This document explains how to harness the power processing of HiFi 4 DSP available in the NXP i.MX 8M Plus processor by running Zephyr RTOS on the DSP.
1 Introduction

Running Zephyr on Arm Cortex-A or Cortex-M cores is widely discussed and there are many examples on how to implement it. However, many Cortex-based microcontroller units (MCUs) and microprocessor units (MPUs) have on-chip digital signal processors (DSPs) incorporated to offload compute-intensive tasks.

The Cadence Tensilica HiFi 4 DSP is one such example of a high-performance embedded DSP optimized for audio, voice, or neural network processing. This application note explains how to harness the power processing of the HiFi 4 DSP available in the NXP i.MX 8M Plus processor, by running Zephyr real-time operating system (RTOS) on the DSP; while Linux operating system (OS) runs on the main Cortex-A core.

Using example applications, this document explains:

• How to launch the applications on the HiFi 4 DSP
• How the HiFi 4 DSP and the main processor core communicate to each other
• How to get the output of the applications

In this document, all the examples are explained using existing drivers and/or frameworks from Linux OS and Zephyr RTOS.

2 Hardware platform

The i.MX 8M Plus EVK board is based on the NXP i.MX 8M Plus applications processor, which is composed of:

• 4x Arm Cortex-A53 up to 1.8 GHz
• 1x Arm Cortex-M7 up to 800 MHz
• Cadence Tensilica HiFi 4 DSP up to 800 MHz

Figure 1 shows the top view of the i.MX 8M Plus EVK board.
3 Zephyr OS

The Zephyr Project is a scalable real-time operating system (RTOS) supporting multiple hardware architectures, optimized for resource-constrained devices, and built with security in mind. It is based on a small-footprint kernel designed for use on resource-constrained systems.

NXP offers various evaluation and prototyping platforms that the Zephyr OS can support. Developers are able to tailor a solution easily to meet their needs using a true open source project with hardware, developer tools, and sensor and device drivers. Security enhancements with Zephyr OS enable easy implementation of device management, connectivity stacks, and file systems.

For more details on the Zephyr RTOS, visit www.zephyrproject.org/.

4 HiFi 4 audio DSP

The HiFi 4 Audio Engine is a highly optimized audio processor geared for efficient execution of audio and voice codecs and pre- and post-processing modules.
In Zephyr, the board that supports the audio DSP from i.MX 8M Plus is nxp_adsp_imx8m.

4.1 Supported features

The Zephyr nxp_adsp_imx8m board configuration supports the hardware features shown in Table 1.

Table 1. Supported hardware features

<table>
<thead>
<tr>
<th>Interface</th>
<th>Controller</th>
<th>Driver/component</th>
</tr>
</thead>
<tbody>
<tr>
<td>SYSTICK</td>
<td>On-chip</td>
<td>systick</td>
</tr>
<tr>
<td>CLOCK</td>
<td>On-chip</td>
<td>clock_control</td>
</tr>
<tr>
<td>PINMUX</td>
<td>On-chip</td>
<td>pinmux</td>
</tr>
<tr>
<td>UART</td>
<td>On-chip</td>
<td>serial port-polling</td>
</tr>
</tbody>
</table>

Note: The port does not support other hardware features currently.

The default configuration can be found in the defconfig file, boards/xtensa/nxp_adsp_imx8m/nxp_adsp_imx8m_defconfig.

4.2 Connections and I/Os

The i.MX 8M Plus EVK board is tested with the pinmux controller configuration shown in Table 2.

Table 2. Connections

<table>
<thead>
<tr>
<th>Board name</th>
<th>SoC name</th>
<th>Usage</th>
</tr>
</thead>
<tbody>
<tr>
<td>UART4 RXD</td>
<td>UART4_TXD</td>
<td>UART console</td>
</tr>
<tr>
<td>UART4 TXD</td>
<td>UART4_RXD</td>
<td>UART console</td>
</tr>
</tbody>
</table>

4.3 System clock

The HiFi 4 DSP core is configured to run at 800 MHz clock speed.

4.4 Serial port

The i.MX 8M Plus SoC has four Universal Asynchronous Receiver/Transmitters (UARTs). Only UART_4 is configured for the DSP console and the remaining UARTs are not used/tested.

5 Building and running Zephyr samples on HiFi 4 DSP

This section describes how to build and run Zephyr samples on HiFi 4 DSP using the following two applications:

• Section 5.1
• Section 5.2

5.1 hello_world application

The Zephyr's hello_world application is a simple sample that can be used with one of the Supported boards and prints "Hello World" to the console.
5.1.1 Load hello_world application on DSP

To load the hello_world application on the DSP, use the Linux remoteproc driver.

In Linux, a generic i.MX remoteproc driver and a DSP-specific driver (imx_dsp_rproc) are already available.

Because the application is running on the DSP, use the imx_dsp_rproc driver. To use the driver, enable CONFIG_IMX_DSP_REMOTEPROC in the Linux kernel.

5.1.2 Compile hello_world application

Compile the hello_world application in Zephyr for the i.MX 8M Plus DSP, it means, compile the application for the nxp_adsp_imx8m board.

Go to the zephyr/ folder from zephyrproject and run:

```
~/zephyrproject/zephyr$ west build -p always -b nxp_adsp_imx8m samples/hello_world/
~/zephyrproject/zephyr$ ls -la build/zephyr
```

```
 total 4288
drwxr-xr-x  14 user nxp   4096 Oct 17 17:05 .
drwxr-xr-x   7 user nxp   4096 Oct 17 17:05 ..
drwxr-xr-x   5 user nxp   4096 Oct 17 17:05 arch
```

```
~/zephyrproject/zephyr$ ls -la build/zephyr
```

```
 total 4288
```

```
drwxr-xr-x  14 user nxp   4096 Oct 17 17:05 .
drwxr-xr-x   7 user nxp   4096 Oct 17 17:05 ..
drwxr-xr-x   5 user nxp   4096 Oct 17 17:05 arch
```

The zephyr.elf file is used as the firmware to be loaded on the DSP.

5.1.3 Run hello_world application on DSP

The subsections that follow explain how to run the hello_world application on HiFi 4 DSP from i.MX 8M Plus.

5.1.3.1 Start i.MX 8M Plus EVK board

Start the i.MX 8M Plus EVK board with a specific device tree source (DTS).

Use imx8mp-evk-dsp.dtb, and after inserting the imx_dsp_rproc.ko kernel module, you get:

```
root@imx8mpevk:~# ls -la /sys/class/remoteproc/
total 0
```

```
drwxr-xr-x  2 root root 0 Mar  3 09:49 .
drwxr-xr-x  90 root root 0 Mar  3 09:49 ..
```

```
lrwxrwxrwx  1 root root 0 Mar  3 09:54 remoteproc0 -> ../../devices/platform/3b6e8000.dsp/remoteproc/remoteproc0
```
Here, remoteproc0, which is for DSP, is used.

5.1.3.2 Check firmware on board

Check the firmware image on the board:

```
root@imx8mpevk:~# ls -la /lib/firmware/imx/zephyr/
```

The firmware must be present in /lib/firmware before the remoteproc driver is probed; however, it can also be given with an absolute path.

5.1.3.3 Insert imx_dsp_rproc.ko kernel module

By default, the i.MX DSP remoteproc protocol waits for a READY reply from the remote processor. Because not all Zephyr sample applications (especially simple applications that do not use the mailbox) send a READY reply, you must use the remoteproc module imx_dsp_rproc.ko without waiting for a reply. The imx_dsp_rproc.ko module is implemented using the kernel module parameter no_mailboxes, as shown below:

```
root@imx8mpevk:~# modinfo imx_dsp_rproc
```

By default, the no_mailboxes parameter is off — do not ignore the reply from the remote processor.

Therefore, first check the imx_dsp_rproc parameter. If it is off, remove the module and insert it with the right parameter.

```
root@imx8mpevk:~# grep -H '' /sys/module/imx_dsp_rproc/parameters/* /no_mailboxes param is off */
```

```
root@imx8mpevk:~# rmmod imx_dsp_rproc /* remove kernel module */
```
5.1.3.4 Load firmware on DSP and run it

To load the firmware on DSP and run it, execute the following commands:

```
root@imx8mpevk:~# echo -n /lib/firmware/imx/zephyr/imx8m-hello-world-zephyr.elf > /sys/class/remoteproc/remoteproc0/firmware
root@imx8mpevk:~# echo start > /sys/class/remoteproc/remoteproc0/state
```

5.1.3.5 Stop firmware

To stop the firmware, use the following command:

```
root@imx8mpevk:~# echo stop > /sys/class/remoteproc/remoteproc0/state
```

5.1.4 Get hello_world application output

To get the hello_world application output, follow these steps:

1. Get console through UART.
2. Open a serial terminal on the fourth serial port:

   ```
   user@developerpc:~# minicom -D /dev/ttyUSB3
   ```

   You see the following message in the terminal (also shown in Figure 2):

   ```
   Hello World! nxp_adsp_imx8m
   *** Booting Zephyr OS build zephyr-v3.5.0-1510-gaa71ed4a1f55 ***
   ```
You can use the above steps to build and test any other sample, such as synchronization or philosophers.

You can also run more complex samples that demonstrate how Linux and Zephyr can work in unison. The next section exemplifies the openamp_rsc_table application.

### 5.2 openamp_rsc_table application

The Zephyr's openamp_rsc_table application demonstrates how to use Open Asymmetric Multi-Processing (OpenAMP) with Zephyr based on a resource table. It is designed to respond to the:

- Linux rpmsg client sample
- Linux rpmsg tty driver

This sample implementation is compatible with platforms that embed a Linux kernel OS on the main processor and a Zephyr application on the coprocessor.

#### 5.2.1 Load openamp_rsc_table application on DSP

As mentioned in Section 5.1.1, to load the openamp_rsc_table application on the DSP, use the imx_dsp_rproc driver, after enabling CONFIG_IMX_DSP_REMOTEPROC in the Linux kernel.

#### 5.2.2 Compile openamp_rsc_table application in Zephyr

Compile the openamp_rsc_table application in Zephyr for the i.MX 8M Plus DSP, it means, compile the application for the nxp_adsp_imx8m board.

Go to the zephyr/ folder from zephyrproject and run:

```
~/zephyrproject/zephyr$ west build -p always -b nxp_adsp_imx8m samples/subsys/ipc/openamp_rsc_table
~/zephyrproject/zephyr$
~/zephyrproject/zephyr$ ls -la build/zephyr total 5284
drwxr-xr-x 14 nxa06898 nxp  4096 Sep 27 17:42 .
drwxr-xr-x  7 nxa06898 nxp  4096 Sep 27 17:42 ..
drwxr-xr-x  5 nxa06898 nxp  4096 Sep 27 17:42 arch
```

...}

```
~/zephyrproject/zephyr$ ls -la build/zephyr total 5284
drwxr-xr-x 14 nxa06898 nxp  4096 Sep 27 17:42 .
drwxr-xr-x  7 nxa06898 nxp  4096 Sep 27 17:42 ..
drwxr-xr-x  5 nxa06898 nxp  4096 Sep 27 17:42 arch
drwxr-xr-x  3 nxa06898 nxp  4096 Sep 27 17:42 boards
drwxr-xr-x  5 nxa06898 nxp  4096 Sep 27 17:42 cmake
-drwxr-xr-x  1 nxa06898 nxp  96 Sep 27 17:42 .cmake
-drwxr-xr-x  1 nxa06898 nxp 13684 Sep 27 17:42 CMakeFiles
-drwxr-xr-x  1 nxa06898 nxp  41787 Sep 27 17:42 .config
-drwxr-xr-x  1 nxa06898 nxp  4096 Sep 27 17:42 drivers
...
drwxr-xr-x  4 nxa06898 nxp  4096 Sep 27 17:42 soc
```
The `zephyr_openamp_rsc_table.elf` file is used as the firmware to be loaded on the DSP.

5.2.3 Run openamp_rsc_table application on DSP in Linux

The subsections that follow explain how to run the openamp_rsc_table application on HiFi 4 DSP from i.MX 8M Plus in Linux.

The `rpmsg_client_sample.ko` and `rpmsg_tty.ko` modules are used to communicate with the openamp_rsc_table application that runs on the DSP. These are sample modules that run on the main processor (Cortex A core).

To build the `rpmsg_client_sample.ko` and `rpmsg_tty.ko` modules, enable the `CONFIG_SAMPLE_RPMSG_CLIENT` and `CONFIG_RPMSG_TTY` configurations, respectively, in the Linux kernel.

5.2.3.1 Start i.MX 8M Plus EVK board

Start the i.MX 8M Plus EVK board with a specific DTS. Use `imx8mp-evk-dsp.dtb`, and after inserting the `imx_dsp_rproc.ko` kernel module, you get:

```
root@imx8mpevk:~# insmod imx_dsp_rproc.ko
[  115.172960] remoteproc remoteproc0: imx-dsp-rproc is available
root@imx8mpevk:~# ls -la /sys/class/remoteproc/
total 0
drwxr-xr-x  2 root root 0 Mar  3 09:49 .
drwxr-xr-x  90 root root 0 Mar  3 09:49 ..
lwxrwxrwx  1 root root 0 Mar  3 20:09 remoteproc0 -> ../../devices/platform/3b6e8000.dsp/remoteproc/remoteproc0
```

Here, `remoteproc0`, which is for DSP, is used.

5.2.3.2 Check firmware on board

Check the firmware image on the board:

```
root@imx8mpevk:~# ls -la /lib/firmware/imx/zephyr/
total 148
drwxr-xr-x  2 root root 4096 Mar 9 2018 .
drwxr-xr-x 11 root root 4096 Mar 9 2018 ..
-rwxr-xr-x  1 root root 41524 Mar 9 2018 imx8-hello-world-zephyr.elf
-rwxr-xr-x  1 root root 57100 Mar 9 2018 imx8m-hello-world-zephyr.elf
-rwxr-xr-x  1 root root 41524 Mar 9 2018 imx8x-hello-world-zephyr.elf
-rwxr-xr-x  1 root root 998304 Mar 9 2018 imx8m-openamp_rsc_table-zephyr.elf
```

The firmware must be present in `/lib/firmware` before the remoteproc driver is probed; however, it can also be given with an absolute path.
5.2.3.3 Insert `imx_dsp_rproc.ko` kernel module

Insert the `imx_dsp_rproc.ko` kernel module as shown below:

```bash
root@imx8mpevk:~# modprobe imx_dsp_rproc
[ 115.172960] remoteproc remoteproc0: imx-dsp-rproc is available
root@imx8mpevk:~# ls -la /sys/class/remoteproc/
total 0
drwxr-xr-x 2 root root 0 Mar  3 09:49 .
drwxr-xr-x 90 root root 0 Mar  3 09:49 ..
lrwxrwxrwx  1 root root 0 Mar  3 20:09 remoteproc0 -> ../../devices/platform/3b6e8000.dsp/remoteproc/remoteproc0
```

5.2.3.4 Insert rpmsg Linux client samples

Insert rpmsg Linux client samples as follows:

```bash
root@imx8mpevk:~# modprobe rpmsg_client_sample.ko     /* rpmsg client sample
driver used to communicate with remote processor over the rpmsg bus */
root@imx8mpevk:~# modprobe rpmsg_tty.ko               /* export rpmsg endpoints
as tty devices, usually found as /dev/ttyRPMSGx */
```

5.2.3.5 Load firmware on DSP and run it

5.2.3.5.1 rpmsg client sample

From Linux, send 100 messages with "hello world" to Zephyr.

Linux console:

```bash
root@imx8mpevk:~# echo -n zephyr_openamp_rsc_table.elf > /sys/class/remoteproc/remoteproc0/firmware
root@imx8mpevk:~# echo start > /sys/class/remoteproc/remoteproc0/state
[ 200.630824] remoteproc remoteproc0: powering up imx-dsp-rproc
[ 200.637393] remoteproc remoteproc0: Booting fw image
zephyr_openamp_rsc_table.elf, size 999412
[ 200.649895] rproc-virtio rproc-virtio.2.auto: assigned reserved memory node
dev0buffer@94300000
[ 200.662289] virtio_rpmsg_bus virtio0: rpmsg host is online
[ 200.667889] virtio-rpmsg-virtio-virtio.2.auto: registered virtio0 (type 7)
[ 200.674715] remoteproc remoteproc0: remote processor imx-dsp-rproc is now up
[ 200.681908] virtio_rpmsg_bus virtio0: creating channel rpmsg-client-sample
addr 0x400
[ 200.689959] rpmsg_client_sample virtio0.rpmsg-client-sample.-1.1024: new
channel: 0x400 -> 0x400!
[ 200.700409] virtio_rpmsg_bus virtio0: creating channel rpmsg-tty addr 0x401
[ 200.707894] rpmsg_client_sample virtio0.rpmsg-client-sample.-1.1024: incoming
msg 1 (src: 0x400)
[ 200.717703] rpmsg_client_sample virtio0.rpmsg-client-sample.-1.1024: incoming
msg 2 (src: 0x400)
[ 200.726580] rpmsg_client_sample virtio0.rpmsg-client-sample.-1.1024: incoming
msg 3 (src: 0x400)
[ 200.735433] rpmsg_client_sample virtio0.rpmsg-client-sample.-1.1024: incoming
msg 4 (src: 0x400)
[ 200.744289] rpmsg_client_sample virtio0.rpmsg-client-sample.-1.1024: incoming
msg 5 (src: 0x400)
```

Running Zephyr RTOS on Cadence Tensilica HiFi 4 DSP

Zephyr console:

*** Booting Zephyr OS build zephyr-v3.4.0-4490-gd885048637d6 ***
Starting application threads!

OpenAMP[remote]  linux responder demo started

OpenAMP[remote]  Linux sample client responder started

[00:00:00.015,000] <dbg> openamp_rsc_table: platform_ipm_callback: platform_ipm_callback: msg received from mb 0

[00:00:00.020,000] <dbg> openamp_rsc_table: mailbox_notify: mailbox_notify: msg received

[00:00:00.024,000] <dbg> openamp_rsc_table: mailbox_notify: mailbox_notify: msg received

[00:00:00.053,000] <dbg> openamp_rsc_table: platform_ipm_callback: platform_ipm_callback: msg received from mb 0

[00:00:00.053,000] <dbg> openamp_rsc_table: mailbox_notify: mailbox_notify: msg received

[00:00:00.070,000] <dbg> openamp_rsc_table: platform_ipm_callback: platform_ipm_callback: msg received from mb 0
5.2.3.5.2 rpmsg TTY demo

On the Linux console, send a message to Zephyr, which replies with the "TTY <add>" prefix. <addr> corresponds to the Zephyr rpmsg-tty endpoint address.

**Linux console:**

```
root@imx8mpevk:~# cat /dev/ttyRPMSG0 &
[1] 1540
root@imx8mpevk:~# echo "Hello Zephyr" >/dev/ttyRPMSG0
TTY 0x0401: Hello Zephyr
root@imx8mpevk:~#```

**Zephyr console:**

```
*** Booting Zephyr OS build zephyr-v3.4.0-4490-gd885048637d6 ***
Starting application threads!
OpenAMP[remote]  linux responder demo started
OpenAMP[remote] Linux tty responder started
[00:00:00.070,000] <dbg> openamp_rsc_table: mailbox_notify: mailbox_notify: msg received
```
5.2.3.6 Stop firmware

To stop the firmware, use the following command:

```
root@imx8mpevk:~# echo stop > /sys/class/remoteproc/remoteproc0/state
```

5.2.4 Get openamp_rsc_table application output

To get the openamp_rsc_table application output, follow these steps:

1. Get console through UART.
2. Open a serial terminal on the fourth serial port:

```
user@developerpc:~# minicom -D /dev/ttyUSB3
```

You see the following messages in the terminal (also shown in Figure 3):

```plaintext
*** Booting Zephyr OS build zephyr-v3.4.0-4490-gd885048637d6 ***
Starting application threads!
OpenAMP[remote]  linux responder demo started
OpenAMP[remote] Linux sample client responder started
OpenAMP[remote] Linux tty responder started
[00:00:00.015,000] <dbg> openamp_rsc_table: platform_ipm_callback: msg received from mb 0
```

Figure 3. openamp_rsc_table application output

6 Acronyms

Table 3 lists the acronyms used in this document.

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>DSP</td>
<td>Digital signal processor</td>
</tr>
<tr>
<td>DTS</td>
<td>Device tree source</td>
</tr>
<tr>
<td>IPC</td>
<td>Inter-process communication</td>
</tr>
</tbody>
</table>

Table 3. Acronyms
Table 3. Acronyms...continued

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>MCU</td>
<td>Microcontroller unit</td>
</tr>
<tr>
<td>MPU</td>
<td>Microprocessor unit</td>
</tr>
<tr>
<td>OpenAMP</td>
<td>Open Asymmetric Multi-Processing</td>
</tr>
<tr>
<td>OS</td>
<td>Operating system</td>
</tr>
<tr>
<td>rproc</td>
<td>Remote processor</td>
</tr>
<tr>
<td>rsc_table</td>
<td>Resource table</td>
</tr>
<tr>
<td>RTOS</td>
<td>Real-time operating system</td>
</tr>
<tr>
<td>UART</td>
<td>Universal Asynchronous Receiver/Transmitter</td>
</tr>
</tbody>
</table>

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8 Revision history

Table 4 summarizesthe revisions to this document.

Table 4. Revision history

<table>
<thead>
<tr>
<th>Document ID</th>
<th>Release date</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AN13970 v.2</td>
<td>28 November 2023</td>
<td>Updated these sections:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Section 5.1.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Section 5.1.3.1</td>
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<tr>
<td></td>
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<td>• Section 5.1.3.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Section 5.1.3.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Section 5.1.3.4</td>
</tr>
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<td>• Section 5.1.3.5</td>
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Table 4. Revision history...continued

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<thead>
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<th>Document ID</th>
<th>Release date</th>
<th>Description</th>
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<tr>
<td>AN13970 v.1</td>
<td>1 June 2023</td>
<td>• Section 5.1.4</td>
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<td></td>
<td>Added a new section: Section 5.2</td>
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<tr>
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<td>Initial public release</td>
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# Contents

1. **Introduction** ...................................................... 2  
2. **Hardware platform** ........................................... 2  
3. **Zephyr OS** ........................................................ 3  
4. **HiFi 4 audio DSP** ............................................. 3  
   4.1 Supported features ............................................ 4  
   4.2 Connections and I/Os ........................................... 4  
   4.3 System clock ..................................................... 4  
   4.4 Serial port ........................................................ 4  
5. **Building and running Zephyr samples on HiFi 4 DSP** ................................................. 4  
   5.1 hello_world application ...................................... 4  
   5.1.1 Load hello_world application on DSP .............. 5  
   5.1.2 Compile hello_world application ..................... 5  
   5.1.3 Run hello_world application on DSP .......... 5  
   5.1.3.1 Start i.MX 8M Plus EVK board ............... 5  
   5.1.3.2 Check firmware on board ......................... 6  
   5.1.3.3 Insert imx_dsp_rproc.ko kernel module ........... 6  
   5.1.3.4 Load firmware on DSP and run it .......... 7  
   5.1.3.5 Stop firmware ....................................... 7  
   5.1.4 Get hello_world application output ............ 7  
   5.2 openamp_rsc_table application ......................... 8  
   5.2.1 Load openamp_rsc_table application on DSP .................. 8  
   5.2.2 Compile openamp_rsc_table application in Zephyr ............................. 8  
   5.2.3 Run openamp_rsc_table application on DSP in Linux ............................................ 9  
   5.2.3.1 Start i.MX 8M Plus EVK board ..................... 9  
   5.2.3.2 Check firmware on board ............................ 9  
   5.2.3.3 Insert imx_dsp_rproc.ko kernel module ........... 10  
   5.2.3.4 Insert rpmsg Linux client samples .............. 10  
   5.2.3.5 Load firmware on DSP and run it .......... 10  
   5.2.3.6 Stop firmware .................................... 13  
   5.2.4 Get openamp_rsc_table application output ...... 13  
6. **Acronyms** ....................................................... 13  
7. **Note about the source code in the document** .................................................. 14  
8. **Revision history** ............................................... 14  
   Legal information ............................................... 16