AN13970

在 Cadence Tensilica HiFi 4 DSP 上运行 Zephyr RTOS

Rev. 2 — 2023年11月28日 应用笔记

文档信息

信息	内容
关键词	AN13970, i.MX 8M Plus, HiFi 4 DSP, Zephyr, IPC, OpenAMP, remoteproc
摘要	本文介绍了如何在 HiFi 4 DSP 上启动示例应用、HiFi 4 DSP 与主核如何通信，以及如何获取示例应用的输出。

1 介绍

业内广泛讨论如何在Arm Cortex-A或Cortex-M核上运行Zephyr，并且已经产生了许多实例。然而，许多基于Cortex的MCU和MPU也选择集成片上DSP来分流计算密集型任务。

Cadence Tensilica HiFi 4 DSP 就是这类高性能嵌入式数字信号处理器（DSP）的示例之一，它针对音频、语音或神经网络处理进行了优化。本应用笔记重点介绍了：如何在主 Cortex-A 核上运行 Linux 操作系统的同时，在 DSP 上运行 Zephyr 实时操作系统，从而利用 DSP 的强大处理能力。

本文档包含一个简单的示例应用 “hello_world”，但也可以使用其他示例。本文档将解释如下问题：

- 如何在 HiFi 4 DSP 上启动示例应用
- HiFi 4 DSP 和主核如何通信
- 如何获取示例应用的输出

在本文档中，所有示例均使用 Linux 操作系统和 Zephyr 实时操作系统的现有驱动程序和/或框架进行说明。

2 硬件平台

i.MX 8M Plus EVK 板基于NXP i.MX 8M Plus 应用处理器，由以下部分组成：

- 四个 Arm Cortex-A53， 频率高达 1.8 GHz
- 一个 Arm Cortex-M7， 频率高达 800 MHz
- Cadence Tensilica HiFi 4 DSP， 频率高达 800 MHz

图 1 显示了i.MX 8M Plus EVK板的俯视图。

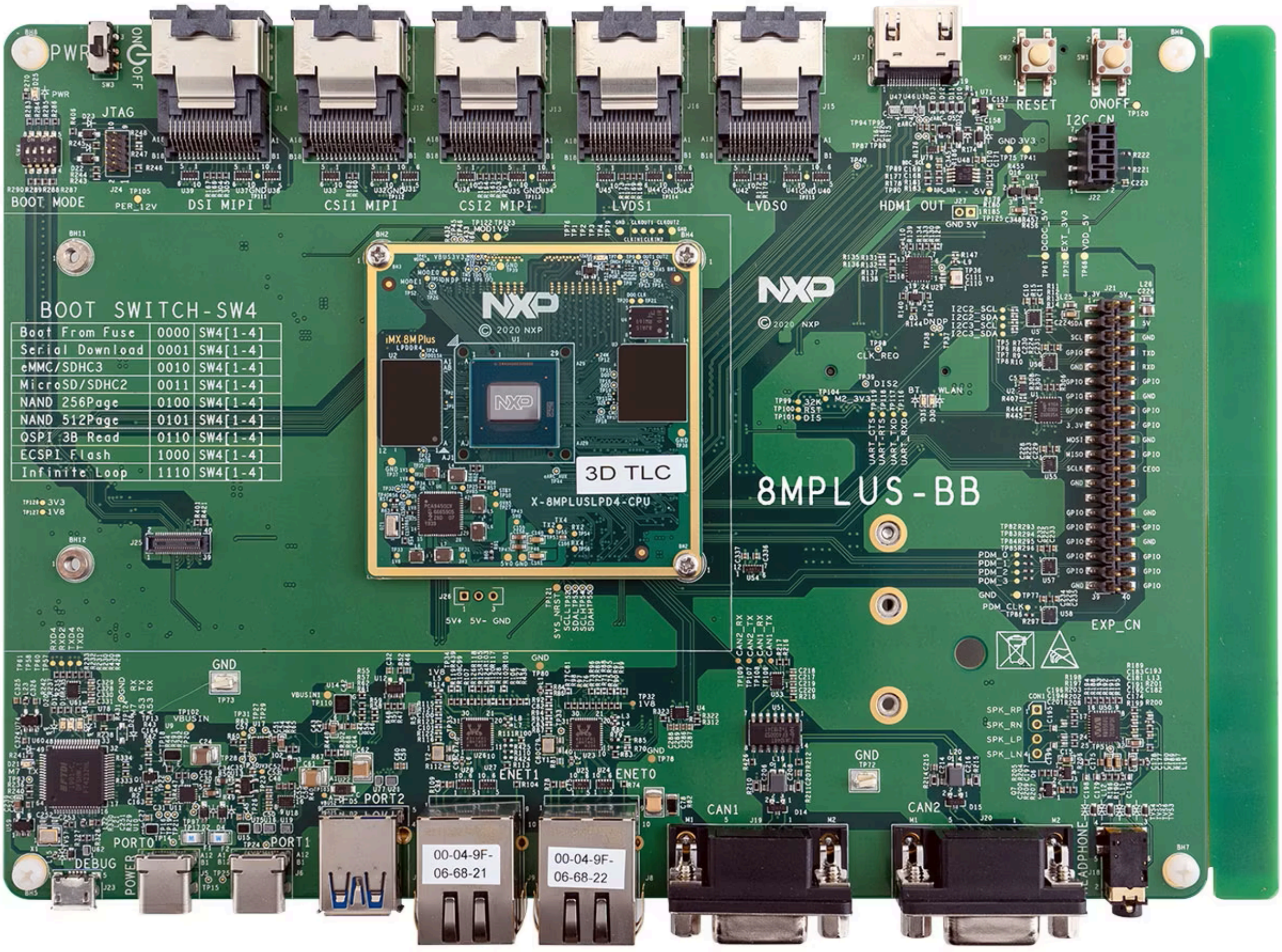


图 **1. i.MX 8M Plus EVK** 板俯视图

如需了解详情，请参阅 i.MX 8M Plus EVK 上的电路板信息。

3 Zephyr 操作系统

Zephyr Project 是一个可扩展的实时操作系统（RTOS），支持多种硬件架构，针对资源受限的器件进行了优化，并在构建时考虑了安全性。它基于小内核，专为在资源受限的系统上使用而设计。

NXP 提供 Zephyr 操作系统支持的各种评估和原型平台。开发人员能够使用包含硬件、开发工具以及传感器和器件驱动程序的真实开源项目，轻松定制符合自身需求的解决方案。Zephyr 操作系统的安全增强功能使设备管理、连接栈和文件系统的实施变得简单。

有关Zephyr RTOS的更多信息，请访问 www.zephyrproject.org/。

4 HiFi 四音频数字信号处理器 DSP

HiFi 四音频引擎是一款高度优化的音频处理器，可实现音频和语音编解码器以及前处理和后处理模块的高效执行。

在 Zephyr 中，支持 i.MX 8M Plus 音频 DSP 的板是 nxp_adsp_imx8m。

4.1 支持的功能

Zephyr nxp_adsp_imx8m 板的配置支持 表 1 中的硬件功能。

表 1. 支持的硬件功能

接口	控制器	驱动程序/组件
SYSTICK	On-chip	systick
CLOCK	On-chip	clock_control
PINMUX	On-chip	pinmux
UART	On-chip	serial port-polling

注：该端口目前不支持其他硬件功能。

默认配置可在 defconfig 文件中找到：boards/xtensa/nxp_adsp_imx8m/nxp_adsp_imx8m_defconfig。

4.2 连接和 I/Os

i.MX 8M Plus EVK 板使用以下pinmux控制器配置进行测试，如 表 2 所示。

表 2. 连接

电路板名称	SoC 名称	用途
UART4 RXD	UART4_TXD	UART 控制台
UART4 TXD	UART4_RXD	UART 控制台

4.3 系统时钟

HiFi 4 DSP 内核配置为以 800 MHz 时钟速度运行。.

4.4 串行端口

i.MX 8M Plus SoC 有四个 UART。仅 UART_4 配置给了 DSP 控制台，其余 UART 没有被使用/测试.

5 在 HiFi 4 DSP 上构建和运行 Zephyr 示例

本节介绍在 HiFi 4 DSP上构建和运行 Zephyr 示例的步骤：

- 章节 5.1
- 章节 5.2

5.1 hello_world 应用

Zephyr's hello_world 应用是一个简单的示例，支持用于多种 Supported boards，并在控制台中打印 “Hello World” 。

5.1.1 在 DSP 上加载 hello_world 应用

要在 DSP 上加载应用，请使用 Linux remoteproc 驱动程序。

在 Linux 中，可以使用 i.MX remoteproc 驱动程序和 DSP 特定驱动程序（imx_dsp_rproc）。

由于应用是在 DSP 上运行，因此要使用 imx_dsp_rproc 驱动程序。为此，请启用 Linux内核中的 `CONFIG_IMX_DSP_REMOTEPROC`。

5.1.2 编译 hello_world application

在 Zephyr 中为 i.MX 8M Plus DSP（即 Zephyr 中的 nxp_adsp_imx8m 板）编译 hello_world 应用。

进入 zephyrproject 中的 zephyr/ 文件夹并运行：

```
~/zephyrproject/zephyr$ west build -p always -b nxp_adsp_imx8m samples/
hello_world/
~/zephyrproject/zephyr$
~/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
drwxr-xr-x  3 user nxp   4096 Oct 17 17:05 boards
drwxr-xr-x  5 user nxp   4096 Oct 17 17:05 cmake
-rw-r--r--  1 user nxp     64 Oct 17 17:05 .cmake.dotconfig.checksum
drwxr-xr-x  6 user nxp   4096 Oct 17 17:05 CMakeFiles
-rw-r--r--  1 user nxp  12355 Oct 17 17:05 cmake_install.cmake
-rw-r--r--  1 user nxp  39648 Oct 17 17:05 .config
...
-rw-r--r--  1 user nxp   2275 Oct 17 17:05 zephyr.dts
-rw-r--r--  1 user nxp    619 Oct 17 17:05 zephyr.dts.d
-rw-r--r--  1 user nxp 124460 Oct 17 17:05 zephyr.dts.pre
-rwxr-xr-x  1 user nxp 715896 Oct 17 17:05 zephyr.elf
-rw-r--r--  1 user nxp 408374 Oct 17 17:05 zephyr_final.map
-rw-r--r--  1 user nxp 408374 Oct 17 17:05 zephyr.map
-rwxr-xr-x  1 user nxp 717052 Oct 17 17:05 zephyr_pre0.elf
-rw-r--r--  1 user nxp 408886 Oct 17 17:05 zephyr_pre0.map
-rw-r--r--  1 user nxp   7273 Oct 17 17:05 zephyr.stat
```

`zephyr.elf` 文件将作为固件加载到 DSP 上。

5.1.3 在 DSP 上运行 hello_world 应用的步骤

以下是在 i.MX 8M Plus的HiFi 4 DSP 上运行 hello_world 应用的步骤。

5.1.3.1 启动 i.MX 8M Plus EVK 板

使用特定 DTS 启动 i.MX 8M Plus EVK 板。

使用 `imx8mp-evk-dsp.dtb`， 插入 `imx_dsp_rproc.ko` 内核模块后，您就可以看到如下脚本：

```
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
root@imx8mpevk:~# cat /sys/class/remoteproc/remoteproc0/firmware
imx/dsp/hifi4.bin
root@imx8mpevk:~#
```

由于 remoteproc1 用于 DSP，因此使用此模块。

5.1.3.2 检查电路板上的固件

检查电路板上的固件镜像：

```
root@imx8mpevk:~# ls -la /lib/firmware/imx/zephyr/
total 1256
drwxr-xr-x  2 root root   4096 Mar  3 11:03 .
drwxr-xr-x 12 root root   4096 Mar  9  2018 ..
-rwxr-xr-x  1 root root  41520 Mar  9  2018 imx8-hello_world-zephyr.elf
-rwxr-xr-x  1 root root  57100 Mar  9  2018 imx8m-hello_world-zephyr.elf
-rwxr-x---  1 root root 996276 Mar  3 10:38 imx8m-openamp_rsc_table-zephyr.elf
-rwxr-xr-x  1 root root  87876 Mar  9  2018 imx8m-philosophers-zephyr.elf
-rwxr-xr-x  1 root root  58124 Mar  9  2018 imx8m-synchronization-zephyr.elf
-rwxr-xr-x  1 root root  41520 Mar  9  2018 imx8x-hello_world-zephyr.elf
root@imx8mpevk:~#
```

在检测 remoteproc 驱动程序之前，固件必须存在于 /lib/firmware 中，但也可以使用绝对路径。

5.1.3.3 插入 `imx_dsp_rproc.ko` 内核模块

默认情况下，i.MX DSP remoteproc 协议等待远程处理器的 READY 回复。由于不是所有Zephyr示例应用 （特别是不使用mailbox的简单应用）会发送 READY 回复，因此必须使用 remoteproc 模块，无需等待回复。这需要使用 no_maiboxes 内核模块参数来实现：

```
root@imx8mpevk:~# modinfo imx_dsp_rproc
filename:       /lib/modules/6.1.55-02981-g63bd8fa873a2/kernel/drivers/
remoteproc/imx_dsp_rproc.ko
author:         Shengjiu Wang <shengjiu.wang@nxp.com>
description:    i.MX HiFi Core Remote Processor Control Driver
license:        GPL v2
...
depends:
intree:         Y
name:           imx_dsp_rproc
parm:           no_mailboxes:There is no mailbox between cores, so ignore remote
 proc reply after start, default is 0 (off). (int)
root@imx8mpevk:~#
```

默认情况下，`no_maiboxes` 参数是 off，即不忽略来自 rproc 的回复。

因此，首先检查 `imx_dsp_rproc` 参数。如果是 off，请删除模块，然后插入正确参数的模块。

```
root@imx8mpevk:~# grep -H '' /sys/module/imx_dsp_rproc/parameters/* /
*no_mailboxes param is off */
/sys/module/imx_dsp_rproc/parameters/no_mailboxes:0
root@imx8mpevk:~#
root@imx8mpevk:~# rmmod imx_dsp_rproc /* remove kernel module */
[ 797.922929] remoteproc remoteproc0: releasing imx-dsp-rproc
root@imx8mpevk:~#
root@imx8mpevk:~# modprobe imx_dsp_rproc no_mailboxes=1 /* insert kernel module
 with the right parameter */
[ 819.930792] remoteproc remoteproc0: imx-dsp-rproc is available
root@imx8mpevk:~#
root@imx8mpevk:~# ls -la /sys/class/remoteproc/ /* now, we have remoteproc0, for
 DSP */
```

```
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 10:20 remoteproc0 -> ../../devices/
platform/3b6e8000.dsp/remoteproc/remoteproc0
root@imx8mpevk:~#
```

5.1.3.4 在 DSP 上加载并运行固件

要在 DSP 上加载固件并运行，请执行以下命令：

```
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
[  107.320099] remoteproc remoteproc0: powering up imx-dsp-rproc
[  107.326031] remoteproc remoteproc0: Direct firmware load for /lib/firmware/
imx/zephyr/imx8m-hello-world-zephyr.elf failed with error -2
[  107.336696] remoteproc remoteproc0: Falling back to sysfs fallback for: /lib/
firmware/imx/zephyr/imx8m-hello-world-zephyr.elf
[  107.348365] remoteproc remoteproc0: Booting fw image /lib/firmware/imx/
zephyr/imx8m-hello-world-zephyr.elf, size 715896
[  107.360096] remoteproc remoteproc0: no resource table found for this firmware
[  107.367735] remoteproc remoteproc0: remote processor imx-dsp-rproc is now up
root@imx8mpevk:~#
```

5.1.3.5 停止固件

要停止固件，请执行以下命令：

```
root@imx8mpevk:~# echo stop > /sys/class/remoteproc/remoteproc0/state
[  206.148281] remoteproc remoteproc0: stopped remote processor imx-dsp-rproc
root@imx8mpevk:~#
```

5.1.4 获取 hello_world 应用输出

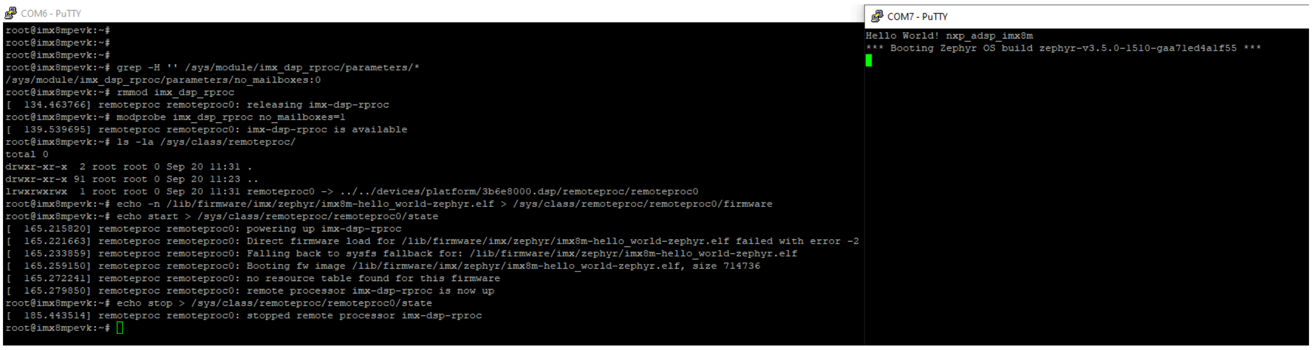
为了获取 hello_world 应用输出，请遵循以下步骤：

1. 通过 UART 获取控制台。
2. 在第四串口上打开串口终端：

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

   您将在终端上看到以下信息（也可在 图 2 中查询）：

   ```
   Hello World! nxp_adsp_imx8m
   *** Booting Zephyr OS build zephyr-v3.5.0-1510-gaa71ed4a1f55 ***
   ```



```
root@imx8mpevk:~#
root@imx8mpevk:~#
root@imx8mpevk:~#
root@imx8mpevk:~# grep -H '' /sys/module/imx_dsp_rproc/parameters/*
/sys/module/imx_dsp_rproc/parameters/no_mailboxes:0
root@imx8mpevk:~# rmmod imx_dsp_rproc
[  134.463766] remoteproc remoteproc0: releasing imx-dsp-rproc
root@imx8mpevk:~# modprobe imx_dsp_rproc no_mailboxes=1
[  139.539695] remoteproc remoteproc0: imx-dsp-rproc is available
root@imx8mpevk:~# ls -la /sys/class/remoteproc/
total 0
drwxr-xr-x  2 root root 0 Sep 20 11:31 .
drwxr-xr-x 91 root root 0 Sep 20 11:23 ..
lrwxrwxrwx  1 root root 0 Sep 20 11:31 remoteproc0 -> ../../devices/platform/3b6e8000.dsp/remoteproc/remoteproc0
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
[  165.215820] remoteproc remoteproc0: powering up imx-dsp-rproc
[  165.221663] remoteproc remoteproc0: Direct firmware load for /lib/firmware/imx/zephyr/imx8m-hello_world-zephyr.elf failed with error -2
[  165.233859] remoteproc remoteproc0: Falling back to sysfs fallback for: /lib/firmware/imx/zephyr/imx8m-hello_world-zephyr.elf
[  165.259150] remoteproc remoteproc0: Booting fw image /lib/firmware/imx/zephyr/imx8m-hello_world-zephyr.elf, size 714736
[  165.272241] remoteproc remoteproc0: no resource table found for this firmware
[  165.279850] remoteproc remoteproc0: remote processor imx-dsp-rproc is now up
root@imx8mpevk:~# echo stop > /sys/class/remoteproc/remoteproc0/state
[  185.443514] remoteproc remoteproc0: stopped remote processor imx-dsp-rproc
root@imx8mpevk:~#
```

```
Hello World! nxp_adsp_imx8m
*** Booting Zephyr OS build zephyr-v3.5.0-1510-gaa71ed4a1f55 ***
```

图 2. **hello_world** 应用输出

您可以使用上述步骤来构建和测试任何其他示例，例如 synchronization 或 philosophers。

您还可以运行更复杂的示例来演示 Linux 和 Zephyr 如何协同工作。下一节举例说明了 openamp_rsc_table 应用程序。

5.2 openamp_rsc_table 应用

Zephyr's openamp_rsc_table 应用演示了如何在 Zephyr 中基于资源表使用开放式非对称多处理（OpenAMP）。它旨在响应：

- Linux rpmsg client sample
- Linux rpmsg tty driver

此示例实现与在主处理器上嵌入 Linux 内核操作系统和在协处理器上嵌入 Zephyr 应用程序的平台兼容。

5.2.1 在 DSP 上加载 openamp_rsc_table 应用

如 章节 5.1.1 中所描述，要在 DSP 上加载 openamp_rsc_table 应用，请在 Linux 内核中启用 `CONFIG_IMX_DSP_REMOTEPROC` 后使用 imx_dsp_rproc 驱动程序。

5.2.2 在 Zephyr 中编译 openamp_rsc_table 应用

在 Zephyr 中为 i.MX 8M Plus DSP 编译 openamp_rsc_table 应用意味着为 nxp_adsp_imx8m 板编译应用。

进入 `zephyrproject` 中的 `zephyr/` 文件夹并运行：

```
~/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
drwxr-xr-x  3 nxa06898 nxp   4096 Sep 27 17:42 boards
drwxr-xr-x  5 nxa06898 nxp   4096 Sep 27 17:42 cmake
-rw-r--r--  1 nxa06898 nxp     96 Sep 27 17:42 .cmake.dotconfig.checksum
drwxr-xr-x  6 nxa06898 nxp   4096 Sep 27 17:42 CMakeFiles
-rw-r--r--  1 nxa06898 nxp  13684 Sep 27 17:42 cmake_install.cmake
-rw-r--r--  1 nxa06898 nxp  41787 Sep 27 17:42 .config
drwxr-xr-x 16 nxa06898 nxp   4096 Sep 27 17:42 drivers
...
drwxr-xr-x  4 nxa06898 nxp   4096 Sep 27 17:42 soc
```

```
drwxr-xr-x 23 nxa06898 nxp   4096 Sep 27 17:42 subsys
-rw-r--r--  1 nxa06898 nxp   2421 Sep 27 17:42 zephyr.dts
-rw-r--r--  1 nxa06898 nxp    730 Sep 27 17:42 zephyr.dts.d
-rw-r--r--  1 nxa06898 nxp 124812 Sep 27 17:42 zephyr.dts.pre
-rw-r--r--  1 nxa06898 nxp 550701 Sep 27 17:42 zephyr_final.map
-rwxr-xr-x  1 nxa06898 nxp 998304 Sep 27 17:42 zephyr_openamp_rsc_table.elf
-rw-r--r--  1 nxa06898 nxp 550701 Sep 27 17:42 zephyr_openamp_rsc_table.map
-rw-r--r--  1 nxa06898 nxp   7463 Sep 27 17:42 zephyr_openamp_rsc_table.stat
-rwxr-xr-x  1 nxa06898 nxp 998476 Sep 27 17:42 zephyr_pre0.elf
-rw-r--r--  1 nxa06898 nxp 551293 Sep 27 17:42 zephyr_pre0.map
...
```

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

5.2.3 在 Linux 中的 DSP 上运行 openamp_rsc_table 应用

以下小节介绍了如何在 Linux 中的 i.MX 8M Plus 板上的 HiFi 4 DSP 运行 `openamp_rsc_table` 应用。

`rpmsg_client_sample.ko` 和 `rpmsg_tty.ko` 模块用于与 DSP 上运行的 `openamp_rsc_table` 应用进行通信。这些是在主处理器（Cortex A 内核）上运行的示例模块。

要构建 `rpmsg_client_sample.ko` 和 `rpmsg_tty.ko` 模块，请分别在 Linux 内核中启用 `CONFIG_SAMPLE_RPMSG_CLIENT` and `CONFIG_RPMSG_TTY` 配置。

5.2.3.1 启动 i.MX 8M Plus EVK 板

使用特定的 DTS 启动 i.MX 8M Plus EVK 板。

使用 `imx8mp-evk-dsp.dtb`，插入 `imx_dsp_rproc.ko` 内核模块后得到：

```
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 ..
lrwxrwxrwx  1 root root 0 Mar  3 20:09 remoteproc0 -> ../../devices/
platform/3b6e8000.dsp/remoteproc/remoteproc0
```

这里使用的是用于DSP的 `remoteproc0`。

5.2.3.2 检查板上固件

如要检查板上的固件镜像，请使用以下命令：

```
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
```

在探测 remoteproc 驱动程序之前，固件必须存在于 `/lib/firmware` 中；然而，它也可以用绝对路径给出。

5.2.3.3 插入 `imx_dsp_rproc.ko` 内核模块

如要插入 `imx_dsp_rproc.ko` 内核模块，请使用以下命令：

```
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 插入 rpmsg Linux 客户端示例

如要插入 rpmsg Linux 客户端示例，请使用以下命令：

```
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 在 DSP 上加载并运行固件

5.2.3.5.1 rpmsg 客户端示例

从 Linux 向 Zephyr 发送 100 条带有 "hello world" 的消息。

Linux 控制台：

```
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
 vdev0buffer@94300000
[  200.662289] virtio_rpmsg_bus virtio0: rpmsg host is online
[  200.667889] rproc-virtio rproc-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)
```

```
[  200.753158] rpmsg_client_sample virtio0.rpmsg-client-sample.-1.1024: incoming
 msg 6 (src: 0x400)
[  200.761988] rpmsg_client_sample virtio0.rpmsg-client-sample.-1.1024: incoming
 msg 7 (src: 0x400)
[  200.770827] rpmsg_client_sample virtio0.rpmsg-client-sample.-1.1024: incoming
 msg 8 (src: 0x400)
[  200.779680] rpmsg_client_sample virtio0.rpmsg-client-sample.-1.1024: incoming
 msg 9 (src: 0x400)
[  200.788511] rpmsg_client_sample virtio0.rpmsg-client-sample.-1.1024: incoming
 msg 10 (src: 0x400)
...
[  201.529273] rpmsg_client_sample virtio0.rpmsg-client-sample.-1.1024: incoming
 msg 93 (src: 0x400)
[  201.538195] rpmsg_client_sample virtio0.rpmsg-client-sample.-1.1024: incoming
 msg 94 (src: 0x400)
[  201.547120] rpmsg_client_sample virtio0.rpmsg-client-sample.-1.1024: incoming
 msg 95 (src: 0x400)
[  201.556048] rpmsg_client_sample virtio0.rpmsg-client-sample.-1.1024: incoming
 msg 96 (src: 0x400)
[  201.564975] rpmsg_client_sample virtio0.rpmsg-client-sample.-1.1024: incoming
 msg 97 (src: 0x400)
[  201.573901] rpmsg_client_sample virtio0.rpmsg-client-sample.-1.1024: incoming
 msg 98 (src: 0x400)
[  201.582816] rpmsg_client_sample virtio0.rpmsg-client-sample.-1.1024: incoming
 msg 99 (src: 0x400)
[  201.591742] rpmsg_client_sample virtio0.rpmsg-client-sample.-1.1024: incoming
 msg 100 (src: 0x400)
[  201.600716] rpmsg_client_sample virtio0.rpmsg-client-sample.-1.1024: goodbye!
[  201.607877] virtio_rpmsg_bus virtio0: destroying channel rpmsg-client-sample
 addr 0x400
[  201.615953] rpmsg_client_sample virtio0.rpmsg-client-sample.-1.1024: rpmsg
 sample client driver is removed
```

Zephyr 控制台：

```
*** 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
```

```
[00:00:00.070,000] <dbg> openamp_rsc_table: mailbox_notify: mailbox_notify: msg
 received

[00:00:00.079,000] <dbg> openamp_rsc_table: platform_ipm_callback:
 platform_ipm_callback: msg received from mb 0

[00:00:00.079,000] <dbg> openamp_rsc_table: mailbox_notify: mailbox_notify: msg
 received

[00:00:00.088,000] <dbg> openamp_rsc_table: platform_ipm_callback:
 platform_ipm_callback: msg received from mb 0

[00:00:00.088,000] <dbg> openamp_rsc_table: mailbox_notify: mailbox_notify: msg
 received

[00:00:00.097,000] <dbg> openamp_rsc_table: platform_ipm_callback:
 platform_ipm_callback: msg received from mb 0

...
[00:00:00.935,000] <dbg> openamp_rsc_table: platform_ipm_callback:
 platform_ipm_callback: msg received from mb 0

[00:00:00.935,000] <dbg> openamp_rsc_table: mailbox_notify: mailbox_notify: msg
 received

[00:00:00.944,000] <dbg> openamp_rsc_table: platform_ipm_callback:
 platform_ipm_callback: msg received from mb 0

[00:00:00.944,000] <dbg> openamp_rsc_table: mailbox_notify: mailbox_notify: msg
 received

[00:00:00.944,000] <dbg> openamp_rsc_table: mailbox_notify: mailbox_notify: msg
 received
```

5.2.3.5.2 rpmsg TTY 演示

在 Linux 控制台上，向 Zephyr 发送信息，其使用 “TTY <add>” 前缀进行回复。<add> 为Zephyr rpmsg-tty 的地址。

Linux 控制台：

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

Zephyr 控制台：

```
*** 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

[00:06:02.049,000] <dbg> openamp_rsc_table: platform_ipm_callback:
 platform_ipm_callback: msg received from mb 0
```

```
[00:06:02.049,000] <dbg> openamp_rsc_table: mailbox_notify: mailbox_notify: msg
 received
```

5.2.3.6 停止固件

要停止固件，请使用以下命令：

```
root@imx8mpevk:~# echo stop > /sys/class/remoteproc/remoteproc0/state
[  495.366531] remoteproc remoteproc0: stopped remote processor imx-dsp-rproc
```

5.2.4 获取 openamp_rsc_table 应用输出

要获取 openamp_rsc_table 应用输出，请执行以下步骤：

1. 通过UART获取控制台。
2. 在第四个串行端口上打开串行终端：

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

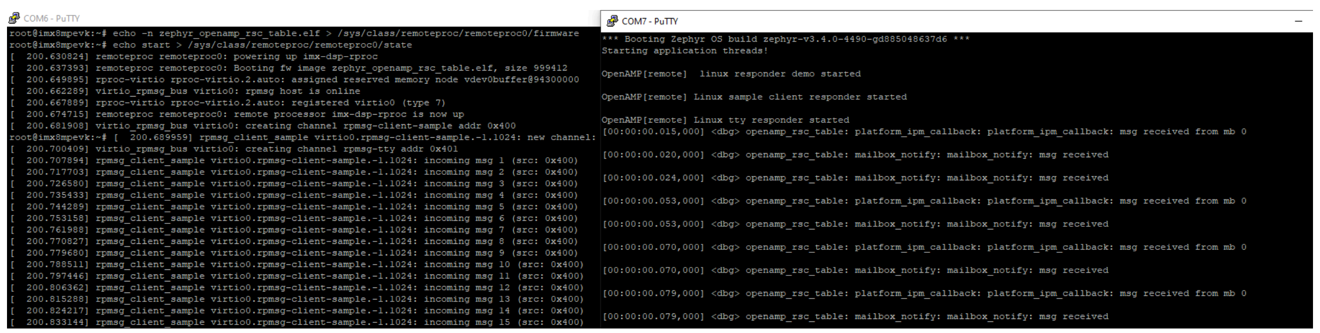
   您在终端中看到以下消息（也显示在 图 3）：

   ```
   *** 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:
    platform_ipm_callback: msg received from mb 0
   ```



```
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 vdev0buffer@94300000
[  200.662289] virtio_rpmsg_bus virtio0: rpmsg host is online
[  200.667889] rproc-virtio rproc-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
root@imx8mpevk:~# [  200.689959] rpmsg_client_sample virtio0.rpmsg-client-sample.-1.1024: new channel:
[  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)
[  200.753158] rpmsg_client_sample virtio0.rpmsg-client-sample.-1.1024: incoming msg 6 (src: 0x400)
[  200.761988] rpmsg_client_sample virtio0.rpmsg-client-sample.-1.1024: incoming msg 7 (src: 0x400)
[  200.770827] rpmsg_client_sample virtio0.rpmsg-client-sample.-1.1024: incoming msg 8 (src: 0x400)
[  200.779680] rpmsg_client_sample virtio0.rpmsg-client-sample.-1.1024: incoming msg 9 (src: 0x400)
[  200.788511] rpmsg_client_sample virtio0.rpmsg-client-sample.-1.1024: incoming msg 10 (src: 0x400)
[  200.797446] rpmsg_client_sample virtio0.rpmsg-client-sample.-1.1024: incoming msg 11 (src: 0x400)
[  200.806362] rpmsg_client_sample virtio0.rpmsg-client-sample.-1.1024: incoming msg 12 (src: 0x400)
[  200.815288] rpmsg_client_sample virtio0.rpmsg-client-sample.-1.1024: incoming msg 13 (src: 0x400)
[  200.824217] rpmsg_client_sample virtio0.rpmsg-client-sample.-1.1024: incoming msg 14 (src: 0x400)
[  200.833144] rpmsg_client_sample virtio0.rpmsg-client-sample.-1.1024: incoming msg 15 (src: 0x400)
```

```
*** 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: 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

[00:00:00.070,000] <dbg> openamp_rsc_table: mailbox_notify: mailbox_notify: msg received

[00:00:00.079,000] <dbg> openamp_rsc_table: platform_ipm_callback: platform_ipm_callback: msg received from mb 0

[00:00:00.079,000] <dbg> openamp_rsc_table: mailbox_notify: mailbox_notify: msg received
```

图 **3. openamp_rsc_table** 应用输出

6 缩略语

Table 3 列出了本文档中使用的缩略语。

Table 3. 缩略语

缩略语	全称
DSP	Digital signal processor

Table 3. 缩略语...continued

缩略语	全称
DTS	Device tree source
IPC	Inter-process communication
MCU	Microcontroller unit
MPU	Microprocessor unit
OpenAMP	Open Asymmetric Multi-Processing
OS	Operating system
rproc	Remote processor
rsc_table	Resource table
RTOS	Real-time operating system
UART	Universal Asynchronous Receiver/Transmitter

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8 修订记录

表 4 汇总了自初始版以来对本文档所做的更改。

表 4. 修订记录

版本号	日期	说明
2	2023 年 11 月 28 日	• 更新以下章节： – 章节 5.1.2 – 章节 5.1.3.1 – 章节 5.1.3.2

表 **4.** 修订记录...续上页

版本号	日期	说明
		– 章节 5.1.3.3 – 章节 5.1.3.4 – 章节 5.1.3.5 – 章节 5.1.4 • 增加新章节：章节 5.2
1	2023 年 6 月 1 日	初次发布

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