RX Family
TFU Fault Diagnosis Example

Introduction
This document describes a fault diagnosis example of an Arithmetic Unit for Trigonometric Functions (TFU) peripheral circuit.

Target Device
This example supports the following devices.
- RX72M Group
- RX72T Group

When using this application note with other Renesas MCUs, careful evaluation is recommended after making modifications to comply with the alternate MCU.
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1. Overview
This document explains a fault diagnosis example of an Arithmetic Unit for Trigonometric Functions (TFU) peripheral circuit to apply kind of functional safety. The fault diagnosis is not only permanent fault but also transient fault.

1.1 TFU Diagnosis Example
This example is implemented in a project and can be used as the application example of TFU fault diagnosis. This software does not get any certification including industrial functional safety specification. If a user needs any certification, the user implements the TFU diagnosis operation refer to this example on the user’s system and needs to get the certification as the system.

1.2 Related documents

1.3 Hardware Structure
This example uses CPU, ROM and RAM to diagnosis TFU. Only when measuring operation time, MTU3 is optionally used.

In detail, please refer to RX72M/72T Group User’s Manual: Hardware.

1.4 Software Structure
This example should be used with TFU intrinsic function to execute TFU hardware calculation. Case of transient error diagnosis, the math standard library, which is embedded in compiler, is used to create the expectation values. If performance evaluation needs, time measurement software is available. A diagnosis results such as error detection point, performance, are showed on the console.

1 “Renesas Debug Virtual Console” case of e2 studio environment or “Terminal I/O” case of EWRX.

1.5 File Structure
This sample codes are stored the “src”, “r_config”, “r_tfu_diag_rx”, “r_bsp” and lower hierarchical folders. Figure 1.2 shows the source and header file structures of this sample. The “src” folder stores files of sample
application, console output operation and time measurement operation. The “r_tfu_diag_rx” folder stores files related to this TFU fault diagnosis example (hereafter, TFU diagnosis software). An initial setting of this example uses the Renesas Board Support Package (BSP) [1].

```
src: sample application (main operation)
  |  tfu_test.c
  +--- output_if: terminal output operation
      |  show_label.c
      |  show_label.h
      |
  +--- tmr_if: time measurement operation
      |  tmr_if.c
      |  tmr_if.h
```

```
r_config: configuration setting
  |  r_bsp_config.h
  |  r_bsp_interrupt_config.h
  |  r_tfu_diag_rx_config.h

r_tfu_diag_rx: TFU fault diagnosis example
  |  r_tfu_diag_rx_if.h
  |
  +--- src
      |  r_tfu_diag_rx.c
      |  r_tfu_diag_rx_private.h
```

```
r_bsp: BSP (Board Support Package) FIT module
```

Figure 1.2  File structure of this example
1.6 Outline of Functions

The functions of sample application and the lower layers show Table 1.1 and the API functions related to the diagnosis operation of TFU show Table 1.2 respectively.

### Table 1.1 Functions of application and the lower layers

<table>
<thead>
<tr>
<th>Item</th>
<th>Contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>main()</td>
<td>Main operation of this example.</td>
</tr>
<tr>
<td>start_label()</td>
<td>Show operation start indication to console.</td>
</tr>
<tr>
<td>end_label()</td>
<td>Show operation end indication to console.</td>
</tr>
<tr>
<td>show_result()</td>
<td>Show iCLK cycles and time of operation to console.</td>
</tr>
<tr>
<td>mtu3_dev_start()</td>
<td>Clear MTU3 module stop.</td>
</tr>
<tr>
<td>mtu3_dev_stop()</td>
<td>Set MTU3 module stop.</td>
</tr>
<tr>
<td>Init_timer()</td>
<td>Initial setting of MTU3.</td>
</tr>
<tr>
<td>start_eval()</td>
<td>Start counting of MTU3.</td>
</tr>
<tr>
<td>stop_eval()</td>
<td>Stop counting of MTU3.</td>
</tr>
<tr>
<td>get_eval_cycle()</td>
<td>Get current MTU3 counter value.</td>
</tr>
</tbody>
</table>

### Table 1.2 API functions (TFU fault diagnosis)

<table>
<thead>
<tr>
<th>Item</th>
<th>Contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>R_TFU_Diag_GetVersion()</td>
<td>Get version number of TFU diagnostic software.</td>
</tr>
<tr>
<td>R_TFU_Diag_Init()</td>
<td>Initial setting of TFU.</td>
</tr>
<tr>
<td>R_TFU_Diag_SinCos()</td>
<td>Diagnostic operation by sine and cosine numerical calculations.</td>
</tr>
<tr>
<td>R_TFU_Diag_AtanHypot()</td>
<td>Diagnostic operation by arctangent and hypotenuse numerical calculations.</td>
</tr>
</tbody>
</table>
2. Functional Information
This example is developed by the following principles.

2.1 Hardware Requirements
This example requires your MCU supports the following feature:
- TFU
- MTU3 (Optional)

2.2 Hardware Resource Requirements
This section details the hardware peripherals that this example requires. Unless explicitly stated, these resources must be reserved for the following driver, and the user cannot use them.

2.2.1 TFU
This example uses the TFU as the diagnosis target module. During operation of this example, the other task cannot access TFU.

2.2.2 MTU3 Channel (optional)
This example uses the MTU3 as the cascade operation connected to CH1 and CH2. If evaluating performance in this example, user cannot use the CH1 and CH2 of MTU3.

2.3 Software Requirements
This example is dependent on the following packages (FIT modules):
- r_bsp

2.4 Limitations
This software does not get any certification including industrial functional safety specification. If a user needs any certification, the user implements the TFU diagnosis operation refer to this example on his/her system and needs to get the certification as the system.

2.5 Supported Toolchains
This example has been confirmed to work with the toolchain listed in 5.1 Confirmed Operation Environment.

2.6 Header Files
Each function call is accessed by including one of or multiple files followed:

show_label.h, tmr_if.h, r_tfu_diag_rx_config.h, r_tfu_diag_rx_if.h and r_tfu_diag_rx_private.h which are supplied with this project code.

2.7 Integer Types
This project uses ANSI C99. These types are defined in stdint.h.

2.8 Configuration Overview
The configuration options in this example are specified in r_tfu_diag_rx_config.h and tfu_test.c. The option names and setting values are listed in the table below.

<table>
<thead>
<tr>
<th>Configuration options</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>#define RX_DEVICE_TYPE</td>
<td>Specify a target device.</td>
</tr>
<tr>
<td>#define DEVICE_RX72M (0)</td>
<td>- When the target device is RX72M, please set to 0.</td>
</tr>
<tr>
<td>#define DEVICE_RX72T (1)</td>
<td>- When the target device is RX72T, please set to 1.</td>
</tr>
<tr>
<td>- Default value = 0</td>
<td>The other device is not supported in this version.</td>
</tr>
<tr>
<td>#define LUTSinSize</td>
<td>Look-up table size for sine and cosine calculation.</td>
</tr>
<tr>
<td>- Default value = 256</td>
<td>Please set this value in this version.</td>
</tr>
</tbody>
</table>
### Configuration options

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>#define LUTAtanSize</code> - Default value = 256</td>
<td>Look-up table size for arctangent and hypotenuse calculation. Please set this value in this version.</td>
</tr>
<tr>
<td><code>#define RES_OUT</code> - undefined</td>
<td>Selecting output diagnosis result to the console or not?</td>
</tr>
<tr>
<td><code>#define TMR_CHK</code> - defined</td>
<td>Selecting output performance evaluation result to the console or not?</td>
</tr>
<tr>
<td><code>#define HW_DIAG_THRE</code> - Default value = 0.05f</td>
<td>Define threshold as affordable error value when permanent fault diagnosis executes. If this value set smaller, error detection ratio may improve but the probability of error occurrence due to calculation error may become larger.</td>
</tr>
<tr>
<td><code>#define SW_DIAG_THRE</code> - Default value = 0.05f</td>
<td>Define threshold as affordable error value when transient fault diagnosis executes. If this value set smaller, error detection ratio may improve but the probability of error occurrence due to calculation error may become larger.</td>
</tr>
<tr>
<td><code>#define BT_DIAG_THRE</code> - Default value = 0.05f</td>
<td>Define threshold as affordable error value when executing both of permanent and transient fault diagnosis. If this value set smaller, error detection ratio may improve but the probability of error occurrence due to calculation error may become larger.</td>
</tr>
</tbody>
</table>

### 2.9 Data Structures

This section details the data structures that are used with the functions of this example. In this project, those data structures are located in `r_tfu_diag_rx_if.h` and `r_tfu_diag_rx_private.h` as the prototype declaration.

```c
/* Diagnostic mode */
typedef enum
{
    DIAG_HW_ERR = 0x1, /* Hard error detection (Comparison of table) */
    DIAG_SW_ERR = 0x2, /* Soft error detection (Comparison of CPU calculation) */
    DIAG_BT_ERR = 0x3, /* Both (hard & soft error detection) */
} DiagMode;

/* Diagnosis configuration */
typedef struct
{
    uint32_t start; /* Start point of input data */
    uint32_t end; /* End point of input data */
    DiagMode mode; /* Diagnosis mode */
    float thresh; /* Threshold value of deviation (relative error) */
} DiagConf;

/* Diagnosis result */
typedef struct
{
    uint32_t h_point; /* Hard error detection point */
    uint32_t s_point; /* Soft error detection point */
    DiagMode knd; /* Kind of detected error */
} DiagRes;

/* LUT sine and cosine diag table type */
typedef struct
{
    const float in;
    const float out[2]; /* expectation value, 0:sine, 1:cosine */
} LUTSinType;
```
/* LUT arctan and hypot diag table type */
typedef struct
{
    const float in[2]; /* input data, 0:x, 1:y */
    const float out[2]; /* expectation value, 0:arctan, 1:hypot */
} LUTAtanType;

2.10 Return Values

This section describes return values of the functions of this example. This return value is located in r_tfu_diag_rx_if.h as the prototype declarations.

/* TFU diagnostic software return value */
typedef enum
{
    TFU_ERR_DET = -3,   /* Detected diagnosis error */
    TFU_ERR_PARAM = -2, /* Parameter error */
    TFU_ERR = -1,       /* General error */
    TFU_OK = 0,
} tfu_return_t;

2.11 Code Size

The sizes of ROM (code and constants), RAM (global data) and maximum stack usage associated with this example are listed below. The size listed extracts only TFU fault diagnosis part whose source code corresponds to “r_tfu_diag_rx.c”.

The ROM and RAM sizes are determined by the build-time configuration options described in “2.8 Configuration Overview”.

The values in the table below are confirmed under the following conditions.

Source code Revision: r_tfu_diag_rx rev1.00

Compiler Version: Renesas Electronics C/C++ Compiler Package for RX Family V3.01.00

    (The options of “-lang = c99”, “-optimize = 0” and “-tfu = intrinsic” are added to the default settings of the integrated development environment.)

GCC for Renesas RX 4.08.04.201902-SP1=GNURX

    (The options of “-std = gnu99” and “MTFU = intrinsic” are added to the default settings of the integrated development environment.)

IAR C/C++ Compiler for Renesas RX version 4.12.1

    (The options of “no optimization” and “TFU intrinsics” are added to the default settings of the integrated development environment.)

Configuration Options: Default settings.

<table>
<thead>
<tr>
<th>Device</th>
<th>Category</th>
<th>File</th>
<th>Memory Used</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Renesas Compiler</td>
<td>GCC</td>
<td>IAR Compiler</td>
<td></td>
</tr>
<tr>
<td>RX72M</td>
<td>ROM</td>
<td>r_tfu_diag_rx.c</td>
<td>8064 bytes</td>
<td>8281 bytes</td>
<td>7206 bytes</td>
<td></td>
</tr>
<tr>
<td></td>
<td>RAM</td>
<td>r_tfu_diag_rx.c</td>
<td>7184 bytes</td>
<td>7184 bytes</td>
<td>7184 bytes</td>
<td></td>
</tr>
<tr>
<td></td>
<td>STACK</td>
<td>r_tfu_diag_rx.c</td>
<td>100 bytes</td>
<td>-</td>
<td>64 bytes</td>
<td></td>
</tr>
</tbody>
</table>
3. Specification of This Example

3.1 Execution Sequence

Execution of this example needs a RX72M RSK+ board\(^1\) or RX72T RSK board\(^2\).

The outline of the execution is following.
- Write the project execution code to a code Flash of in the RX72M RSK+ board or RX72T RSK board (hereafter boards).
- Power on the board.
- Run the execution code.
- If the execution finished without error, the message showed by Figure 3.1 appears in the “Renesas Debug Console” or “Terminal I/O which are equipped with the e2 studio or EWRX respectively. To output this message, “RES_OUT” macro should be defined.
- If a fault detected during the operation, the message showed by Figure 3.2 appears in the corresponding console. To output this message, “RES_OUT” macro should be defined.
- The operation cycles and time show the console. To output this message, “TMR_CHK” macro should be defined.

\(^{1}\) Product name is Renesas Starter Kit+ for RX72M \([2]\).  
\(^{2}\) Product name is Renesas Starter Kit for RX72T \([3]\).

![Figure 3.1 Result Message (No fault detection)](image)

![Figure 3.2 Result Message (Fault detection)](image)
3.2 Diagnosis Methods Overview

Explain overview of the diagnostic method applicable to permanent and transient fault. Calculation using TFU is executed via a TFU intrinsic function which is built in each compiler. The TFU intrinsic function supports the following two kinds of operation.

sine and cosine simultaneous operation: __sincosf in CC-RX, EWRX, __builtin_rx_sincosf in GCC
arctangent and hypotenuse simultaneous operation: __atan2hypotf in CC-RX, EWRX, __builtin_rx_atan2hypotf in GCC

In this section, explain using only __sincosf and __atan2hypotf as the TFU intrinsic function.

3.2.1 Permanent Fault
- Sine and cosine

(1) Allocate look-up table which stores input $\theta$, sine expectation $\sin(\theta)$ and cosine expectation $\cos(\theta)$. The size is 3072 bytes (256 x 3 x float size).
(2) Execute __sincosf whose input $\theta$ is loaded from look-up table.
(3) Using the input $\theta$ inputted from __sincosf, TFU calculates sine and cosine simultaneously. And then, TFU returns those results $a1 = \sin(\theta)$ and $a2 = \cos(\theta)$ to __sincosf.
(4) TFU diagnosis software compares TFU calculation results which are $a1$ and $a2$ with look-up table expectation values which are $a1'$ and $a2'$. The difference is defined as the relative error $|a1 - a1'| / |a1'|$ or $|a2 - a2'| / |a2'|$. The comparison is also considering calculation error. If the comparison results do not match even if considering the calculation error, it is judged by detecting a permanent error.
Arctangent and hypotenuse

1. Allocate look-up table which stores base input x, height input y, arctangent expectation arctan(y/x) and hypotenuse expectation \((x^2 + y^2)^{1/2}\). The size is 4096 bytes (256 x 4 x float size).

2. Execute \_atan2hypotf whose base input x and height input y are loaded from look-up table.

3. Using the base input x and height input y inputted from \_atan2hypotf, TFU calculates arctangent and hypotenuse simultaneously. And then, TFU returns those results \(a1 = \arctan(y/x)\) and \(a2 = (x^2 + y^2)^{1/2}\) to \_atan2hypotf.

4. TFU diagnosis software compares TFU calculation results which are a1 and a2 with look-up table expectation values which are a1' and a2'. The difference is defined as the relative error \(|a1 - a1'| / |a1'|\) or \(|a2 - a2'| / |a2'|\). The comparison is also considering calculation error. If the comparison results do not match even if considering the error, it is judged by detecting a permanent error.

Figures 3.4 and 3.5 show the fault diagnosis process for sine & cosine and arctangent & hypotenuse, respectively.
3.2.2 Transient Fault

- Sine and cosine

(1) Allocate look-up table which stores input $\theta$, sine expectation $\sin(\theta)$ and cosine expectation $\cos(\theta)$. The size is 3072 bytes (256 x 3 x float size). However, sine expectation $\sin(\theta)$ and cosine expectation $\cos(\theta)$ are not used for transient fault diagnosis.

(2) Execute __sincosf whose input $\theta$ is loaded from look-up table.

(3) Using the input $\theta$ inputted from __sincosf, TFU calculates sine and cosine simultaneously. And then, TFU returns those results $a1 = \sin(\theta)$ and $a2 = \cos(\theta)$ to __sincosf.

(4) To create results by another calculation method as the expectation values, calculating sine and cosine using mathematic float type standard library sinf and cosf respectively.

(5) TFU diagnosis software compares TFU calculation results which are $a1$ and $a2$ with the standard library calculation results which are $a1' = \sin(\theta)$ and $a2' = \cos(\theta)$. The difference is defined as the relative error $|a1 - a1'| / |a1|$ or $|a2 - a2'| / |a2|$. The comparison is also considering calculation error. If the comparison results do not match even if considering the error, it is judged by detecting a transient error.

![Diagram](image)

**Figure 3.6 Transient Fault (sine & cosine)**

- Arctangent and hypotenuse

(1) Allocate look-up table which stores base input $x$, height input $y$, arctangent expectation $\arctan(y/x)$ and hypotenuse expectation $(x^2 + y^2)^{1/2}$. The size is 4096 bytes (256 x 4 x float size). However, arctangent expectation $\arctan2f(y, x)$ and hypotenuse expectation $(x^2 + y^2)^{1/2}$ are not used for transient fault diagnosis.

(2) Execute __atan2hypotf whose base input $x$ and height input $y$ are loaded from look-up table.

(3) Using the base input $x$ and height input $y$ inputted from __atan2hypotf, TFU calculates arctangent and hypotenuse simultaneously. And then, TFU returns those results $a1 = \arctan(y/x)$ and $a2 = (x^2 + y^2)^{1/2}$ to __atan2hypotf.

(4) To create results by another calculation method, calculating arctangent and hypotenuse using mathematic float type standard library atan2f and hypotf respectively.

(5) TFU diagnosis software compares TFU calculation results which are $a1$ and $a2$ with library calculation results which are $a1' = \arctan2f(y, x)$ and $a2' = (x^2 + y^2)^{1/2}$. The difference is defined as the relative error $|a1 - a1'| / |a1|$ or $|a2 - a2'| / |a2|$. The comparison is also considering calculation error. If the comparison results do not match even if considering the error, it is judged by detecting a transient error.
3.3 Operation Flow Example

In this section, describes the software operation flow of this sample. Figure 3.8 shows the operation flow of initial setting of TFU and diagnosis software. Figure 3.9 shows the operation flow of diagnostics for permanent fault and transient fault.

![Diagram of Operation Flow Example](image)

**Figure 3.8 Initialization Flow Example**
Figure 3.9 Diagnosis Flow Example

1. Set diagnosis configuration
   - Input data position
   - Diagnosis mode
   - Error threshold

2. Initialize diagnosis result
   - Error detection position (permanent and transient)

3. Is diagnosis permanent?
   - Yes
     - 4. Diagnosis sine and cosine operations for permanent fault: Call R_TFU_Diag_SinCos
     - 5. Diagnosis arctan and hypot operations for permanent fault: Call R_TFU_Diag_AtanHypot
     - 6. Is any permanent error detected? (Yes or No)
       - Yes: Permanent error detection, indicate error position
       - No: End

   - No
     - 7. Is diagnosis transient?
       - Yes
         - 8. Diagnosis sine and cosine operations for transient fault: Call R_TFU_Diag_SinCos
         - 9. Diagnosis arctan and hypot operations for transient fault: Call R_TFU_Diag_AtanHypot
         - 10. Is any transient error detected? (Yes or No)
           - Yes: Transient error detection, indicate error position
           - No: End

   - No: Diagnosis completed
### 3.4 Performance of Diagnosis Operation (Measurement Example)

Table 3.1 and Table 3.2 show the diagnosis operation time of RX72M and RX72T respectively as the performance reference. Those operation times are measured by the execution interval for each kind of operation.

Please keep your mind those results are depend on the condition and environment.

#### Table 3.1 RX72M operation time

<table>
<thead>
<tr>
<th>Kind of fault</th>
<th>Operation</th>
<th>CC-RX V3.01.00</th>
<th>EWRX V4.12.1</th>
<th>GCC V4.08.04</th>
</tr>
</thead>
<tbody>
<tr>
<td>Permanent</td>
<td>Sine and cosine</td>
<td>153</td>
<td>114</td>
<td>193</td>
</tr>
<tr>
<td></td>
<td>Arctangent and hypotenuse</td>
<td>168</td>
<td>123</td>
<td>205</td>
</tr>
<tr>
<td>Transient</td>
<td>Sine and cosine</td>
<td>236</td>
<td>237</td>
<td>379</td>
</tr>
<tr>
<td></td>
<td>Arctangent and hypotenuse</td>
<td>101,714</td>
<td>330,770</td>
<td>101,485</td>
</tr>
</tbody>
</table>

#### Table 3.2 RX72T operation time

<table>
<thead>
<tr>
<th>Kind of fault</th>
<th>Operation</th>
<th>CC-RX V3.01.00</th>
<th>EWRX V4.12.1</th>
<th>GCC V4.08.04</th>
</tr>
</thead>
<tbody>
<tr>
<td>Permanent</td>
<td>Sine and cosine</td>
<td>181</td>
<td>135</td>
<td>230</td>
</tr>
<tr>
<td></td>
<td>Arctangent and hypotenuse</td>
<td>199</td>
<td>145</td>
<td>244</td>
</tr>
<tr>
<td>Transient</td>
<td>Sine and cosine</td>
<td>277</td>
<td>269</td>
<td>451</td>
</tr>
<tr>
<td></td>
<td>Arctangent and hypotenuse</td>
<td>100,336</td>
<td>284,940</td>
<td>100,417</td>
</tr>
</tbody>
</table>
4. API Functions

TFU diagnosis software (r_tfu_diag_rx.c) has four API functions. Describing their specification in this section.

4.1 R_TFU_Diag_GetVersion()

This function returns the version number of TFU diagnosis software.

**Format**

```c
uint32_t R_TFU_Diag_GetVersion(void);
```

**Parameters**

`None`

**Return Values**

- `TFU_DIAG_VERSION_MAJOR` (upper 16bit): Major version number
- `TFU_DIAG_VERSION_MINOR` (lower 16bit): Minor version number

**Properties**

Prototyped in “r_tfu_diag_rx_if.h”.

**Description**

Return major and minor version number of TFU diagnosis software.

This software version number is “1.00”.

- Upper 16 bit indicates major version number

- Lower 16 bit indicates minor version number
  - `TFU_DIAG_VERSION_MINOR`: current value = H‘00.

**Reentrant**

Function is reentrant.

**Example**

Example showing this function being used.

```c
#include <stdio.h>
#include "r_tfu_diag_rx_if.h"

uint32_t version;

version = R_TFU_Diag_GetVersion();

printf("TFU diag software version = %d.%02d\n", ver >> 16u, ver & 0xFFFF);
```

**Special Notes**

Return value itself will be change depend on the diagnosis software version.
4.2 R_TFU_Diag_Init()

This function initializes TFU.

**Format**

```c
void R_TFU_Diag_Init(void);
```

**Parameters**

*None*

**Return Values**

*None*

**Properties**

Prototyped in "r_tfu_diag_rx_if.h".

**Description**

This function initializes TFU by calling __init_tfu() intrinsic function.

TFU initialization is relevant, only if CC-RX or GCC compiler is used.

No operation executes on this function, If EWRX compiler is used.

**Reentrant**

Function is not reentrant.

**Example**

Example showing this function being used.

```c
#include <math.h>
#if defined(__CCRX__)
#include <mathf.h>
#endif
#include <stdio.h>
#include "r_tfu_diag_rx_if.h"

tfu_return_t ret;
DiagConf conf;
DiagRes res;

/* Initialize TFU */
R_TFU_Diag_Init();

printf("TFU is initialized\n");

/* ==== Hard error diagnosis ==== */
/* Diagnosis sine and cosine operations for hard error */
conf.start = 0;
conf.end = (LUTSinSize - 1);
conf.mode = DIAG_HW_ERR;
conf.thresh = HW_DIAG_THRE;
res.h_point = conf.start;
res.s_point = conf.start;

ret = R_TFU_Diag_SinCos(&conf, &res);
if (TFU_OK == ret) {
    printf("Func completed: R_TFU_Diag_SinCos [start point = %d, end point
    = %d] \n", conf.start, conf.end);
} else if (TFU_ERR_DET == ret) {
```
printf("HW error detected: R_TFU_Diag_SinCos [HW error point = %d] \n", res.h_point);
    goto err_end;
else
{
    printf("unknown error: R_TFU_Diag_SinCos [error code = %d] \n", ret);
    goto err_end;
}

/* ==== Soft error diagnosis ==== */
/* Diagnosis arctan and hypot operations for soft error */
conf.start = 0;
conf.end = (LUTSinSize - 1);
conf.mode = DIAG_SW_ERR;
conf.thresh = SW_DIAG_THRE;
res.h_point = conf.start;
res.s_point = conf.start;

ret = R_TFU_Diag_AtanHypot(&conf, &res);
if (TFU_OK == ret)
{
    printf("Func completed: R_TFU_Diag_AtanHypot [start point = %d, end point = %d] \n", conf.start, conf.end);
}
else if (TFU_ERR_DET == ret)
{
    printf("SW error detected: R_TFU_Diag_AtanHypot [SW error point = %d] \n", res.s_point);
    goto err_end;
} else
{
    printf("unknown error: R_TFU_Diag_AtanHypot [error code = %d] \n", ret);
    goto err_end;
}

printf("Test completed\n");
while(1);

err_end:
    printf("Any error detected\n");
    while(1);

**Special Notes**
No operation executes on this function, If EWRX compiler is used.
4.3 R_TFU_Diag_SinCos()

This function does sine and cosine diagnostic operations.

**Format**

tfu_return_t R_TFU_Diag_SinCos(DiagConf *conf, DiagRes *res);

**Parameters**

*conf* - Diagnostic configuration.

*res* - Diagnostic result.

**Return Values**

TFU_OK: Processing completed successfully

TFU_ERR_PARAM: Parameter error

TFU_ERR_DET: Detected any fault

**Properties**

Prototyped in “r_tfu_diag_rx_if.h”.

**Description**

This function does sine and cosine diagnostic operations. The following operations are executed.

- Verify input configuration parameter
  
  If table index or diagnosis mode is illegal, returns error(=TFU_ERR_PARAM).

- Load input $\theta$ from look-up table.

- Execute sine and cosine calculation using TFU.
  
  This is executed by calling TFU intrinsic function. When CC-RX or EWRX compiler is used, the TFU intrinsic function is __sincosf(). When GCC compiler is used, it is __builtin_rx_sincosf().

- If the diagnosis mode is permanent fault, executing permanent fault detect operations.
  
  Load sine and cosine expectation values from look-up table.
  
  Evaluate the relative error between the calculation result of TFU to the expectation value with numerical calculation error. If the relative error exceeds the threshold of numerical calculation error, judging a permanent fault is detected and returns the detection point of permanent fault.

- If the diagnosis mode is transient fault, executing transient fault detect operations.
  
  Do the calculation of sine and cosine using mathematic float type standard library sinf and cosf respectively.
  
  Evaluate the relative error between the calculation result of TFU to the calculation value using sinf and cosf with numerical calculation error. If the relative error exceeds the threshold of numerical calculation error, judging a permanent fault is detected and returns the detection point of permanent fault.

**Reentrant**

Function is not reentrant.

**Example**

Example is same as “4.2 R_TFU_Diag_Init”.

**Special Notes**

This function needs the mathematic float type standard library build in each compiler.
4.4 R_TFU_Diag_AtanHypot()

This function does arctangent and hypotenuse diagnostic operations.

Format

```c
tfu_return_t R_TFU_Diag_AtanHypot(DiagConf *conf, DiagRes *res);
```

Parameters

- `conf` - Diagnostic configuration.
- `res` - Diagnostic result.

Return Values

- **TFU_OK**: Processing completed successfully
- **TFU_ERR_PARAM**: Parameter error
- **TFU_ERR_DET**: Detected diagnosis error

Properties

Prototyped in "r_tfu_diag_rx_if.h".

Description

This function does arctangent and hypotenuse diagnostic operations. The following operations are executed.

- Verify input configuration parameter
  - If table index or diagnosis mode is illegal, returns error (= TFU_ERR_PARAM).

- Load input base x and height y from look-up table.

- Execute arctangent and hypotenuse calculation using TFU.
  - This is executed by calling TFU intrinsic function. When CC-RX or EWRX compiler is used, the TFU intrinsic function is `__atan2hypotf()`. When GCC compiler is used, it is `__builtin_rx_atan2hypotf()`.

- If the diagnosis mode is permanent fault, executing permanent fault detect operations,
  - Load arctangent and hypotenuse expectation values from look-up table.
  - Evaluate the relative error between the calculation result of TFU to the expectation value with numerical calculation error. If the relative error exceeds the threshold of numerical calculation error, judging a permanent fault is detected and returns the detection point of permanent fault.

- If the diagnosis mode is transient fault, executing transient fault detect operations,
  - Do the calculation of arctangent and hypotenuse using mathematic float type standard library `atan2f` and `hypotf` respectively.
  - Evaluate the relative error between the calculation result of TFU to the calculation value using `atan2f` and `hypotf` with numerical calculation error. If the relative error exceeds the threshold of numerical calculation error, judging a permanent fault is detected and returns the detection point of permanent fault.

Reentrant

Function is not reentrant.

Example

Example is same as "4.2 R_TFU_Diag_Init".

Special Notes

This function needs the mathematic float type standard library build in each compiler.
5. Appendices

5.1 Confirmed Operation Environment

This section describes confirmed operation environment of this example.

Table 5.1 Confirmed Operation Environment

<table>
<thead>
<tr>
<th>Item</th>
<th>Contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Integrated development environment</td>
<td>Renesas Electronics e² studio Version V7.5.0</td>
</tr>
<tr>
<td></td>
<td>IAR Embedded Workbench for Renesas RX 4.12.1</td>
</tr>
<tr>
<td>C compiler</td>
<td>Renesas Electronics C/C++ Compiler Package for RX Family V3.01.00</td>
</tr>
<tr>
<td></td>
<td>Compiler option: The following option is added to the default settings of the integrated development environment.</td>
</tr>
<tr>
<td></td>
<td>-lang = c99, -optimize = 0 (level 0: no optimization), -tfu = Intrinsic (use trigonometric function)</td>
</tr>
<tr>
<td>GCC for Renesas RX 4.08.04.201902-SP1-GNURX</td>
<td>Compiler option: The following option is added to the default settings of the integrated development environment.</td>
</tr>
<tr>
<td></td>
<td>-std = gnu99, MTFU = intrinsic</td>
</tr>
<tr>
<td>IAR C/C++ Compiler for Renesas RX version 4.12.1</td>
<td>Compiler option: The following option is added to the default settings of the integrated development environment.</td>
</tr>
<tr>
<td></td>
<td>no optimization, TFU intrinsics</td>
</tr>
<tr>
<td>Endian</td>
<td>Big endian/little endian</td>
</tr>
<tr>
<td>Revision of the module</td>
<td>Rev.1.00</td>
</tr>
<tr>
<td>Board used</td>
<td>Renesas Starter Kit+ for RX72M</td>
</tr>
<tr>
<td></td>
<td>Renesas Starter Kit+ for RX72T</td>
</tr>
</tbody>
</table>

6. Provided Modules

The module provided can be downloaded from the Renesas Electronics website.

7. Reference Documents

User’s Manual: Hardware
RX72M Group User’s Manual: Hardware Rev.1.00 (R01UH0804EJ)
RX72T Group User’s Manual: Hardware Rev.1.00 (R01UH0803EJ)
The latest versions can be downloaded from the Renesas Electronics website.

Technical Update/Technical News
The latest information can be downloaded from the Renesas Electronics website.

User’s Manual: Development Tools
RX Family CC-RX Compiler User’s Manual Rev.1.08 (R20UT3248EJ)
The latest information can be downloaded from the Renesas Electronics website.
### Revision History

<table>
<thead>
<tr>
<th>Rev.</th>
<th>Date</th>
<th>Description</th>
<th>Page</th>
<th>Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.00</td>
<td>Aug 31, 2019</td>
<td>—</td>
<td>—</td>
<td>First edition issued.</td>
</tr>
</tbody>
</table>


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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Corporate Headquarters
TOYOSHU FORESIA, 3-2-24 Toyosu,
Koto-ku, Tokyo 135-0061, Japan
www.renesas.com

Contact information
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