modem: Asserting RESETN causes a hardware reset of the modem.
- Most of the time, the MCU also controls the modem's power supply.

1.2.1 Reset Signal

Refer to the module's data sheet for information on the RESETN signal. The RESETN signal is active low.

To reset the modem, the host application can use the following methods:

- UART
Use `AT^RESET`. (Refer to the *RYZ014 Modules AT Command User's Manual*.)
- RESETN
The application software asserts RESETN to perform a hardware reset. For timing information and constraints, refer to the module's data sheet.
- Power supply shutdown
Before any power supply shutdown, a software shutdown using `AT+SQNSSHDN` is highly advised. Once this command is sent, only a hardware reset using the RESETN line restarts the module. Turning VBAT back on will not restart the module.

1.2.2 Wake Source

When needed, the host application can wake the modem up by toggling any wake source. There are four pins of the module that can be used as external wake sources: WAKE0, WAKE1, RTS0, and RTS1. `AT+SQNHWCFG` can be used to show the wake source configuration and change it. Refer to the *Use Cases with AT Commands Application Note* for more details.

1.2.3 PS_STATUS

PS_STATUS reflects the module's current status. It is low when the module is in sleep / deep sleep mode and goes high when the module is active.

PS_STATUS can be used to supply power to antenna switches for dynamic matching, or to power any component that needs to be turned on when the modem wakes up.

When no hardware flow control is used, monitoring PS_STATUS is mandatory for proper AT command communication. Before sending any new command, the host must ensure that:

- PS_STATUS is high.
- The modem AT buffer is ready. The AT buffer is ready when the host receives an `OK` response to an AT command.

The figures below show the behavior of the PS_STATUS line with respect to the CTS0 line used when hardware flow control is on. The CTS0 line goes low when the modem is ready to receive AT commands.

1.2.3.1 Modem Wakes Up from Sleep Mode

In this case, the PS_STATUS and CTS0 lines are asserted at the same time; the modem is ready to receive AT commands as soon as it wakes up.

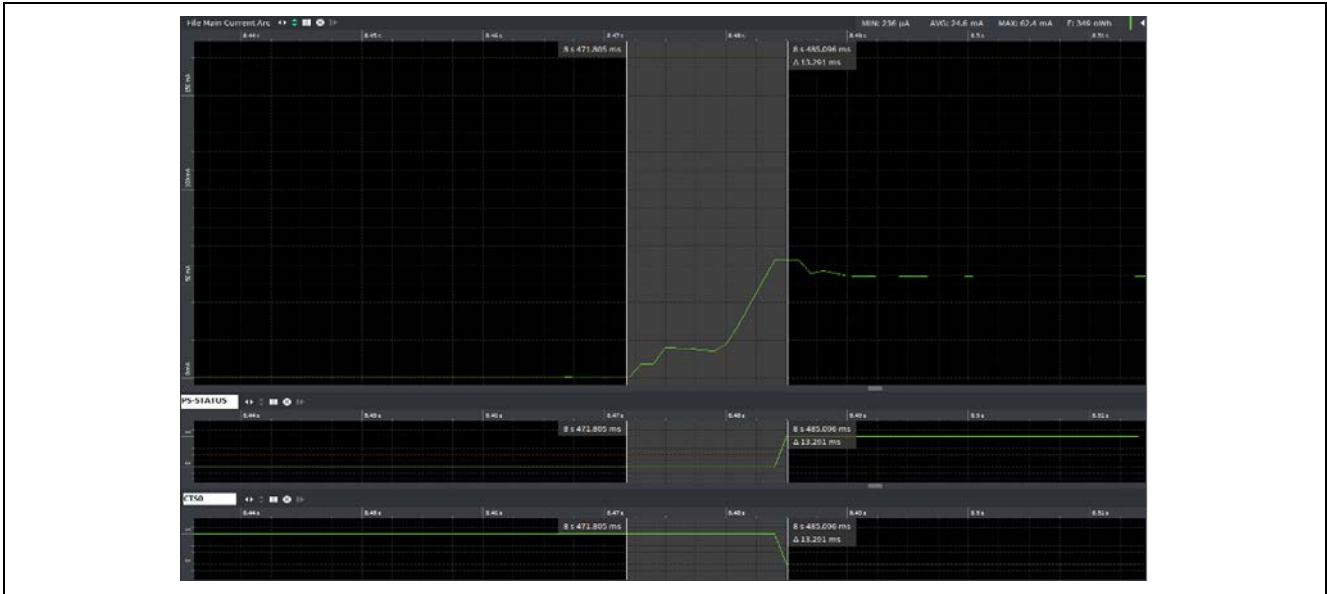


Figure 5. Modem Wakes Up from Sleep Mode

1.2.3.2 Modem Wakes Up from Deep Sleep Mode

Here the PS_STATUS line transitions 345 ms earlier than the CTS0 line. Therefore, if the CTS0 line is not monitored by the host MCU, then the latter needs to perform AT polling as indicated above.

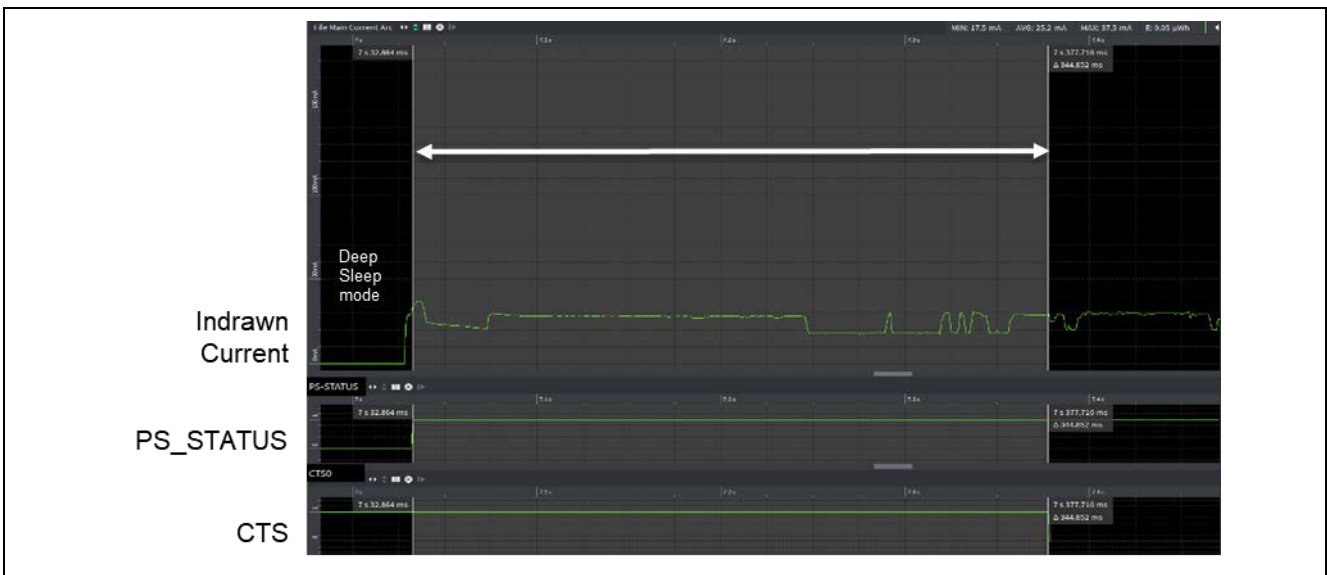


Figure 6. Modem Wakes Up from Deep Sleep Mode

1.2.3.3 RRC Idle

During RRC Idle, the modem will go to sleep mode in between paging opportunities. In Figure 7, PS_STATUS and CTS0 lines are toggling together, 13 ms after the modem wakes up to listen to the paging opportunity.

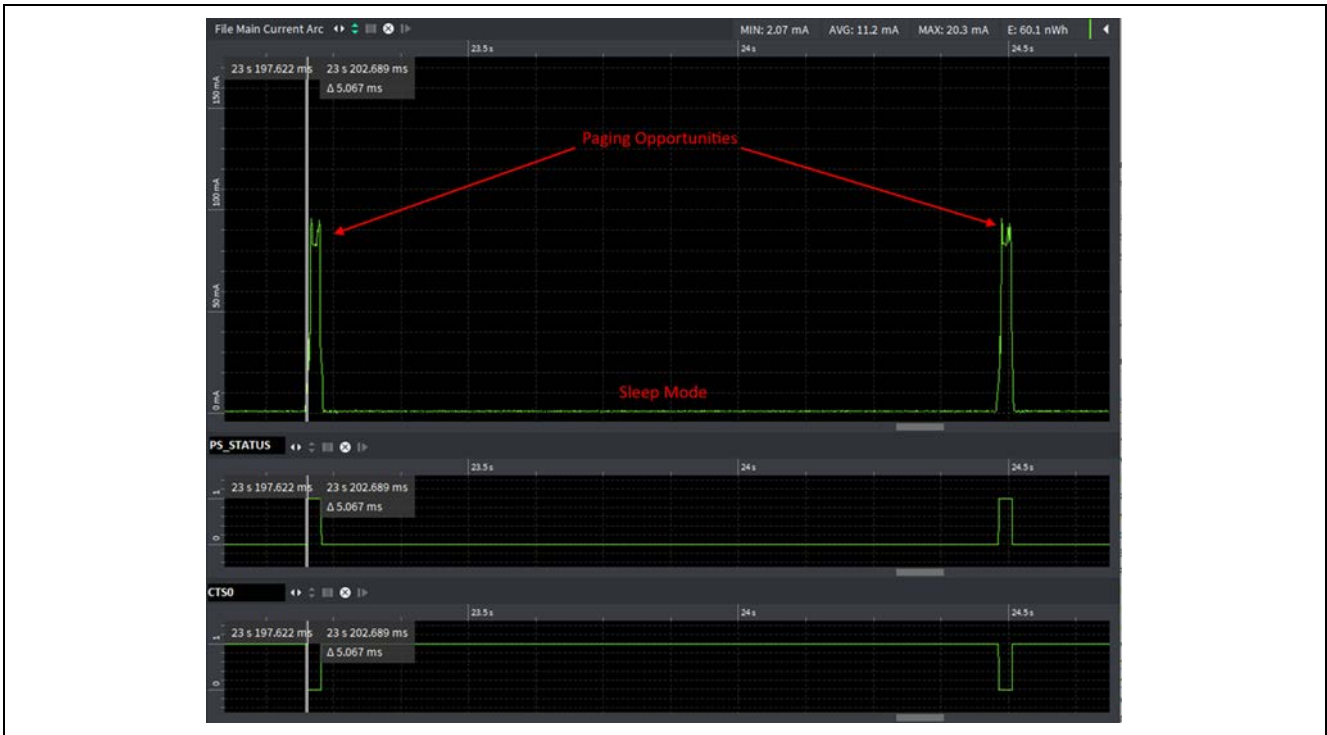


Figure 7. RRC Idle

1.3 Block Diagram

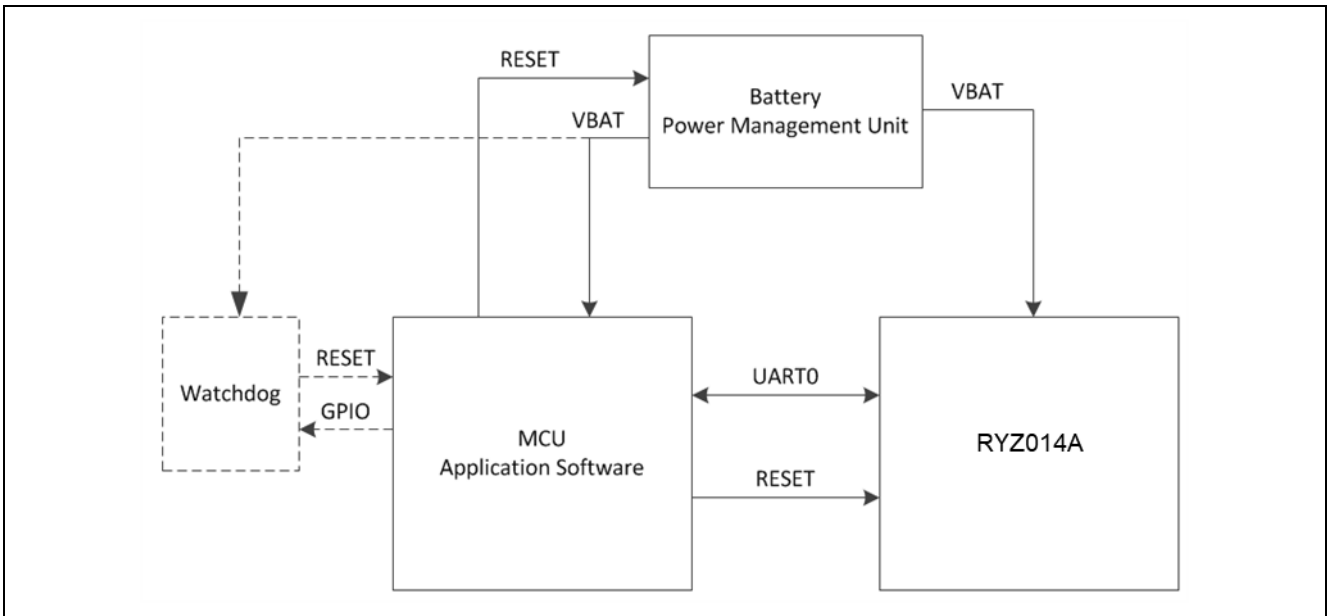


Figure 8. System Block Diagram

The power management unit (PMU) is responsible for supplying power to the different blocks. The device can be battery or mains powered. The PMU is controlled by the host application. Resetting the PMU causes a whole platform reset (host and modem). The PMU is also responsible for the battery charge.

The optional watchdog resets the MCU to avoid any system lock-up. The application software must restart the watchdog periodically to avoid spurious triggering.

The watchdog value must take the low power consumption constraints of the system into account. For instance, PSM mode capable devices must have a watchdog value longer than the longest value of the PSM timer. The modem has its own hardware watchdog.

2. Software Integration

RYZ014 modules are 'slim' modems. They require a host running a dedicated software (called the 'connection manager') to:

- Control the modem.
- Manage the connectivity and handle errors reported by the network or the end server.
- Parse and act on unsolicited response codes.
- Manage unexpected events, especially in M2M applications where human intervention is not possible.
- Schedule and control application and modem software upgrades over the air.

This chapter details the AT dialogue between modem and application software, then presents examples of connection manager implementations.

2.1 AT Parser Generic Rules

The host MCU interacts with the RYZ014 modem using AT commands.

At boot, the modem sends a `+SYSSTART` URC when it is ready to process AT commands. Any AT command sent to the modem before the reception of the `+SYSSTART` URC is discarded.

The modem starts in `CFUN=0` (minimum functionality) mode. It does not try to attach to the network until the host MCU sets it in `CFUN=1` (full functionality).

AT commands are handled serially by the modem. The host MCU must never send a new AT command before receiving the acknowledgment of the previous one. There are two types of AT commands:

- Synchronous
 - The AT command returns a result. This can take several seconds. The execution time of an AT command depends, most of the time, on the network. It is therefore not possible to define a typical figure. The host MCU should implement its own AT command timeout as explained in section 2.2.5.1.
 - During the execution of a synchronous command, no other commands or URC can be processed. All incoming traffic is put aside until the command ends.
- Asynchronous
 - The AT command returns within 300 ms. The result is communicated later using a specific URC. The host MCU must be ready to receive the URC at any time. RYZ014 modules activate the RING line of the AT UART to notify of pending URC(s).

2.1.1 AT Command Syntax

Note: All AT commands supported by RYZ014 modules comply with 3GPP TS 27.005-11.0.0 section 4.

2.1.1.1 Command Line

Commands can take three different forms:

- Write Commands

Syntax	Description
<code>AT<cmd></code>	Basic command, no '+' prefix.
<code>AT<cmd>=xx</code>	Basic command with parameter.
<code>AT+<cmd></code>	Extended command (prefixed with '+').
<code>AT+<cmd>=, ,xx</code>	Some parameters may be omitted.
<code>AT^<cmd></code>	Some private AT commands use other characters instead of '+', for example, <code>AT^RESET</code>

- Read Commands

Syntax	Description
<code>AT+<cmd>?</code>	To check current parameter values.

- Test Commands

Syntax	Description
AT+<cmd>=?	To check possible parameter values.

AT commands are terminated with:

Syntax	Description
<CR>	Command line termination character (settable).
AT+<cmd1>;AT+<cmd2>	Semicolons. Any URC generated by the first command might arrive during the execution of the second command.

2.1.1.2 Responses

There are four types of responses:

- Information Text

Syntax	Description
[+<cmd>:]free text<CR><LF>	Response to write command. Multi-line response is possible. Each line has the same format.
+<cmd>: (0-3),(0,1),(0-10,15), ("aa", "bb")<CR><LF>	Response to a test command.

- Result Codes

Syntax	Description
<CR><LF><result code><CR><LF>	Verbose result code (ATV1, default).
<numeric><CR>	Abbreviated result code (ATV0).

- Intermediate Result Code

An intermediate result code reports on the progress of a DCE's action.

For example, after successfully opening a socket connection in command mode using **AT+SQNSD**, the DCE sends the intermediate result code **CONNECT**.

After that, the DCE moves from command mode to online data mode and does not accept any more AT commands. In this mode, all data is forwarded to the IP stack and transmitted.

- Unsolicited Results Code

Syntax	Description
+<cmd>:... ...*	Unsolicited result codes signal an event not directly associated with the latest issued AT command.

2.1.2 Process AT Command Response

Depending on the command and its results, the responses can be:

Syntax	Description
<CR><LF><result code><CR><LF>	Verbose response to a command (after ATV1).
[+<cmd>:]free text<CR><LF> <CR><LF><result code><CR><LF>	Verbose response to a command (after ATV1).
CONNECT	Response to particular commands.
>	Prompt for data. Response to particular commands.

The <result code> mentioned in the table above can be:

Syntax	Description
OK	Command execution succeeded.
NO CARRIER	Network communication lost.
ERROR	Generic error. Can be replaced by the next two items.
+CME ERROR: <err>	Error related to MT operation.
+CMS ERROR: <err>	Error related to the mobile equipment or the network.

2.1.3 Process Unsolicited Result Code

The DTE must check for URCs, which may be issued at any time by the DCE, and handle them.

Most of the time, no URC is inserted between the emission of an AT command and the reception of the corresponding result code. However, this is not guaranteed by design. The following sequence can happen, if seldom:

1. The host starts sending AT command "AT+SQNSD=..."
2. The modem starts sending URC.
3. The mode completes URC transmission before echoing the "AT+SQNSD=..." command.
4. The modem processes the "AT+SQNSD=..." command and replies OK; meanwhile, no other URC can be sent to the host.

It is good practice that the DTE pauses briefly (for example, 20 ms) after the reception of an AT command result code or URC before issuing a new AT command. This gives the module the opportunity to transmit buffered URCs and reduce the likelihood of the situation described above.

2.2 Connection Manager

The connection manager is part of the application software running on the MCU. It enables/disables and manages the connectivity and, more generally, the status of the product.

The connection manager's task is to ensure that the connectivity is set up and restored in case an unexpected situation arises:

- Long device activation delays
- Loss of network connectivity
- Loss of communication between the host and the module

The connection manager development is the user's responsibility. Renesas provides generic rules and block diagram examples. The implementation is left to the user.

2.2.1 Autoconnect

By default, after booting, the modem is in a 'standby' mode:

```
AT+CFUN?
+CFUN: 0
OK
```

It is also in standby mode after sending a +SYSSTART URC (corresponding to a restart). The connection manager must handle this event and set the modem to the correct mode.

The modem can connect automatically at start. Refer to the AT command +SQNAUTOCONNECT. If this feature is activated, the modem is configured in CFUN=1 mode after reboot.

2.2.2 Operator Modes

The **AT+SQNCTM** command sets the 'operator mode'. Operator modes configure the module according to the requirements of a specific network/carrier:

- Supported RF bands to scan
- Predefined scanning profile
- Roaming enabled or not
 - When roaming is disabled, the modem does not attach after **CEREG: 5**. Only **CEREG: 1** is supported.
- Feature group in UE capability
- PDN configuration
- LwM2M support

Only the 'standard' mode is supported, corresponding to the following configuration:

Mode / Bands	Roaming	PDN configuration	LwM2M support
Standard: 1, 2, 3, 4, 5, 8, 12, 13, 17, 18, 19, 20, 25, 26, 28, 66	Enabled	None	Disabled

2.2.3 Network Connectivity

The host sees the modem either:

- Connecting to the network: **+CEREG: 2** state
- Connected to the network: **+CEREG: 1** or **5**
- Disconnected: all other **+CEREG** states

Network connectivity issues (disconnections) have several possible causes.

2.2.3.1 PLMN Selection

The principles of PLMN selection in E-UTRA are based on the 3GPP PLMN selection principles. First, the UE NAS layer selects a PLMN and its equivalent PLMNs as described in Figure 9.

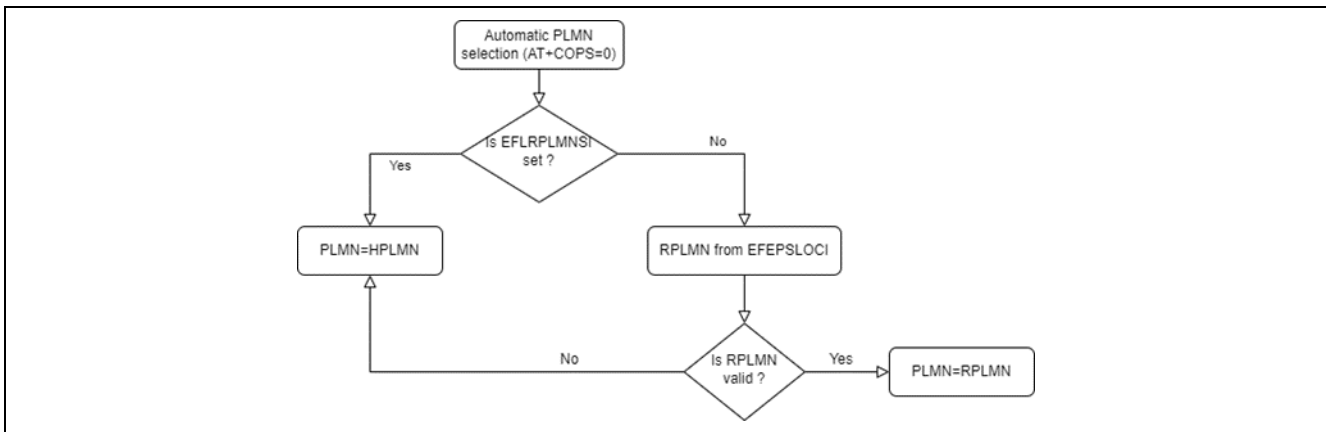


Figure 9. System Block Diagram

The UE then scans the configured E-UTRA frequency bands and, for each carrier frequency, detects the strongest cell. It reads the cell system information to identify its PLMN(s). The UE may connect to each carrier in turn ('initial cell selection') or use stored information to shorten the search ('stored information cell selection').

The UE searches for a cell:

- Whose PLMN is the selected PLMN or an equivalent PLMN
- Which is not barred or reserved
- Whose tracking area is not in the 'forbidden tracking areas for roaming' list

If it cannot find a suitable cell, it looks for an acceptable cell whose attributes satisfy the cell selection criteria while not being barred. The UE then selects the PLMN to register on according to the rules of the 3GPP specification 23.122.

2.2.3.2 Scanning for Suitable Cells

While the modem scans for suitable cells, the network connectivity is down. The modem reports the scanning operation with the **+CEREG:2** URC. The host must wait for the **+CEREG:1** or **+CEREG:5** URC. Scan time depends on the number of bands configured in the modem.

By default, the modem scans the whole seventeen bands it supports. The host can narrow down the number of bands to be scanned using the **AT+SQNBANDSEL** command.

- Cell detection duration per EARFCN is 30 ms (18 mJ or 1.3 μ Ah). Scanning the full 17 bands will take 186 seconds (~ 3 min) and use 115 J (8.4 mAh).
- Once scanning is over, PLMN acquisition (decoding MIB and SIB1) for each candidate cell will take: $2 \times 2 \times 80 = 320$ ms per candidate cell, with a power budget of 176 mJ (12.8 μ Ah).

The bands to be configured depend on the carrier chosen for the device. The most frequently used bands for each region of the world are:

Region	Bands
North America	2, 4, 5, 12, 13, 25
EMEA	1, 3, 8, 20, 28
Japan	1, 8, 18, 19, 26
Australia	1, 3, 8, 28

In a given region, if the SIM card and data plan do not allow roaming with all available carriers, it is recommended to narrow the bands to those used by the supported carriers. Avoiding unnecessary band scanning and attach attempts on forbidden carriers improves the power consumption.

If no suitable cells are found, the modem carries on scanning the bands several times, with pauses between each scan.

Note: Band priority cannot be changed.

For example, in standard operator mode, when all 17 bands are configured, the scanning goes as follows:

- During the first five seconds, the modem repetitively scans all the configured bands with a pause of 500 ms between each scan.
- During the next thirty seconds, the modem scans the bands with a break between each scan increased to five seconds.
- If all the previous scans have failed, the modem carries on scanning every thirty seconds.

2.2.3.3 Out of Coverage

LTE-M coverage info is available on the GMSA website.

If the UE is placed in a location where no Cat-M1 network is available, the modem sends a **+CEREG:0**, **+CEREG:4** or **+CEREG:80** instead of **+CEREG:1** or **+CEREG:5**. The host can either decide to scan other bands or to shut down the module and retry later (depending on the power constraints of the application).

The MCU defines the bands to be scanned with **AT+SQNBANDSEL** command and reconfigures the modem when no coverage is found after a given period.

T0, T1, T2 and T3 durations depend on battery constraints and band settings.

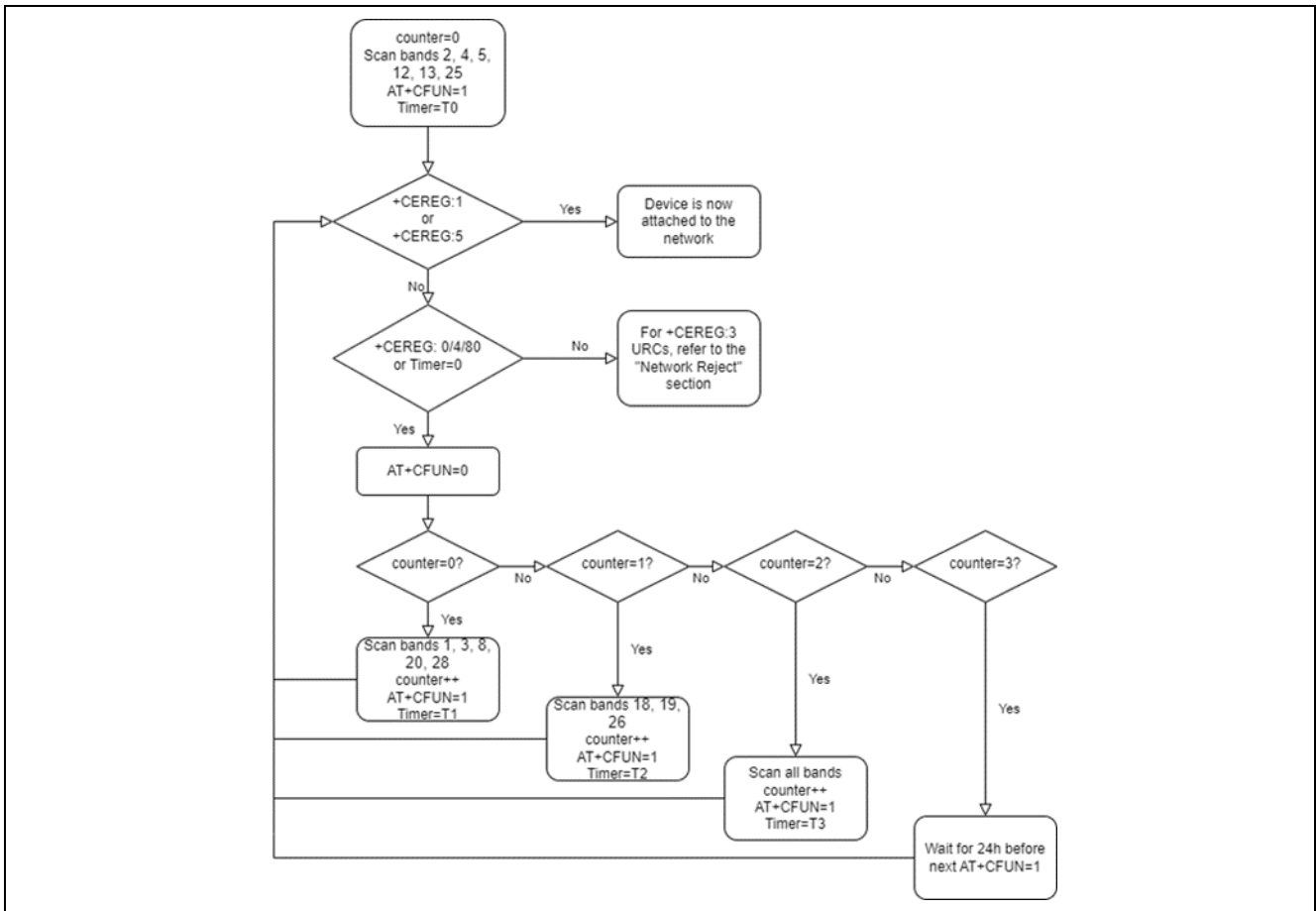


Figure 10. Out of Coverage Flowchart

2.2.3.4 Network Reject

The network can reject the modem if it does not have the correct APN or its IMEI is invalid for the network.

The host application should activate the +CEREG URC with AT+CEREG=3 before sending AT+CFUN=1 to get the <reject_cause>.

To get the reject cause as a text string once the +CEREG URC is received, use: AT+CEER.

The +CEREG URC indicating the reject cause is followed by the +CEREG: 2 URC notifying that the UE carries on searching for another suitable cell. In some cases described in the 3GPP standard, the modem can send a +CEREG: 0 URC when getting rejected by the network. The modem may even start a timer during which the LTE stack is forbidden from reattaching to the network. In that case, it is recommended to switch off the device and retry later.

The most common reject causes are:

- No suitable cells in tracking area
- Illegal mobile equipment
- IMSI unknown at HLR
- PLMN not allowed
- Location area not allowed
- Roaming not allowed in this location area
- Network failure
- Network congestion

Moving the device to another location may help.

If the registration type is manual (`+COPS = 1`), then the host must restart a manual PLMN search or force automatic PLMN selection mode (`AT+COPS=0`).

If the registration type is automatic (`+COPS = 0`), the modem may look for an allowed PLMN if the rejection cause was roaming restriction.

Illegal mobile equipment indicates possible problems with either the SIM card or the modem IMEI.

2.2.3.5 SIM

The first time a non-activated SIM card is inserted into a Cat M1 device, the SIM will first launch a BIP session for its activation.

In that case, data connectivity can be slow to start (up to a few minutes). The MCU must not reset the modem in the meantime. The duration depends on the SIM, the network, and the RF conditions.

There is no specific URC notifying an ongoing BIP session. However, it is possible to activate the SIM status `+SQNSIMST` URCs to know when the SIM is ready. These URC are disabled by default and can be enabled using `AT+SQNSIMST=1`.

(1) Multi IMSI SIM Support

Some SIM cards, especially MVNO SIM cards, implement a multi IMSI feature. They behave as follows:

- They have a default IMSI they use until the network's MCC is known.
- Once the modem is attached and the MCC is known, the SIM switches from default to primary IMSI if it exists.
- If the primary IMSI reports limited service after a specific timer expires, the SIM falls back on the default IMSI.
- In the worst case scenario, an out-of-the-box attach in the field can take three full scans:
 - First attach with the default IMSI
 - Second scan with the primary IMSI, which fails
 - Third scan with default IMSI that succeeds

2.2.4 Network Connectivity Loss

In the case that the modem managed to connect to the network, there are multiple possible reasons why network connectivity could be lost over time:

- RF conditions.

The propagation channel can change and lead to radio link failures, whether the device is moving or static. The connection manager is informed of the connectivity loss by a `+CEREG:0` or `+CEREG:4` URC. These URC can be turned on or off using the `AT+CEREG` command.

Refer to *RYZ014 Modules AT Command User's Manual* and 3GPP TS 27.007 section 10.1.22 for more details on the `+CEREG` command.

The modem can also emit the proprietary URC `+CEREG:80` when the PLMN is lost. This URC is sent as soon as the network connectivity is broken. It is followed by `+CEREG:1` if the modem can attach to the network again or by `+CEREG:2` while the modem resumes scanning for suitable cells.

Note: If the modem is stuck in the `+CEREG:80` state, the host application must reset the modem.

- Network reject
The network can reject the modem after a cell reselection. The host application should activate the **+CEREG** URC with **AT+CEREG=3** to get the `<reject_cause>`.
- Unidentified reason
This category includes all software bugs not pinpointed during the product certification and field tests. The connection manager must handle that case and make sure that the connectivity can be recovered, for example with a modem reset.
- Modem FOTA
Connectivity is lost during a modem upgrade (reboot). During the downtime, the connection manager must not reset the modem and must wait for the upgrade's completion. Refer to section 3 for the list of URCs sent during firmware upgrade.
- AT Communication Interruption
Communications between the host MCU and the modem relies entirely on AT commands exchange. When the communication breaks down, the modem does not respond to any AT command sent by the MCU. In that case, the host MCU should perform a hardware reset of the module.
- SIM card failure
If the SIM card fails, the network connectivity is lost. SIM card accessibility can be checked with the **AT+CPIN?** command. In case of a SIM hardware failure, **ERROR** is returned.

2.2.5 AT Communication Interruption

AT commands are the only way the MCU communicates with the modem. Several reasons can cause the modem to be unresponsive to AT commands.

2.2.5.1 AT Commands Timeout

The application software can trigger a modem reset if it receives no answer to an AT command. The current AT Commands Reference Manual specifies no timeout for synchronous AT command, because many commands depend on the network. As a rule of thumb, the host should reset the modem after 60 seconds of unresponsiveness, barring some specific data AT commands which can take longer to execute on very slow networks, or those whose timeout parameter can be extended over 60 s.

2.2.5.2 Software Firmware Upgrade

During a modem software upgrade, local or FOTA, the modem disconnects from both the network and the host. The connection manager must not reset the modem during a firmware upgrade.

2.2.5.3 Data Mode

Before most IP data transfers, the modem enters data mode and accepts data from MCU. In this mode, no AT response is possible. Refer to the *AT Commands User's Manual* for more details.

A typical example is the use of **AT+SQNSSENDEXT** to send data to a server over a socket. The second parameter is the length of data to be sent. If the data block sent by the MCU is shorter than the length given in the command, the modem stalls and keeps the UART in data mode. This usually happens when the length given in the command tallies the termination characters (for example, `\r\n`) but the data does not include them.

2.2.5.4 PPP Session

The modem supports the PPP protocol for data transfer on top of data over AT commands. In that case as well, the host MCU will first have to pause the PPP session to enter AT command mode again.

2.2.6 Data Retries

The device is required to comply to GSMA TS35 rules to avoid flooding the network in case of issue.

The following scenarios can be run during device certification:

Test Case ID	Test Case Name
TS35_5.1_TC_001	Basic RRC and data connection establishment / release, ensuring connection request are not excessive.
TS35_5.1_TC_008d	Failure scenario (wrong APN).
TS35_5.1_TC_008g	Failure scenario (IoT server not reachable).
TS35_5.1_TC_008h	Failure scenario (SMSC not reachable).

TC 001 checks that the IoT device application is capable of sending data frequently; there is no specific requirement at the connection manager level. The other three test cases check the IoT Device Application's behavior whenever the network communication requests fail.

The connection manager must not initiate more than 30 retries in one hour (test duration) to pass. The simplest way to comply is setting a suitable back-off period after each failure. For example, following a failure to set up a data connection, the MCU should wait five seconds before retrying. If the retry also fails, the MCU should wait twenty seconds, and so on: each back-off is longer than the previous one.

To pass the SMS transfer (TC_008h) test, the host application must not retry to send SMS more than eight times. The module automatically resends every unsuccessful SMS three times.

Each operator has its own data retry requirements, if any. In general, the connection manager should avoid piling up retries as far as possible.

2.2.7 Power Management

2.2.7.1 Power Saving Modes

Low power management is mandatory in power sensitive devices. In addition to the legacy RRC Idle mode, RYZ014 modules also support PSM modes which comply with 3GPP standard.

During PSM Idle duration, the modem cannot be reached from the network.

RRC Idle or PSM modes should be chosen according to the expected inactivity duration of the product:

- Products which must always be reachable must use the RRC Idle mode. They must not be power consumption sensitive.
- For products active every hour to every few days, the PSM mode can be used.

PSM efficiency highly depends on the network settings. Some networks do not accept large values for T3412-extended, resulting in spurious TAU procedures that drain the battery. Other networks do not allow very small T3324 values, wherefore the device must remain pointlessly longer in RRC Idle mode before entering deep sleep mode.

If power consumption is critical, the connection manager can turn off the modem using **AT+CFUN=0** or **AT+CFUN=4** instead of relying on one of the aforementioned modes. The network operator must agree with this policy, best fitted for devices talking no more than once or twice a day.

The connection manager must be aware that the network is not obliged to support PSM modes. If power consumption is an issue, the connection manager must ensure the device does not remain in RRC Idle mode all the time.

Please refer to the *Use Cases with AT Commands* and the *Power Consumption Measurement on RYZ014-Based Modules* application notes for more details on how to set the PSM mode.

Mode	Wake-up Latency
Deep sleep	< 2 secs
Sleep	< 15 ms
Standby	< 1 ms
Modem active	< 1 ms

2.2.7.2 PDN Idle Timer

The network sets a PDN idle timer whose value is unknown to the module. When the PDN idle timer expires, the network disconnects the modem from the network.

In PSM mode, if the PDN idle timer is lower than the T3412 value, the modem can find itself disconnected when it wakes up. It must therefore perform a full reattachment procedure, losing the benefits of the seamless reconnection.

Each carrier sets its own PDN idle timer value or offers private APNs with custom PDN idle timer values. The user must contact its SIM provider and make sure that the PDN idle timer value is compatible with its application.

2.2.7.3 Low Power Modes

To allow the module to enter low power modes, the host MCU must handle the wake sources (RTS0 or WAKE0 depending on the hardware architecture) and drive them high whenever the module must go to sleep. Beware that even if all wake sources are disabled, the platform does not enter sleep or deep sleep mode as long as:

- Network exchanges are performed.
- URCs or data pending are pending in the UART buffer.

The modem will not send any URC when exiting sleep or deep sleep modes. The host MCU should monitor the CTS line if hardware flow control is activated to know whether the modem is ready to receive AT commands. If hardware flow control is disabled, the PS_STATUS line will toggle as soon as the module exits sleep or deep sleep modes. The MCU must then send **AT+CFUN?** until the UE answers **OK** to ensure that the UARTs are operational.

2.2.8 Examples of Implementation

The following section provides typical examples of connection manager implementations for devices in different low power modes.

2.2.8.1 RRC Idle

In this first example, there is no power constraint. The device remains in RRC Idle between two data transfers, rather than entering sleep mode. PSM is not configured. This case shows how +CEREG URCS must be handled by the connection manager. URCS are asynchronous and must be captured and parsed on the fly.

The AUTOCONNECT mode is activated to avoid sending AT+CFUN=1 after each +SYSSTART URC.

Timer1 detects any issues with the SIM card. If the modem never connects at startup, the SIM card is either not inserted or broken and not readable.

Timer2 depends on the number of bands scanned. The greater the number of bands scanned, the longer the modem remains in the connecting state.

The maximum number of disconnections before reset (X) is typically set to two.

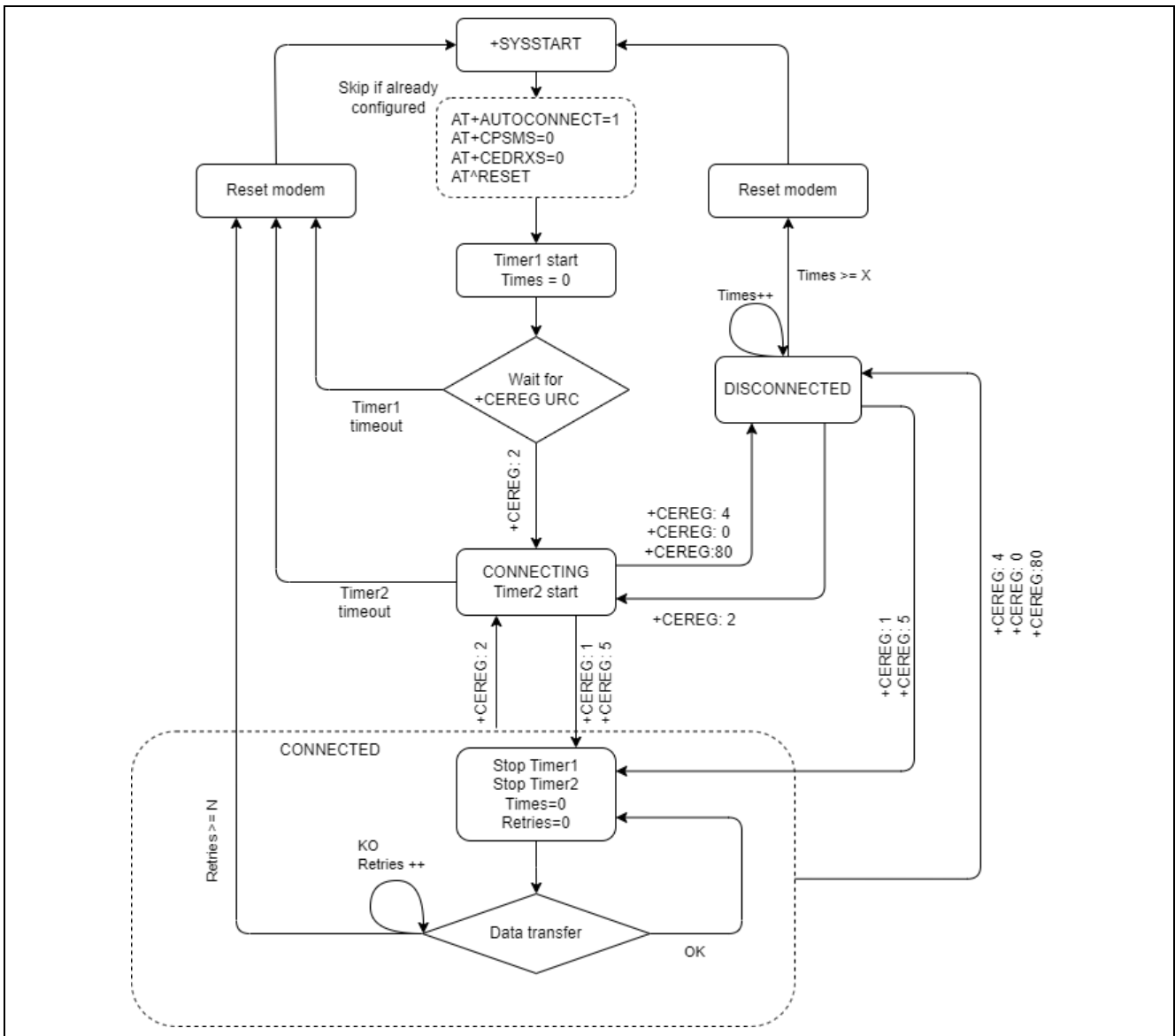


Figure 11. RRC Idle Processing

2.2.8.2 PSM

In this example, the device is an environment air monitor which sends its measurements to a cloud server. A timer (Timer3) regularly wakes the device up.

To spare battery power, the device is configured in PSM mode with the following timers (assuming that the network accepts these values):

- T3412: 2 hours
- T3324: 16 seconds
- Timer3 should be set so that: T3324 < Timer3 < T3412

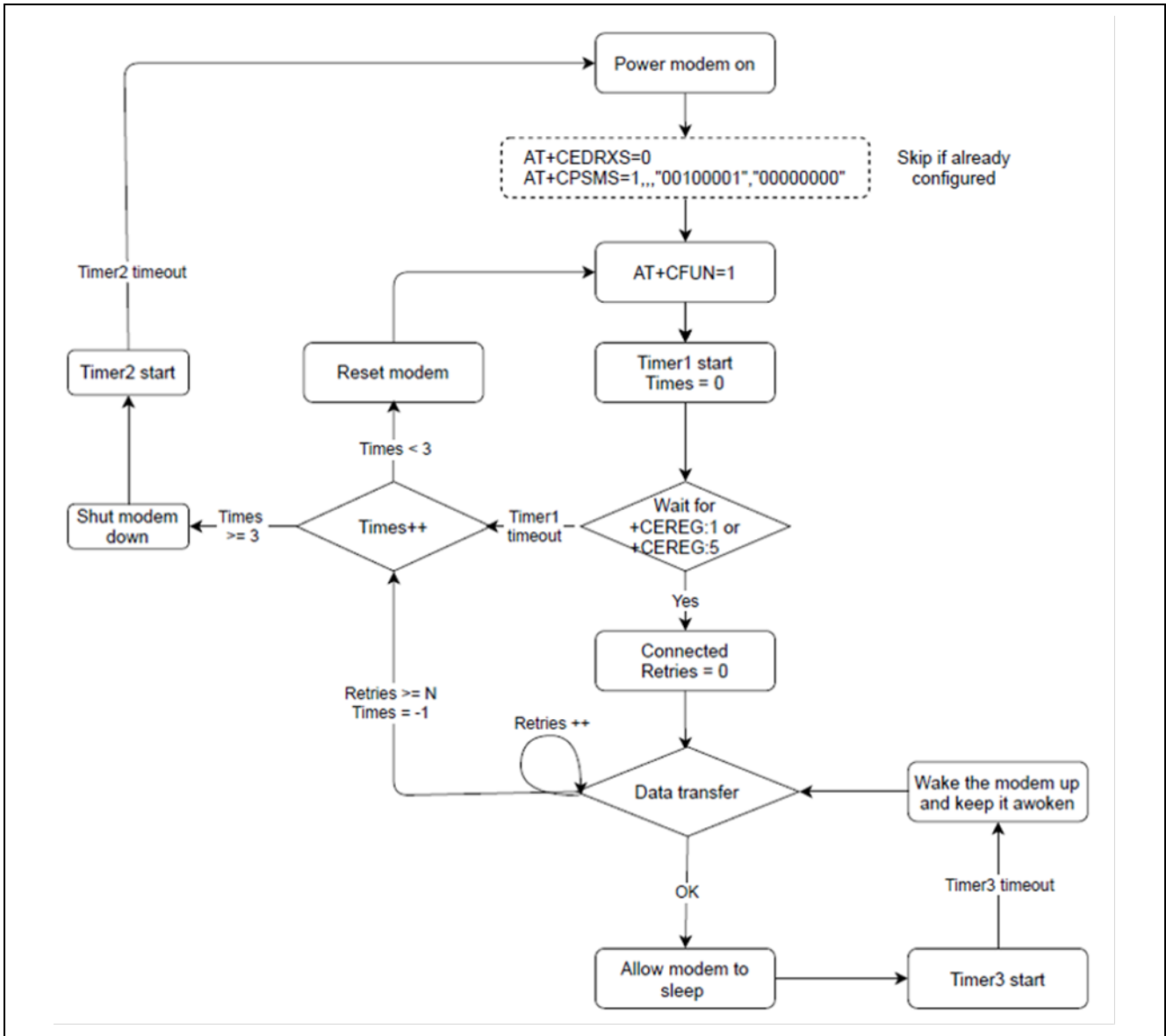


Figure 12. PSM Flow Example

Typical behavior:

- The device is registered to network, goes into RRC Idle and enters PSM after T3324 fires.
- Each time Timer3 expires, the modem wakes up:
 - If possible, the UE connects to the network, sends data and then goes back into PSM for another Timer3 period.
 - If the modem cannot connect, it keeps scanning for a period of time decided by the connection manager (Timer1).
 - If no cell is found, the modem is reset.
 - After three consecutive resets, the modem is shut down for a period defined by Timer2.

In this example, it is assumed that the MCU does not enter low power modes. If the MCU also supports low power modes, the RING line must be used to wake it up.

The timers' values depend on the application and on the power consumption constraints of the device:

- When Timer1 is started, the modem scans according to predefined parameters. To reduce power consumption, the scanning algorithm includes pauses. Refer to section 2.2.7.1 for scanning rules.
 - The recommended value of Timer1 is several minutes: 5 minutes.
 - The recommended value of Timer2 is several hours, depending on the application.
 - Timer3's value depends on how often data must be sent. Timer3's value should be greater than T3412-extended's value to avoid wasting energy in spurious TAU procedures.

The device should set the number of data transfer retries (N in the diagram below) according to the TS35 rules (see section 2.2.6 for more details).

2.2.8.3 CFUN0/CFUN4

In this example, the device is a push button. It only sends data.

Since the sleep period is higher than 6 hours, it uses CFUN1/CFUN4 mode instead of PSM.

Energy efficiency demands the MCU issue **AT+CFUN=4** (or **AT+CFUN=0**) as soon as all data have been sent.

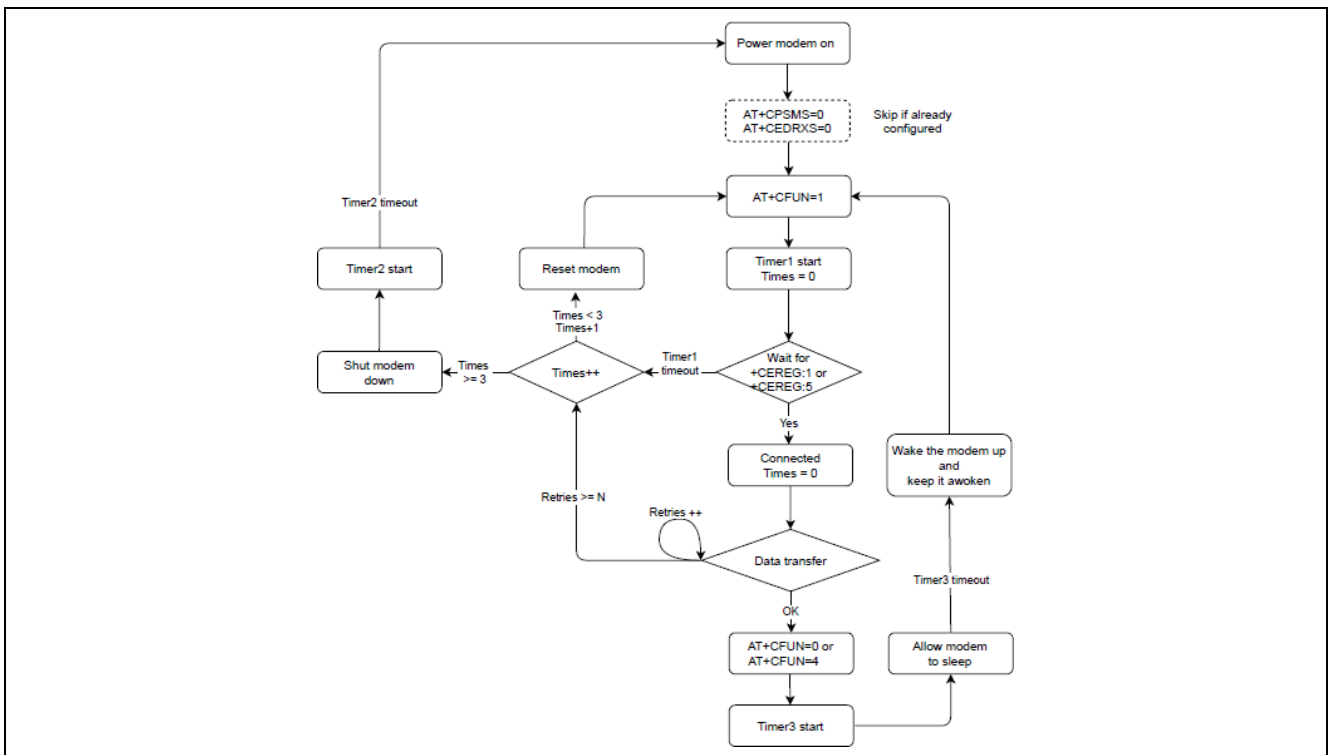


Figure 13. CFUN0/CFUN4 Use Case Example

Typical behaviour:

- The device is registered to the network and sends data.
 - When the data transfer is over, the MCU turns the modem off using **AT+CFUN=4** or **AT+CFUN=0**.
- Each time Timer3 expires, the MCU turns the modem on again using **AT+CFUN=1**.
 - If there is network coverage, the UE connects to the network, sends data and is shut down again by the MCU for another Timer3 duration.
 - If the network coverage is gone, the modem keeps scanning for a period of time set by the connection manager (Timer1).
 - If no cell is found, the modem is reset.
 - After three consecutive resets, the modem is shut down for a period defined by Timer2.

The timers' values depend on the application and on the power consumption constraints of the device:

- When Timer1 is started, the modem scans according to predefined parameters. To reduce power consumption, the scanning algorithm includes pauses. Please refer to section 2.2.7.1 for scanning rules. The recommended value of Timer1 is several minutes: 5 minutes. The recommended value of Timer2 is several hours, depending on the application. Timer3's value depends on how often data must be sent.

The device should set the number of data transfer retries (N in the above diagram) according to the TS35 rules (see section Data Retries for more details).

3. Firmware Upgrade Over-the-Air

During the product's lifetime, the firmware has to be updated, either locally or over-the-air.

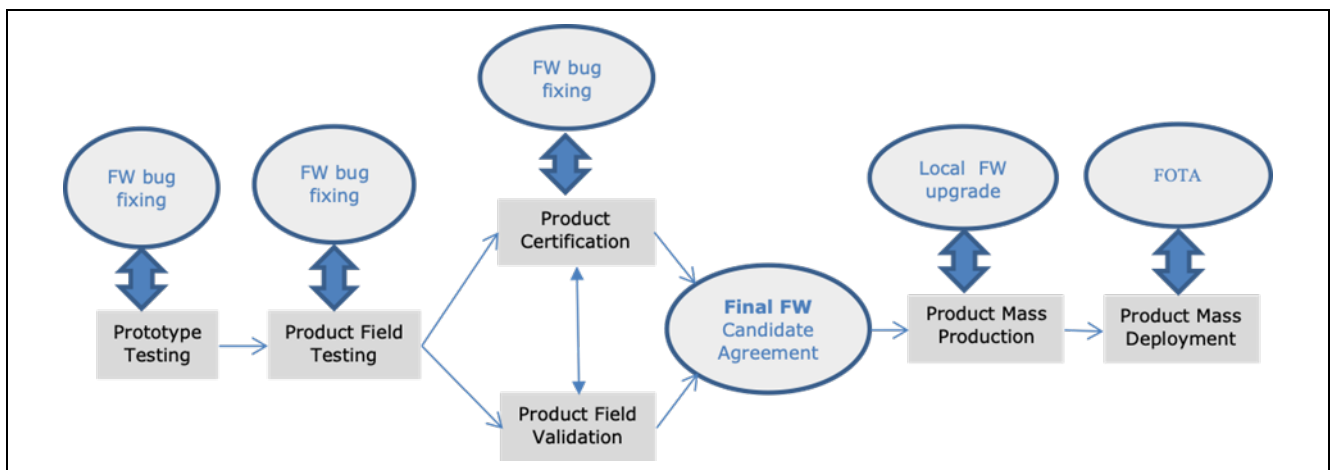


Figure 14. Firmware Upgrade Events

3.1 Local Firmware Upgrade

The Sequans's Firmware Upgrade tool (SFU) performs local firmware upgrade. Refer to the *RYZ014A Firmware Upgrade Quick Start Guide* for details.

Compared to FOTA, local upgrade is more flexible (all parts of the software image can be updated) and faster. Furthermore, since it does not require any download from the network, it does not impact the data plan.

The local upgrade is mostly used during the following phases of a project:

- Prototype testing
- Product field testing
- Product certification
- Product field validation
- Manufacturing

The firmware often needs to be updated during manufacturing, since the version shipped is not guaranteed to be up to date.

Once the product is massively deployed, the firmware must be updated using FOTA. If the product has multi-link radio capabilities, the firmware can be downloaded over WiFi or BLE, with no data plan cost, and then pushed from the MCU to the module. Refer to the *Firmware Upgrade from Host MCU Application Note* for guidelines on how to implement such a tool.

3.2 Firmware Upgrade Over-the-Air (FOTA)

The RYZ014A supports device-initiated FOTA. The connection manager must check that the battery level of the device is high enough before triggering a FOTA upgrade.

If the battery level allows it, the connection manager triggers the FOTA using the proprietary AT command `AT+SQNSUPGRADE`. Refer to the *Use Cases with AT Commands Application Note* for more details.

The modem sends several URC during the upgrade. The connection manager controls the upgrade process, modem reboot, and connectivity.

The connection manager must not reset the modem while the upgrade is ongoing.

3.2.1 Differential Upgrade

RYZ014-based modules support differential software upgrade over the air. Full software upgrade is reserved to local mode only.

LTE-M devices' throughput is low and can slow even more under poor RF conditions. Using a full firmware image could take a long time – typically several hours for a device located on a cell's edge – or even fail. If the device is battery powered, upgrades can drain the battery very quickly. Additionally, IoT devices' data plans are often limited. Differential upgrade is therefore recommended.

Although differential and full upgrade lead to the same final product, differential upgrades require paying attention to a few points.

First, the differential upgrade is tailored to two specific versions of the software. Thus, unless the current software version matches the reference image used to generate the DUP file, the upgrade will fail.

The firmware image is made of four different parts:

- Boot ROM
- Updater
- UE firmware
- Filesystem

Any of these parts, except for the boot ROM, can be updated over the air, separately or together.

Upgrading the filesystem part will only impact the Renesas filesystem partition; the user filesystem partition remains unchanged.

The differential image is built file by file, meaning that the following file operations in the differential filesystem image are supported:

- File add: The file exists in the target but not in the source/
- File delete: The file exists in the source but not in the target.
- Directory add: The directory exists in the target but not in the source.
- Directory delete: The directory exists in the source but not in the target.
- File diff: The file exists in both source and target, but its contents differ.

Note: A 'directory delete' erases all the files and subdirectories the directory contained.

In most cases, the UE firmware is the only part of the module image that is upgraded once products are deployed.

The diff package between the last and penultimate official software releases is available at renesas.com/RYZ014A. Users can also generate their own differential image if they need to upgrade from another software version. Instructions are described in section 2.3.2.

In both modes, the MCU will receive `+SQNFOTA` URCs from the UE to be informed of the upgrade progress. The connection manager shall not reset the modem while an upgrade is ongoing.

4. Factory Reset

If the modem shows erratic behavior such as crash loops or repeated disconnections for no apparent reason, the MCU may have to perform a factory reset with the command **AT+SQNSFACTORYRESET**.

After a factory reset, the MCU must reconfigure the device. The LPM settings, the file system, and the PSI (platform specific information, such as the UART configuration) need to be restored.

Acronyms and Abbreviations

DCE	Data Communications Equipment
DTE	Data Terminal Equipment
URC	Unsolicited Response Code
BIP	Bearer Independent Protocol
CTS	Clear To Send
RTS	Request To Send
PSM	Power Saving Mode
UE	User Equipment
MCU	Microcontroller Unit
UART	Universal Asynchronous Receiver Transmitter
PPP	Point to Point Protocol
SMS	Short Message Service
SMSC	SMS Center
GPIO	General Purpose Input Output
RRC	Radio Resource Control
PMU	Power Management Unit
LTE	Long Term Evolution
APN	Access Point Name
PDN	Packet Data Network
PLMN	Public Land Mobile Network
EARFCN	E-UTRA Absolute Radio Frequency Channel Number
IMEI	International Mobile Equipment Identity
IMSI	International Mobile Subscriber Identity
HLR	Home Location Register
FOTA	Firmware Over The Air
TAU	Tracking Area Update
PER	Packet Error Rate

Revision History

Rev.	Date	Description	
		Page	Summary
1.00	Dec.07.20	-	Initial release.
1.40	Mar.18.22	-	Update.
2.00	Oct.26.22	-	Deleted eDRX description.
3.00	Jan.27.23	-	Technical and editorial updates to all sections.
3.10	Mar.09.23	-	Updated frequently used bands table in section 2.2.3.2.

General Precautions in the Handling of Microprocessing Unit and Microcontroller Unit Products

The following usage notes are applicable to all Microprocessing unit and Microcontroller unit products from Renesas. For detailed usage notes on the products covered by this document, refer to the relevant sections of the document as well as any technical updates that have been issued for the products.

1. Precaution against Electrostatic Discharge (ESD)

A strong electrical field, when exposed to a CMOS device, can cause destruction of the gate oxide and ultimately degrade the device operation. Steps must be taken to stop the generation of static electricity as much as possible, and quickly dissipate it when it occurs. Environmental control must be adequate. When it is dry, a humidifier should be used. This is recommended to avoid using insulators that can easily build up static electricity.

Semiconductor devices must be stored and transported in an anti-static container, static shielding bag or conductive material. All test and measurement tools including work benches and floors must be grounded. The operator must also be grounded using a wrist strap. Semiconductor devices must not be touched with bare hands. Similar precautions must be taken for printed circuit boards with mounted semiconductor devices.

2. Processing at power-on

The state of the product is undefined at the time when power is supplied. The states of internal circuits in the LSI are indeterminate and the states of register settings and pins are undefined at the time when power is supplied. In a finished product where the reset signal is applied to the external reset pin, the states of pins are not guaranteed from the time when power is supplied until the reset process is completed. In a similar way, the states of pins in a product that is reset by an on-chip power-on reset function are not guaranteed from the time when power is supplied until the power reaches the level at which resetting is specified.

3. Input of signal during power-off state

Do not input signals or an I/O pull-up power supply while the device is powered off. The current injection that results from input of such a signal or I/O pull-up power supply may cause malfunction and the abnormal current that passes in the device at this time may cause degradation of internal elements. Follow the guideline for input signal during power-off state as described in your product documentation.

4. Handling of unused pins

Handle unused pins in accordance with the directions given under handling of unused pins in the manual. The input pins of CMOS products are generally in the high-impedance state. In operation with an unused pin in the open-circuit state, extra electromagnetic noise is induced in the vicinity of the LSI, an associated shoot-through current flows internally, and malfunctions occur due to the false recognition of the pin state as an input signal become possible.

5. Clock signals

After applying a reset, only release the reset line after the operating clock signal becomes stable. When switching the clock signal during program execution, wait until the target clock signal is stabilized. When the clock signal is generated with an external resonator or from an external oscillator during a reset, ensure that the reset line is only released after full stabilization of the clock signal. Additionally, when switching to a clock signal produced with an external resonator or by an external oscillator while program execution is in progress, wait until the target clock signal is stable.

6. Voltage application waveform at input pin

Waveform distortion due to input noise or a reflected wave may cause malfunction. If the input of the CMOS device stays in the area between V_{IL} (Max.) and V_{IH} (Min.) due to noise, for example, the device may malfunction. Take care to prevent chattering noise from entering the device when the input level is fixed, and also in the transition period when the input level passes through the area between V_{IL} (Max.) and V_{IH} (Min.).

7. Prohibition of access to reserved addresses

Access to reserved addresses is prohibited. The reserved addresses are provided for possible future expansion of functions. Do not access these addresses as the correct operation of the LSI is not guaranteed.

8. Differences between products

Before changing from one product to another, for example to a product with a different part number, confirm that the change will not lead to problems. The characteristics of a microprocessing unit or microcontroller unit products in the same group but having a different part number might differ in terms of internal memory capacity, layout pattern, and other factors, which can affect the ranges of electrical characteristics, such as characteristic values, operating margins, immunity to noise, and amount of radiated noise. When changing to a product with a different part number, implement a system-evaluation test for the given product.

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