
phyFLEX-AM62L BSP Manual DRAFT

PHYTEC Messtechnik GmbH

2026 年 02 月 13 日

1	支持的硬件	3
1.1	Libra FPSC 器件	3
2	开始使用	5
2.1	下载镜像	5
2.2	将镜像写入 SD 卡	6
2.3	首次启动	8
3	编译 BSP	9
3.1	基本设置	9
3.2	下载 BSP	9
4	安装操作系统	13
4.1	启动模式开关 (S1)	13
4.2	Flash eMMC	13
4.3	烧写 SPI NOR Flash	19
5	开发	23
5.1	独立编译准备	23
5.2	单独编译 U-Boot	24
5.3	单独编译内核	26
5.4	主机网络准备	27
5.5	从网络启动内核	29
5.6	获取 BSP 开发中版本	30
5.7	获取最新的 Upstream 支持	31
5.8	Format SD card	31
6	设备树 (DT)	39
6.1	介绍	39
6.2	PHYTEC AM62L BSP 设备树概念	39
7	访问外设	43
7.1	AM62L 引脚复用	43
7.2	RS232	44
7.3	网络	44
7.4	SD card	46
7.5	eMMC Devices	47

7.6	SPI 主设备	54
7.7	GPIOs	55
7.8	ADC	57
7.9	LED 灯	59
7.10	I ² C 总线	59
7.11	EEPROM	59
7.12	RTC	61
7.13	USB 主控制器	63
7.14	CAN FD	64
7.15	视频	65
7.16	显示	66
7.17	电源管理	67
7.18	热管理	68
7.19	看门狗	69

Head AM62L FPSC BSP 手册模板	
文档标题	Head AM62L FPSC BSP 手册模板
文档类型	BSP 手册
型号	Head
Yocto 手册	Scarthgap
发布日期	XXXX/XX/XX
母文档	Head AM62L FPSC BSP 手册模板

下表显示了与本手册兼容的 BSP：

适用 BSP	BSP 发布类型	BSP 发布日期	BSP 状态
BSP-Yocto-Ampliphy-AM62Lx-ALPHA2	Alpha	2025/07/10	已发布

本手册指导您完成 BSP 包的安装、编译和烧写，并描述如何使用 **phyFLEX-AM62L FPSC Kit** 的硬件接口。本手册还包括如何从源码编译内核、u-boot 镜像。本手册包含需要在 PC(Linux 操作系统) 上执行的指令。

备注

This document contains code examples that describe the communication with the board over the serial shell. The code examples lines begin with `host:~$`, `target:~$` or `u-boot=>`. This describes where the commands are to be executed. Only after these keywords must the actual command be copied.

PHYTEC provides a variety of hardware and software documentation for all of its products. This includes any or all of the following:

QS Guide

A short guide on how to set up and boot a phyCORE based board.

Hardware Manual

A detailed description of the System-on-Module and accompanying carrierboard.

Yocto Guide

A comprehensive guide for the Yocto version the phyCORE uses. This guide contains an overview of Yocto; introducing, installing, and customizing the PHYTEC BSP; how to work with programs like Poky and Bitbake; and much more.

BSP 手册

A manual specific to the BSP version of the phyCORE. Information such as how to build the BSP, booting, updating software, device tree, and accessing peripherals can be found here.

Development Environment Guide

This guide shows how to work with the Virtual Machine (VM) Host PHYTEC has developed and prepared to run various Development Environments. There are detailed step-by-step instructions for Eclipse and Qt Creator, which are included in the VM. There are instructions for running demo projects for these programs on a phyCORE product as well. Information on how to build a Linux host PC yourself is also a part of this guide.

Pin Muxing Table

phyCORE SOMs have an accompanying pin table (in Excel format). This table will show the complete default signal path, from the processor to the carrier board. The default device tree muxing option will also be included. This gives a developer all the information needed in one location to make

muxing changes and design options when developing a specialized carrier board or adapting a PHYTEC phyCORE SOM to an application.

除了这些标准手册和指南之外，PHYTEC 还将提供产品变更通知、应用说明和技术说明。这些文档将根据具体案例进行针对性提供。大部分文档都可以在我们产品的 <https://www.phytec.de/produkte/system-on-modules/phyflex-am62lx-fpsc/#downloads/> 中找到。

支持的硬件

在我们的网页上，您可以查看适用于 BSP 版本 BSP-Yocto-Ampliphy-AM62Lx-ALPHA2 的所有 Machine 及其对应的 Article Numbers(产品型号)：[网页](#)。

如果您在“Supported Machines”一栏选择了特定的 **Machine Name**，您可以查看该 machine 下可用的 **Article Numbers** 以及硬件信息的简短描述。如果您只有硬件的 **Article Numbers**，您可以将 **Machine Name** 下拉菜单留空，仅选择您的 **Article Numbers**。现在，它应该会显示您特定硬件所需的 **Machine Name**

1.1 Libra FPSC 器件

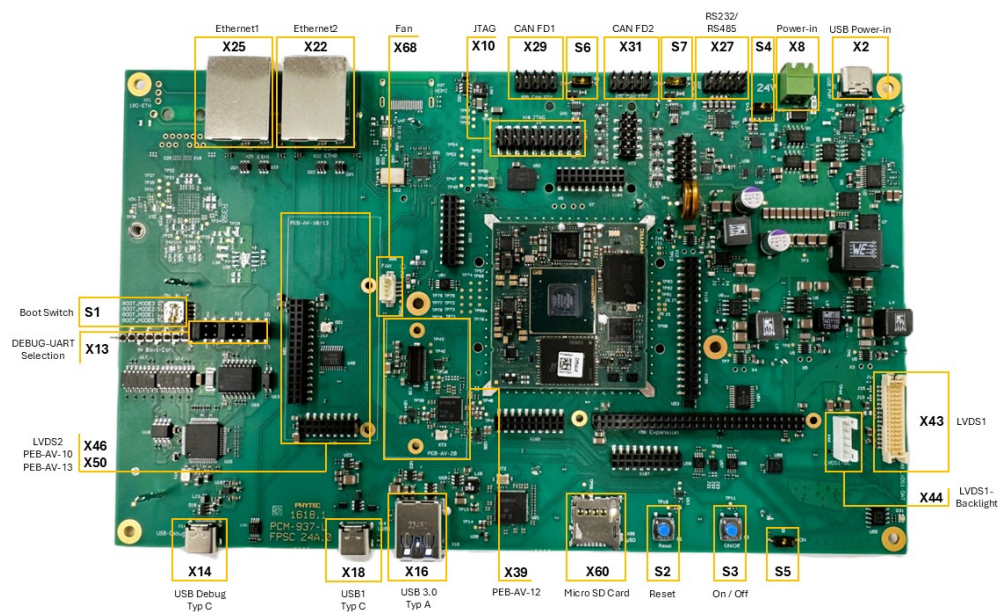


图 1: Libra 器件 (顶部)

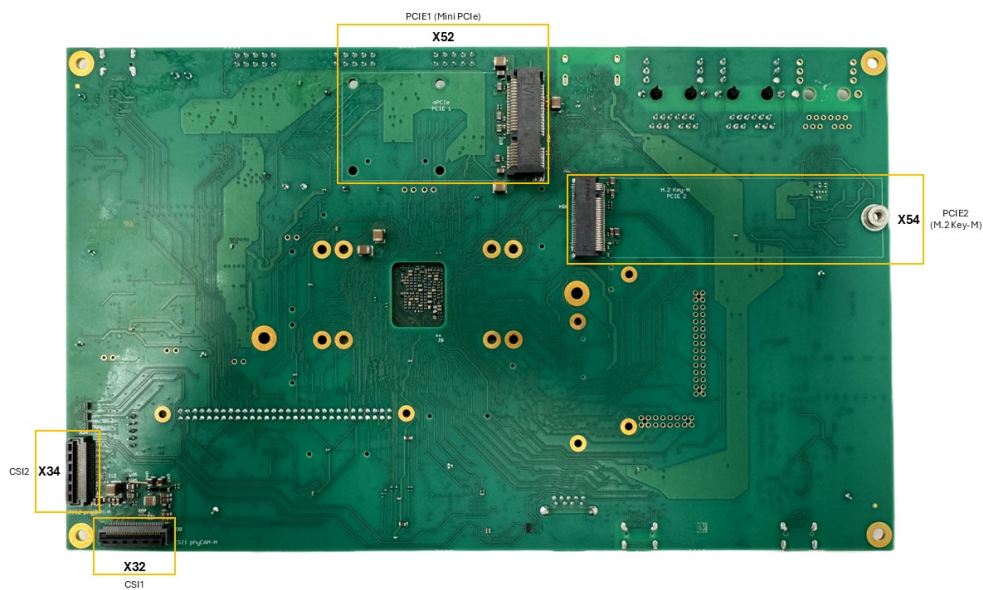


图 2: Libra 器件 (底部)

The **phyFLEX-AM62L FPSC Kit** is shipped with a pre-flashed SD card. It contains the phytec-qt6demo-image and can be used directly as a boot source. The eMMC is programmed with only a U-Boot by default. You can get all sources from the [BSP downloads](#) page. This chapter explains how to flash a BSP image to SD card and how to start the board.

There are several ways to flash an image to SD card or even eMMC. Most notably using simple, sequential writing with the Linux command line tool `dd`. An alternative way is to use PHYTEC's system initialization program called `partup`, which makes it especially easy to format more complex systems. You can get [prebuilt Linux binaries of partup](#) from its release page. Also read `partup`'s [README](#) for installation instructions.

2.1 下载镜像

The image contains all necessary files and makes sure partitions and any raw data are correctly written. Both the `partup` package and the WIC image, which can be flashed using `dd`, can be downloaded from our [BSP downloads](#) page.

Note that you can find different image versions and variants on our download server. The images are located on the server by folders per "BSP-Version", "Distro-Name" and "Machine-Name".

Example to download a `partup` package and a WIC image from the download server:

```
host:~$ wget https://download.phytec.de/Software/Linux/BSP-Yocto-AM62Lx/BSP-Yocto-Ampliphy-AM62Lx-ALPHA2/  
↪images/ampliphy-vendor/am62lxx-libra-fpsc-1/phytec-qt6demo-image-am62lxx-libra-fpsc-1.rootfs.partup  
host:~$ wget https://download.phytec.de/Software/Linux/BSP-Yocto-AM62Lx/BSP-Yocto-Ampliphy-AM62Lx-ALPHA2/  
↪images/ampliphy-vendor/am62lxx-libra-fpsc-1/phytec-qt6demo-image-am62lxx-libra-fpsc-1.rootfs.wic.xz
```

备注

For eMMC, more complex partitioning schemes or even just large images, we recommend using the `partup` package, as it is faster in writing than `dd` and allows for a more flexible configuration of the target flash device.

2.2 将镜像写入 SD 卡

警告

要创建 SD 卡启动盘，必须要拥有 Linux PC 上的 root 权限。在选择烧写设备时请务必小心！所选设备上的所有文件将在命令执行后立即被擦除，而且擦除前不会有任何进一步的确认！

选择错误的设备可能会导致 **数据丢失**，例如，可能会擦除您当前所在 PC 上的系统！

2.2.1 寻找正确的设备

要创建 SD 卡启动盘，首先要找到 PC 上您 SD 卡对应的正确设备名称。在开始将镜像复制到 SD 卡之前，请卸载任何已挂载的分区。

1. 为了获取正确的设备名称，请移除您的 SD 卡并执行：

```
host:~$ lsblk
```

2. 现在插入你的 SD 卡，然后再次执行命令：

```
host:~$ lsblk
```

3. 比较两个输出，以获取第二个输出中的新设备名称。这些是 SD 卡的设备名称（如果 SD 卡已格式化，则包括设备名称和对应的分区）。
4. 为了验证找到的设备名称的最终正确性，请执行命令 `sudo dmesg`。在其输出的最后几行中，您应该也能找到设备名称，例如 `/dev/sde` 或 `/dev/mmcblk0`（具体取决于您的系统）。

或者，您可以使用图形化的程序，例如 [GNOME Disks](#) 或 [KDE Partition Manager](#) 来找到正确的设备。

现在您已经得到了正确的设备名称，例如 `/dev/sde`，如果 SD 卡曾格式化过，需要确认已取消其分区的挂载，您可以在输出中看到带有附加了数字的设备名称（例如 `/dev/sde1`），它们是 SD 卡的分区。一些 Linux 发行版系统在设备插入时会自动挂载分区。在写入之前，必须卸载这些分区，以避免数据损坏。

卸载所有这些分区，例如：

```
host:~$ sudo umount /dev/sde1
host:~$ sudo umount /dev/sde2
```

Now, the SD card is ready to be flashed with an image, using either `partup`, `dd` or `bmaptool`.

2.2.2 Using bmaptool

One way to prepare an SD card is using `bmaptool`. Yocto automatically creates a block map file (`<IMAGENAME>-<MACHINE>.wic.bmap`) for the WIC image that describes the image content and includes checksums for data integrity. `bmaptool` is packaged by various Linux distributions. For Debian-based systems install it by issuing:

```
host:~$ sudo apt install bmap-tools
```

通过以下命令将 WIC 镜像烧写到 SD 卡：

```
host:~$ bmaptool copy phytec-qt6demo-image-am62lxx-libra-fpsc-1?(.rootfs).wic?(.xz) /dev/<your_device>
```

将 `<your_device>` 替换为您之前找到的 SD 卡设备名称，并确保将文件 `<IMAGENAME>-<MACHINE>.wic.bmap` 与 WIC 镜像文件放在一起，以便 `bmaptool` 知道哪些块需要写入，哪些块需要跳过。

警告

bmaptool 仅擦写 SD 卡上镜像数据所在的区域。这意味着在写入新的镜像后，之前写入的旧 U-Boot 环境变量可能仍然可用。

2.2.3 使用 partup

使用 partup 烧写 SD 卡只需一个命令：

```
host:~$ sudo partup install phytec-qt6demo-image-am62lxx-libra-fpsc-1?(.rootfs).partup /dev/<your_device>
```

确保将 <your_device> 替换为您之前找到的设备名称。

关于 partup 的进一步使用说明，请参阅其 [官方文档](#)。

警告

使用 *resize2fs* 版本 1.46.6 及更早版本的 PC 系统（例如 Ubuntu 22.04）无法烧写在 Mickledore 以及更新的 yocto 版本上创建的 partup 软件包。这个是因为 *resize2fs* 新增了默认选项而导致的兼容性问题。有关详细信息，请参阅 [release notes](#)。

备注

partup 具有清除 eMMC user 区域中特定区域的功能，我们提供的 partup 程序中用该功能擦除 U-Boot 环境变量。这是 *bmaptool* 工具所无法完成的一点，如前一部分所提到的。

partup 相较于其他烧写工具的一个主要优势是，它可以配置 MMC 的特定部分，比如他可以直接写入 eMMCboot 分区，无需调用其他命令。

2.2.4 使用 dd

在卸载所有 SD 卡的挂载分区后，您可以烧写 SD 卡。

一些 PHYTEC BSP 会生成未压缩的镜像（文件名扩展名为 *.wic），而另一些则生成压缩的镜像（文件名扩展名为 *.wic.xz）。

要写入未压缩的镜像 (*.wic)，请使用以下命令：

```
host:~$ sudo dd if=phytec-qt6demo-image-am62lxx-libra-fpsc-1?(.rootfs).wic of=/dev/<your_device> bs=1M \
↳ conv=fsync status=progress
```

或者要写入压缩后的镜像 (*.wic.xz)，请使用以下命令：

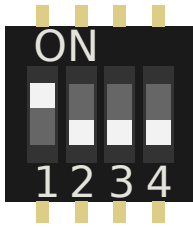
```
host:~$ xzcat phytec-qt6demo-image-am62lxx-libra-fpsc-1?(.rootfs).wic.xz | sudo dd of=/dev/<your_device> \
↳ bs=1M conv=fsync status=progress
```

再次确保将 <your_device> 替换为之前找到的设备名称。

参数 *conv=fsync* 强制在 *dd* 返回之前对设备进行 *sync* 操作。这确保所有数据块都已写入 SD 卡，而没有任何数据缓存在内存中。参数 *status=progress* 将打印出进度信息。

2.3 首次启动

- 要从 SD 卡启动，*bootmode switch (S1)* 需要设置为以下位置：



- 插入 SD 卡
- Connect the target and the host with **USB-C** on (X14) debug USB
- 给开发板通电

本节将指导您使用 Yocto 和 phyLinux 脚本进行 AM62L BSP 的编译。更多有关 phytec meta-layer 和 Yocto 的信息，请访问：Yocto Reference Manual (scarthgap)。

3.1 基本设置

如果您从未在您的主机上使用 Yocto 编译过 Phytec BSP，您应查看 Yocto Reference Manual (scarthgap) 中的 BSP Workspace 安装一节。

3.2 下载 BSP

There are two ways to get the BSP sources. You can download the complete BSP sources from our [BSP downloads](#) page; or you can fetch and build it yourself with Yocto. This is particularly useful if you want to make customizations.

The phyLinux script is a basic management tool for PHYTEC Yocto BSP releases written in Python. It is mainly a helper to get started with the BSP sources structure.

- 创建一个新的项目文件夹，获取 phyLinux 脚本，并赋予脚本具备可执行权限：

```
host:~$ mkdir ~/yocto
host:~$ cd yocto/
host:~/yocto$ wget https://download.phytec.de/Software/Linux/Yocto/Tools/phyLinux
host:~/yocto$ chmod +x phyLinux
```

警告

我们需要一个空的项目文件夹，phyLinux 首先会清理当前所在的工作目录。从一个不为空的目录下调用 phyLinux 将会产生告警。

- 运行 phyLinux：

```
host:~/yocto$ ./phyLinux init
```

备注

在首次初始化时，phyLinux 脚本会要求您在 /usr/local/bin 目录中安装 Repo 工具。

- During the execution of the init command, you need to choose your processor platform (SoC), PHYTEC's BSP release number, and the hardware (MACHINE) you are working on.

备注

If you cannot identify your board with the information given in the selector, have a look at the invoice for the product. And have a look at the webpage of [our BSP](#).

- 也可以通过命令行参数直接传递这些信息：

```
host:~/yocto$ DISTRO=ampliphy-vendor MACHINE=am62lxx-libra-fpsc-1 ./phyLinux init -p am62l-fpsc -r  
↳ BSP-Yocto-Ampliphy-AM62Lx-ALPHA2
```

After the execution of the init command, phyLinux will print a few important notes. For example, it will print your git identity, SOC and BSP release which was selected as well as information for the next steps in the build process.

3.2.1 开始构建

- 设置 Shell 环境变量：

```
host:~/yocto$ source sources/poky/oe-init-build-env
```

备注

在每次打开新的用于编译的 shell 时，都需要先执行这一步骤。

- 当前的工作目录会变更为 build/。
- 编译您的镜像：

```
host:~/yocto/build$ bitbake phytec-qt6demo-image
```

备注

对于第一次编译，我们建议从我们的较小的非图形化镜像 phytec-headless-image 开始，以查看一切是否正常工作。

```
host:~/yocto/build$ bitbake phytec-headless-image
```

第一次构建过程在现代的 Intel Core i7 处理器上大约需要 40 分钟。后续的构建将使用本次编译产生的缓存，大约需要 3 分钟。

3.2.2 BSP 镜像

所有由 Bitbake 生成的镜像都放在 `~/yocto/build/deploy*/images/<machine>`。例如以下列表是 `am62lxx-libra-fpsc-1` machine 生成的所有文件：

- **u-boot.img**: U-Boot bootloader image
- **oftree**: 默认内核设备树
- **ti-boot3.bin**: First stage bootloader (R5 SPL)
- **tispl.bin**: Secondary program loader (SPL)
- **bl1.bin**: ARM Trusted Firmware binary
- **bl31.bin**: ARM Trusted Firmware binary
- **fitImage**: Linux 内核 FIT 镜像
- **fitImage-its*.its**
- **Image**: Linux 内核镜像
- **Image.config**: 内核 config 文件
- **k3-am62l32-libra-fpsc*.dtb**: Kernel device tree file
- **phytec-qt6demo-image*.tar.gz**: 根文件系统
- **phytec-qt6demo-image*.rootfs.wic.xz**: 压缩的 SD 卡镜像

4.1 启动模式开关 (S1)

小技巧

Hardware revision baseboard: 1618.1

The Libra FPSC features a boot switch with four individually switchable ports to select the phyFLEX-AM62L FPSC default bootsource.

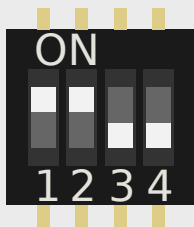


图 1: eMMC



图 2: SD 卡

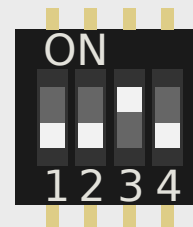


图 3: SPI NOR

4.2 Flash e.MMC

为了保持文档的一致性和简洁性，假设已经配置好了 TFTP 服务器；所有生成的镜像（如上所列）都被复制到默认的 `/srv/tftp` 目录。如果您没有进行设置，您需要修改路径到包含镜像的目录。有关如何设置 TFTP 服务器和目录的说明，请参见 [Setup Network Host](#)。

To boot from e.MMC, make sure that the BSP image is flashed correctly to the e.MMC and the *bootmode switch (S1)* is set to **e.MMC**.

警告

When eMMC and SD card are flashed with the same (identical) image, the UUIDs of the boot partitions are also identical. If the SD card is connected when booting, this leads to non-deterministic behavior as Linux mounts the boot partition based on UUID.

```
target:~$ blkid
```

可以运行上述命令来检查系统启动在这种条件下是否会受到影响。如果 mmcblk2p1 和 mmcblk1p1 具有相同的 UUID，则会影响系统正确启动。

4.2.1 Flash eMMC from Network

AM62L boards have an Ethernet connector and can be updated over a network. Be sure to set up the development host correctly. The IP needs to be set to 192.168.3.10, the netmask to 255.255.255.0, and a TFTP server needs to be available. From a high-level point of view, an eMMC device is like an SD card. Therefore, it is possible to flash the **WIC image** (<name>.wic) from the Yocto build system directly to the eMMC. The image contains the bootloader, kernel, device tree, device tree overlays, and root file system.

Flash eMMC via Network in Linux on Host

It is also possible to install the OS at eMMC from your Linux host. As before, you need a complete image on your host.

小技巧

需要保证设备和存储镜像的主机之间的网络正常！ *Setup Network Host*

查看主机上可用的镜像文件：

```
host:~$ ls /srv/tftp
phytec-qt6demo-image-am62lxx-libra-fpsc-1.rootfs.wic.xz
phytec-qt6demo-image-am62lxx-libra-fpsc-1.rootfs.wic.bmap
```

Send the image with the `bmaptool` command combined with `ssh` through the network to the eMMC of your device:

```
host:~$ scp /srv/tftp/phytec-qt6demo-image-am62lxx-libra-fpsc-1.rootfs.wic.* root@192.168.3.11:/tmp && ssh \
root@192.168.3.11 "bmaptool copy /tmp/phytec-qt6demo-image-am62lxx-libra-fpsc-1.rootfs.wic.xz /dev/mmcblk0"
"
```

Flash eMMC via Network in Linux on Target

You can update the eMMC from your target.

小技巧

需要保证设备和存储镜像的主机之间的网络正常！ *Setup Network Host*

Take a compressed or decompressed image with the accompanying block map file `*.bmap` on the host and send it with `ssh` through the network to the eMMC of the target with a one-line command:

```
target:~$ scp <USER>@192.168.3.10:/srv/tftp/phytec-qt6demo-image-am62lxx-libra-fpsc-1.rootfs.wic.* /tmp &&
↵ bmaptool copy /tmp/phytec-qt6demo-image-am62lxx-libra-fpsc-1.rootfs.wic.xz /dev/mmcblk0
```

Flash eMMC from Network in U-Boot on Target

These steps will show how to update the eMMC via a network.

小技巧

This step only works if the size of the image file is less than 1GB due to limited usage of RAM size in the Bootloader after enabling OP-TEE.

小技巧

需要保证设备和存储镜像的主机之间的网络正常! *Setup Network Host*

解压缩您的镜像

```
host:~$ unxz /srv/tftp/phytec-headless-image-am62lxx-libra-fpsc-1.rootfs.wic.xz
```

通过网络将您的镜像加载到内存中:

- 使用 DHCP

```
u-boot=> dhcp phytec-headless-image-am62lxx-libra-fpsc-1.rootfs.wic
BOOTP broadcast 1
DHCP client bound to address 192.168.3.1 (1 ms)
Using ethernet@30be0000 device
TFTP from server 192.168.3.10; our IP address is 192.168.3.1
Filename 'phytec-headless-image-am62lxx-libra-fpsc-1.rootfs.wic'.
Load address: 0x40480000
Loading: #####
#####
#####
...
...
...
#####
#####
11.2 MiB/s
done
Bytes transferred = 911842304 (36599c00 hex)
```

- 使用静态 IP 地址 (必须先设置 serverip 和 ipaddr)。

```
u-boot=> tftp ${loadaddr} phytec-headless-image-am62lxx-libra-fpsc-1.rootfs.wic
Using ethernet@30be0000 device
TFTP from server 192.168.3.10; our IP address is 192.168.3.11
Filename 'phytec-headless-image-am62lxx-libra-fpsc-1.rootfs.wic'.
Load address: 0x40480000
Loading: #####
#####
#####
```

(续下页)

(接上页)

```

...
...
...
#####
#####
11.2 MiB/s
done
Bytes transferred = 911842304 (36599c00 hex)

```

Write the image to the eMMC:

```

u-boot=> mmc dev 0
switch to partitions #0, OK
mmc0(part 0) is current device
u-boot=> setexpr nblk ${filesize} / 0x200
u-boot=> mmc write ${loadaddr} 0x0 ${nblk}

MMC write: dev # 0, block # 0, count 1780942 ... 1780942 blocks written: OK

```

4.2.2 Flash e.MMC from USB stick

Flash e.MMC from USB in Linux

These steps will show how to flash the eMMC on Linux with a USB stick. You only need a complete image saved on the USB stick and a bootable WIC image. (e.g. phytec-qt6demo-image-am62lxx-libra-fpsc-1.yocto-imageext). Set the *bootmode switch (S1)* to SD card.

- 插入并挂载 U 盘:

```

[ 60.458908] usb-storage 1-1.1:1.0: USB Mass Storage device detected
[ 60.467286] scsi host0: usb-storage 1-1.1:1.0
[ 61.504607] scsi 0:0:0:0: Direct-Access                        8.07 PQ: 0 ANSI: 2
[ 61.515283] sd 0:0:0:0: [sda] 3782656 512-byte logical blocks: (1.94 GB/1.80 GiB)
[ 61.523285] sd 0:0:0:0: [sda] Write Protect is off
[ 61.528509] sd 0:0:0:0: [sda] No Caching mode page found
[ 61.533889] sd 0:0:0:0: [sda] Assuming drive cache: write through
[ 61.665969] sda: sda1
[ 61.672284] sd 0:0:0:0: [sda] Attached SCSI removable disk
target:~$ mount /dev/sda1 /mnt

```

- 现在查看您在 USB 优盘上保存的镜像文件:

```

target:~$ ls /mnt
phytec-qt6demo-image-am62lxx-libra-fpsc-1.rootfs.wic.xz
phytec-qt6demo-image-am62lxx-libra-fpsc-1.rootfs.wic.bmap

```

- Write the image to the phyFLEX-AM62L FPSC e.MMC (MMC device 2 without partition):

```

target:~$ bmaptool copy /mnt/phytec-qt6demo-image-am62lxx-libra-fpsc-1.rootfs.wic.xz /dev/mmcblk0

```

- After a complete write, your board can boot from eMMC.

小技巧

在此之前, 您需要将*bootmode switch (S1)* 配置为 eMMC。

Flash e.MMC from USB stick in U-Boot on Target

小技巧

此步骤仅在镜像文件小于 1GB 的情况下会被执行成功，因为在启用 OPTEE 后，Bootloader 中可用的 RAM 大小有限，不足以加载超过 1GB 的镜像

These steps will show how to update the e.MMC via a USB device. Configure the *bootmode switch (S1)* to SD card and insert an SD card. Power on the board and stop in U-Boot prompt. Insert a USB device with the copied uncompressed WIC image to the USB slot.

将镜像从 USB 设备加载到 RAM 中：

```
u-boot=> usb start
starting USB...
USB0:  USB EHCI 1.00
scanning bus 0 for devices... 2 USB Device(s) found
       scanning usb for storage devices... 1 Storage Device(s) found
u-boot=> fatload usb 0:1 0x58000000 phytec-headless-image-am62lxx-libra-fpsc-1.rootfs.wic
497444864 bytes read in 31577 ms (15 MiB/s)
```

Write the image to the e.MMC:

```
u-boot=> mmc dev 0
switch to partitions #0, OK
mmc0(part 0) is current device
u-boot=> setexpr nblk ${filesize} / 0x200
u-boot=> mmc write 0x58000000 0x0 ${nblk}

MMC write: dev # 0, block # 0, count 1024000 ... 1024000 blocks written: OK
u-boot=> boot
```

4.2.3 Flash e.MMC from SD card

Even if there is no network available, you can update the e.MMC. For that, you only need a ready-to-use image file (*.wic) located on the SD card. Because the image file is quite large, you need to allocate more SD card space. To create a new partition or enlarge your SD card, see *Resizing ext4 Root Filesystem*.

或者，使用 partup 包烧写 SD 卡，如 *Getting Started* 中所述。这样就可使用 SD 卡的全部容量。

Flash e.MMC from SD card in Linux on Target

You can also flash the e.MMC on Linux. You only need a partup package or WIC image saved on the SD card.

- 检查在 SD 卡上保存的 partup 包或 WIC 镜像文件：

```
target:~$ ls
phytec-qt6demo-image-am62lxx-libra-fpsc-1.rootfs.partup
phytec-qt6demo-image-am62lxx-libra-fpsc-1.rootfs.wic.xz
phytec-qt6demo-image-am62lxx-libra-fpsc-1.rootfs.wic.bmap
```

- Write the image to the phyFLEX-AM62L FPSC e.MMC (MMC device 0 **without** partition) using *partup*:

```
target:~$ partup install phytec-qt6demo-image-am62lxx-libra-fpsc-1.rootfs.partup /dev/mmcblk0
```

Flashing the partup package has the advantage of using the full capacity of the eMMC device, adjusting partitions accordingly.

备注

另外, 也可以使用 `bmaptool` 工具:

```
target:~$ bmaptool copy phytec-qt6demo-image-am62lxx-libra-fpsc-1.rootfs.wic.xz /dev/mmcblk0
```

请注意, 在使用 `bmaptool` 烧写时, 根文件系统分区并不会使用 eMMC 的最大容量。

- After a complete write, your board can boot from eMMC.

警告

Before this will work, you need to configure the *bootmode switch (S1)* to eMMC.

Flash e.MMC from SD card in U-Boot on Target

小技巧

This step only works if the size of the image file is less than 1GB due to limited usage of RAM size in the Bootloader after enabling OPTEE. If the image file is too large use the *Updating e.MMC from SD card in Linux on Target* subsection.

- 将一个可用的镜像烧写到 SD 卡, 并创建一个 EXT4 格式的第三分区。将 WIC 镜像 (例如 `phytec-qt6demo-image.rootfs.wic`) 复制到该分区。
- Configure the *bootmode switch (S1)* to SD card and insert the SD card.
- 打开电源并进入 U-Boot。
- 加载镜像:

```
u-boot=> ext4load mmc 1:3 ${loadaddr} phytec-headless-image-am62lxx-libra-fpsc-1.rootfs.wic
reading
911842304 bytes read in 39253 ms (22.2 MiB/s)
```

- Switch the mmc dev to eMMC:

```
u-boot=> mmc list
FSL_SDHC: 1 (SD)
FSL_SDHC: 0 (eMMC)
u-boot=> mmc dev 0
switch to partitions #0, OK
mmc0(part 0) is current device
```

- Flash your WIC image (for example `phytec-qt6demo-image.rootfs.wic`) from the SD card to eMMC. This will partition the card and copy `tiboot3.bin`, `tispl.bin`, `u-boot.img`, `Image`, `dtb`, `dtbo`, and root file system to eMMC.

```
u-boot=> setexpr nblk ${filesize} / 0x200
u-boot=> mmc write ${loadaddr} 0x0 ${nblk}
```

(续下页)

(接上页)

```
MMC write: dev # 0, block # 0, count 1780942 ... 1780942 blocks written: OK
```

- Power off the board and change the *bootmode switch (S1)* to e.MMC.

4.3 烧写 SPI NOR Flash

The phyFLEX-AM62L FPSCs are optionally equipped with SPI NOR Flash. To boot from SPI Flash, set *bootmode switch (S1)* to **SPI NOR**. The SPI Flash is usually quite small. The **phyFLEX-AM62L FPSC Kit** only has 64MiB SPI NOR flash populated. Only the bootloader and the environment can be stored. The kernel, device tree, and file system are taken from other boot sources.

The SPI NOR flash partition table is defined in the U-Boot device tree. It can be printed with:

```
u-boot=> => mtd list
SF: Detected mt35xu512aba with page size 256 Bytes, erase size 4 KiB, total 64 MiB
List of MTD devices:
* nor0
- device: flash@0
- parent: spi@fc40000
- driver: jedec_spi_nor
- path: /bus@f0000/bus@fc00000/spi@fc40000/flash@0
- type: NOR flash
- block size: 0x1000 bytes
- min I/O: 0x1 bytes
- 0x000000000000-0x000000400000 : "nor0"
  - 0x000000000000-0x000000080000 : "ospi.tiboot3"
  - 0x000000080000-0x000000280000 : "ospi.tispl"
  - 0x000000280000-0x000000680000 : "ospi.u-boot"
  - 0x000000680000-0x0000006c0000 : "ospi.env"
  - 0x0000006c0000-0x000000700000 : "ospi.env.backup"
```

We have two possibilities for flashing:

- Flash SPI NOR with a combined binary, which contains all the necessary files (tiboot3.bin, tispl.bin and u-boot.img) on the correct offsets. A whole SPI NOR device in Linux is always marked as first MTD device (e.g. /dev/mtd0) in U-Boot the device is called nor0.
- Flash SPI NOR with separate binaries to the corresponding partition. This can be used when only certain bootloader part needs to be updated.

4.3.1 通过网络烧写 SPI NOR Flash

The SPI NOR can contain the bootloader and environment to boot from. The arm64 kernel can not decompress itself, the image size extends the SPI NOR flash populated on the phyFLEX-AM62L FPSC.

小技巧

需要保证设备和存储镜像的主机之间的网络正常! *Setup Network Host*

在开发板 linux 环境中通过网络烧写 SPI NOR Flash

- 将镜像从主机复制到开发板：

```
host:~$ scp ti-boot-container.img root@192.168.3.11:/root
```

- 查找要擦除的 U-boot 分区的块数：

```
target:~$ mtdinfo /dev/mtd0
mtd0
Name:                fc40000.spi.0
Type:                nor
Eraseblock size:     131072 bytes, 128.0 KiB
Amount of eraseblocks: 512 (67108864 bytes, 64.0 MiB)
Minimum input/output unit size: 1 byte
Sub-page size:       1 byte
Character device major/minor: 90:0
Bad blocks are allowed: false
Device is writable:  true
```

- Erase the necessary SPI NOR device/partition and flash it:

```
target:~$ flash_erase /dev/mtd0 0x0 0
target:~$ flashcp ti-boot-container.img /dev/mtd0
```

在开发板的 U-Boot 环境中通过网络烧写 SPI NOR

Similar to updating the eMMC over a network, be sure to set up the development host correctly. The IP needs to be set to 192.168.3.10, the netmask to 255.255.255.0, and a TFTP server needs to be available.

- SPI NOR Flash 需要使用特殊格式的 U-Boot 镜像。确保您使用了正确的镜像文件。通过 tftp 加载镜像，然后将 bootloader 写入 Flash：

```
u-boot=> tftp ${loadaddr} ti-boot-container.img
u-boot=> mtd write nor0 ${loadaddr} 0 ${filesize}
SF: Detected mt35xu512aba with page size 256 Bytes, erase size 4 KiB, total 64 MiB
Writing 3752323 byte(s) at offset 0x00000000
```

- Optinally erase the environment partition as well. This way, the environment can be written after booting from SPI NOR flash:

```
u-boot=> mtd erase ospi.env
u-boot=> mtd erase ospi.env.backup
```

4.3.2 Flash SPI NOR Flash from SD card

The bootloader on SPI NOR flash can be also flashed from SD card.

Flash SPI NOR from SD card in kernel on Target

- Copy the SPI NOR flash U-boot container to the first partition on the SD card.
- Mount the SD card:

```
target:~$ mount /dev/mmcblk1p1 /mnt
```

- Find the number of blocks to erase of the SPI NOR:


```
target:~$ mtdinfo /dev/mtd0
mtd0
Name:                fc40000.spi.0
Type:                nor
Eraseblock size:     131072 bytes, 128.0 KiB
Amount of eraseblocks: 512 (67108864 bytes, 64.0 MiB)
Minimum input/output unit size: 1 byte
Sub-page size:       1 byte
Character device major/minor: 90:0
Bad blocks are allowed: false
Device is writable:   true
```

- Erase the SPI NOR and flash it:

```
target:~$ flash_erase /dev/mtd0 0x0 0
target:~$ flashcp /mnt/ti-boot-container.img /dev/mtd0
```

Flash SPI NOR from SD card in U-Boot on Target

- Copy the SPI NOR flash U-boot container to the first partition on the SD card.
- A specially formatted U-boot image for the SPI NOR flash is used. Ensure you use the correct image file. Load the image from the SD card, erase and write the bootloader to the flash:

```
u-boot=> mmc dev 1
u-boot=> fatload mmc 1:1 ${loadaddr} ti-boot-container.img
u-boot=> mtd write nor0 ${loadaddr} 0 ${filesize}
```

- Optinally erase the environment partition as well. This way, the environment can be written after booting from SPI NOR flash:

```
u-boot=> mtd erase ospi.env
u-boot=> mtd erase ospi.env.backup
```


5.1 独立编译准备

In this section, we describe how to build the U-Boot and the Linux kernel without using the [Yocto Project](#). This procedure makes the most sense for development. The U-Boot source code, the Linux kernel, and all other git repositories are available on [GitHub](#).

5.1.1 Git 仓库

- 使用的 U-Boot 仓库：

```
https://github.com/phytec/u-boot-phytec-ti
```

- 我们的 U-Boot 基于 u-boot-phytec-ti 并添加了一些硬件相关的补丁。
- 使用的 Linux 内核仓库：

```
https://github.com/phytec/linux-phytec-ti
```

- 我们的 AM62L 内核是基于 linux-phytec-ti 内核。

要找出核心板应使用的 u-boot 和 kernel 版本对应的 git 仓库 tag 标签，请查看您的 BSP 源文件夹：

```
meta-phytec/recipes-kernel/linux/linux-phytec-ti_*.bb  
meta-phytec/recipes-bsp/u-boot/u-boot-phytec-ti_*.bb
```

5.1.2 获取 SDK

You can download the SDK from the [SDK downloads](#) page, or build it yourself with Yocto:

- 移动到 Yocto 的 build 目录：

```
host:~$ source sources/poky/oe-init-build-env  
host:~$ bitbake -c populate_sdk phytec-qt6demo-image # or another image
```

在成功编译后，SDK 安装包保存在 build/deploy*/sdk。

5.1.3 安装 SDK

- 设置正确的权限并安装 SDK:

```
host:~$ chmod +x phytec-ampliphy-vendor-glibc-x86_64-phytec-qt6demo-image-aarch64-toolchain-BSP-Yocto-
↳ Ampliphy-AM62Lx-ALPHA2.sh
host:~$ ./phytec-ampliphy-vendor-glibc-x86_64-phytec-qt6demo-image-aarch64-toolchain-BSP-Yocto-
↳ Ampliphy-AM62Lx-ALPHA2.sh
=====
Enter target directory for SDK (default: /opt/ampliphy-vendor/BSP-Yocto-Ampliphy-AM62Lx-ALPHA2):
You are about to install the SDK to "/opt/ampliphy-vendor/BSP-Yocto-Ampliphy-AM62Lx-ALPHA2". Proceed
↳ [Y/n]? Y
Extracting SDK...done
Setting it up...done
SDK has been successfully set up and is ready to be used.
```

5.1.4 使用 SDK

通过在工具链目录中 source *environment-setup* 文件来初始化您的 shell 交叉编译环境:

```
host:~$ source /opt/ampliphy-vendor/BSP-Yocto-Ampliphy-AM62Lx-ALPHA2/environment-setup-aarch64-phytec-linux
```

5.1.5 安装所需工具

独立编译 Linux kernel 和 U-Boot 需要主机安装一些额外的工具。对于 Ubuntu, 您可以使用以下命令安装它们:

```
host:~$ sudo apt install bison flex libssl-dev bc libncurses-dev python3 python3-setuptools python3-dev
↳ python3-yaml python3-jjsonschema python3-pyelftools swig yamllint libgnutls28-dev
```

警告

Using the SDK on older host distributions (e.g., Ubuntu 20.04 LTS) with Scarthgap TI-based BSPs can cause issues when building U-Boot or Linux kernel tools for host use. If you encounter an "undefined reference" error, a workaround is to prepend the host's binutils to the PATH.

```
host$ export PATH=/usr/bin:$PATH
```

在加载 SDK *environment-setup* 后, 运行此命令。

请注意, 在较新版本的发行版 (如 Ubuntu 22.04) 中未观察到 SDK 相关问题, 这些发行版似乎无需任何修改即可正常工作。

5.2 单独编译 U-Boot

5.2.1 获取源代码

- 获取 U-Boot 源代码:

```
host:~$ git clone https://github.com/phytec/u-boot-phytec-ti
```

- 要获取正确的 *U-Boot tag*, 您需要查看我们的 release notes, 可以在这里找到: [release notes](#)
- 此版本中使用的 *tag* 称为 11.01.02
- 查看所需的 *U-Boot tag*:

```
host:~$ cd ~/u-boot-phytec-ti/  
host:~/u-boot-phytec-ti$ git fetch --all --tags  
host:~/u-boot-phytec-ti$ git checkout tags/11.01.02
```

- 设置编译环境：

```
host:~/u-boot-phytec-ti$ source /opt/ampliphy-vendor/BSP-Yocto-Ampliphy-AM62Lx-ALPHA2/environment-  
↪ setup-aarch64-phytec-linux
```

5.2.2 获取所需的二进制文件

要编译 bootloader, 您需要将这些文件复制到您的 u-boot-phytec-ti 编译目录, 并将其重命名以适应 *mkimage* 脚本:

- **ARM Trusted firmware binaries:**
 - bl1.bin
 - bl31.bin
 - binary blobs

If you already built our BSP with Yocto, you can get the bl1.bin, bl31.bin and binary blobs from the directory mentioned here: *BSP Images*

或者你可以在这里下载文件: <https://download.phytec.de/Software/Linux/BSP-Yocto-AM62Lx/BSP-Yocto-Ampliphy-AM62Lx-ALPHA2/images/ampliphy-vendor/am62lxx-libra-fpsc-1/>

警告

确保您重命名所需的文件, 以和 *mkimage tool* 兼容。

5.2.3 编译 bootloader

Build tiboot3.bin, tispl.bin and u-boot.img:

```
host:~/u-boot-phytec-ti$ make phycore_am62lx_defconfig  
host:~/u-boot-phytec-ti$ make BL1=/path/to/bl1.bin BL31=/path/to/bl31.bin BINMAN_INDIRS=/path/  
↪ to/binary_blobs
```

5.2.4 Create bootloader binaries for flashing

Use with UDA filesystem mode

To use the newly generated files with UDA filesystem boot. They can be copied to the medium as is. E.g. to test this standalone build with SD-Card boot copy the binaries to the SD-Card boot partition:

```
host:~/|u-boot-repo-name|$ cp tiboot3.bin tispl.bin u-boot.img /path/to/SD-Card/boot
```

提示

如果您有我们的 BSP Yocto 工程代码, 具体的偏移值也会在 Yocto 变量"BOOTLOADER_SEEK"和"BOOTLOADER_SEEK_EMMC"中声明。

Use with block device

The three binaries can be used with block devices. E.g. eMMC and SPI NOR. Create a combined image of all three:

```
host:~/u-boot-phytec-ti$ dd if=tiboot3.bin of=ti-boot-container.img conv=fsync
host:~/u-boot-phytec-ti$ dd if=tispl.bin of=ti-boot-container.img seek=1024 conv=fsync
host:~/u-boot-phytec-ti$ dd if=tispl.bin of=ti-boot-container.img seek=5120 conv=fsync
```

- flash to a block device e.g. eMMC:

```
target:~$ echo 0 > /sys/class/block/mmcblk0boot0/force_ro
target:~$ dd if=ti-boot-container.img of=/dev/mmcblk0boot0 conv=fsync
```

5.3 单独编译内核

5.3.1 配置源代码

- 使用的 linux-phytec-ti 分支可以在 [release notes](#) 中找到
- 此版本所需的标签称为 v6.12.35-11.01.05-phy
- Check out 所需的 linux-phytec-ti 标签:

```
host:~$ git clone https://github.com/phytec/linux-phytec-ti
host:~$ cd ~/linux-phytec-ti/
host:~/linux-phytec-ti$ git fetch --all --tags
host:~/linux-phytec-ti$ git checkout tags/v6.12.35-11.01.05-phy
```

- 为了提交更改，强烈建议切换到一个新分支:

```
host:~/linux-phytec-ti$ git switch --create <new-branch>
```

- 设置编译环境:

```
host:~/linux-phytec-ti$ source /opt/ampliphy-vendor/BSP-Yocto-Ampliphy-AM62Lx-ALPHA2/environment-
↪ setup-aarch64-phytec-linux
```

5.3.2 编译内核

- 编译 Linux 内核:

```
host:~/linux-phytec-ti$ make phytec_ti_defconfig
host:~/linux-phytec-ti$ make -j$(nproc)
```

- 安装内核模块，比如安装到 NFS 目录:

```
host:~/linux-phytec-ti$ make INSTALL_MOD_PATH=/home/<user>/<rootfspath> modules_install
```

- 镜像可以在 ~/linux-phytec-ti/arch/arm64/boot/Image 找到
- The dtb can be found at ~/linux-phytec-ti/arch/arm64/boot/dts/ti/k3-am62l3-libra-rdk-fpsc.dtb
- 要（重新）编译设备树和 -overlay 文件，只需运行

```
host:~/linux-phytec-ti$ make dtbs
```

备注

如果您遇到以下编译问题：

```
scripts/dtc/yamltree.c:9:10: fatal error: yaml.h: No such file or directory
```

确保您在主机系统上安装了 *"libyaml-dev"* 包：

```
host:~$ sudo apt install libyaml-dev
```

5.3.3 将内核复制到 SD 卡

内核及 module 和对应的设备树二进制文件可以用以下方式复制到已挂载的 SD 卡上。

```
host:~/linux-phytec-ti$ cp arch/arm64/boot/Image /path/to/sdcard/boot/
host:~/linux-phytec-ti$ cp arch/arm64/boot/dts/ti/k3-am62l3-libra-rdk-fpsc.dtb /path/to/sdcard/boot/oftree
host:~/linux-phytec-ti$ make INSTALL_MOD_PATH=/path/to/sdcard/root/ modules_install
```

5.4 主机网络准备

为了在 bootloader 中执行涉及网络的各种任务，需要配置一些主机服务。在开发主机上，必须安装和配置 TFTP、NFS 和 DHCP 服务。启动以太网所需的工具如下：

```
host:~$ sudo apt install tftpd-hpa nfs-kernel-server kea
```

5.4.1 TFTP 服务设置

- 首先，创建一个目录来存储 TFTP 文件：

```
host:~$ sudo mkdir /srv/tftp
```

- 然后将您的 BSP 镜像文件复制到此目录，并确保 other 用户也对 tftp 目录中的所有文件具有读取权限，否则将无法从开发板访问这些文件。

```
host:~$ sudo chmod -R o+r /srv/tftp
```

- 您还需要为相应的接口配置一个静态 IP 地址。PHYTEC 开发板的默认 IP 地址是 192.168.3.11。可以将主机地址设置为 192.168.3.10，子网掩码为 255.255.255.0

```
host:~$ ip addr show <network-interface>
```

将 <network-interface> 替换为连接到开发板的网络接口。您可以通过不指定网络接口来显示所有可选网络接口。

- 返回的结果应包含以下内容：

```
inet 192.168.3.10/24 brd 192.168.3.255
```

- 创建或编辑 /etc/default/tftpd-hpa 文件：

```
# /etc/default/tftpd-hpa

TFTP_USERNAME="tftp"
TFTP_DIRECTORY="/srv/tftp"
```

(续下页)

(接上页)

```
TFTP_ADDRESS=":69"
TFTP_OPTIONS="-s -c"
```

- 将 TFTP_DIRECTORY 设置为您的 TFTP 服务器根目录
- 将 TFTP_ADDRESS 设置为 TFTP 服务监听的主机地址（设置为 0.0.0.0:69 以监听 69 端口上所有 IP）。
- 设置 TFTP_OPTIONS，以下命令显示可配置的选项：

```
host:~$ man tftpd
```

- 重新启动服务以应用配置更改：

```
host:~$ sudo service tftpd-hpa restart
```

现在将开发板的以太网端口连接到您的主机。我们还需要在开发板和运行 TFTP 服务的主机之间建立网络连接。TFTP 服务器的 IP 地址应设置为 192.168.3.10，子网掩码为 255.255.255.0。

NFS 服务器设置

- 创建一个 NFS 目录：

```
host:~$ sudo mkdir /srv/nfs
```

- Temporarily export the nfs directory: The NFS server is not restricted to a certain file system location, so all we have to do is to export our root file system to the embedded network. In this example, the whole directory is exported and the "lab network" address of the development host is 192.168.3.10. The IP address has to be adapted to the local needs:

```
host:~$ sudo exportfs -i -o rw,no_root_squash,sync,no_subtree_check 192.168.3.0/255.255.255.
↪0:/srv/nfs
```

- unexport the rootfs when finished:

```
host:~$ sudo exportfs -u 192.168.3.0/255.255.255.0:/srv/nfs
```

Permanent export

- To make the export persistent across reboots on most distributions, modify the /etc/exports file and export it:

```
/srv/nfs 192.168.3.0/255.255.255.0(rw,no_root_squash,sync,no_subtree_check)
```

- 现在 NFS 服务器需要再次读取 /etc/exportfs 文件：

```
host:~$ sudo exportfs -ra
```

DHCP 服务器设置

- 创建或编辑 /etc/kea/kea-dhcp4.conf 文件；以内部子网为例，将 <network-interface> 替换为物理网络接口的名称：


```
{
  "Dhcp4": {
    "interfaces-config": {
      "interfaces": [ "<network-interface>/192.168.3.10" ]
    },
    "lease-database": {
      "type": "memfile",
      "persist": true,
      "name": "/tmp/dhcp4.leases"
    },
    "valid-lifetime": 28800,
    "subnet4": [{
      "id": 1,
      "next-server": "192.168.3.10",
      "subnet": "192.168.3.0/24",
      "pools": [
        { "pool": "192.168.3.1 - 192.168.3.255" }
      ]
    }]
  }
}
```

警告

在创建子网时请小心，因为这可能会扰乱公司网络政策。为了安全起见，请使用不同的子网，并通过 `interfaces` 配置选项指定该网络。

- 现在 DHCP 服务需要重新读取 `/etc/kea/kea-dhcp4.conf` 文件：

```
host:~$ sudo systemctl restart kea-dhcp4-server
```

当您启动/重启主机时，如果 `kea-dhcp4` 配置中指定的网络接口未处于活动状态，`kea-dhcp4-server` 将无法启动。因此请确保在连接接口后启动或者重启该 `systemd` 服务。

备注

DHCP server setup is only needed when using dynamic IP addresses. For our vendor BSPs, static IP addresses are used by default.

```
u-boot=> env print ip_dyn
ip_dyn=no
```

To use dynamic IP addresses for netboot, `ip_dyn` needs to be set to `yes`.

5.5 从网络启动内核

从网络启动意味着通过 TFTP 加载内核和设备树，并通过 NFS 加载根文件系统。但 bootloader 需要从另外的启动设备加载。

5.5.1 在主机上放置网络启动的镜像

- Copy the kernel fitImage, which already contains device-tree and all device-tree overlays to your tftp directory:

```
host:~$ cp fitImage /srv/tftp
```

- Copy the booting script to your tftp directory:

```
host:~$ cp net_boot_fit.scr.uimg /srv/tftp
```

- 确保 other 用户对 tftp 目录中的所有文件具有读取权限，否则将无法从开发板访问它们：

```
host:~$ sudo chmod -R o+r /srv/tftp
```

- 将根文件系统解压到您的 NFS 目录中：

```
host:~$ sudo tar -xvzf phytec-qt6demo-image-am62lxx-libra-fpsc-1.tar.xz -C /srv/nfs
```

备注

请确保使用 sudo 执行命令，以保留根文件系统中文件的所属权限。

5.5.2 Set appropriate U-boot variables

Since the nfsroot directory could be different in other networks, we do not set any default values. Enter the following commands to modify the bootloader environment.

```
u-boot=> setenv nfsroot /srv/nfs
```

Set any overlay configurations needed:

```
u-boot=> setenv overlays overlay.dtbo
```

5.5.3 从开发板启动

Set the correct boot target, if not already set by u-boot board code and boot into network boot:

```
u-boot=> setenv boot_targets dhcp
u-boot=> boot
```

5.5.4 开发板上的网络设置

如果要自定义开发板上的以太网配置，请按照此处的说明进行操作：[Network Environment Customization](#)

5.6 获取 BSP 开发中版本

5.6.1 当前 release 的开发中版本

这些 release manifest 文件是为了让您访问 Yocto BSP 的开发版本。它们不会在 phyLinux 选择菜单中显示，需要手动选择。可以使用以下命令行来完成此操作：

```
host:~$ ./phyLinux init -p am62l-fpsc -r BSP-Yocto-Ampliphy-AM62Lx-FPSC-PD25.1.y
```

这将初始化一个 BSP，用于跟踪当前版本（BSP-Yocto-Ampliphy-AM62Lx-ALPHA2）的最新开发版本。从现在开始，在此文件夹中执行 `repo sync` 将从我们的 Git 仓库中拉取所有最新的更改：

```
host:~$ repo sync
```

5.6.2 即将发布版本的开发中版本

即将发布版本的开发中版本可以通过这种方式访问。请执行以下命令，并查找一个比最新版本（BSP-Yocto-Ampliphy-AM62Lx-ALPHA2）的 PDXX.Y 数字更高的版本，并且以 .y 结尾：

```
host:~$ ./phyLinux init -p am62l-fpsc
```

5.7 获取最新的 Upstream 支持

We have a vanilla manifest that makes use of the Yocto master branches (not a vendor release), Linux, and U-Boot. This can be used to test the latest upstream kernel/U-Boot.

备注

master 分支的 manifest 反映了最新的开发状态。有时会出现一些 bug。我们会定期修复 master 分支。

```
host:~$ ./phyLinux init -p am62l-fpsc -r BSP-Yocto-Ampliphy-AM62Lx-master
```

5.8 Format SD card

使用单一的 SD 卡启动盘对存储介质进行烧写是开发过程中的常见任务。本章节针对此场景提供基础说明。大多数镜像的大小超过了默认的 root 分区剩余容量。要使用 SD 卡进行烧写，根文件系统需要扩展或创建一个单独的分区。有几种不同的方法可以格式化 SD 卡。最简单的方法是使用 Gparted。

5.8.1 Gparted

- 获取 GParted:

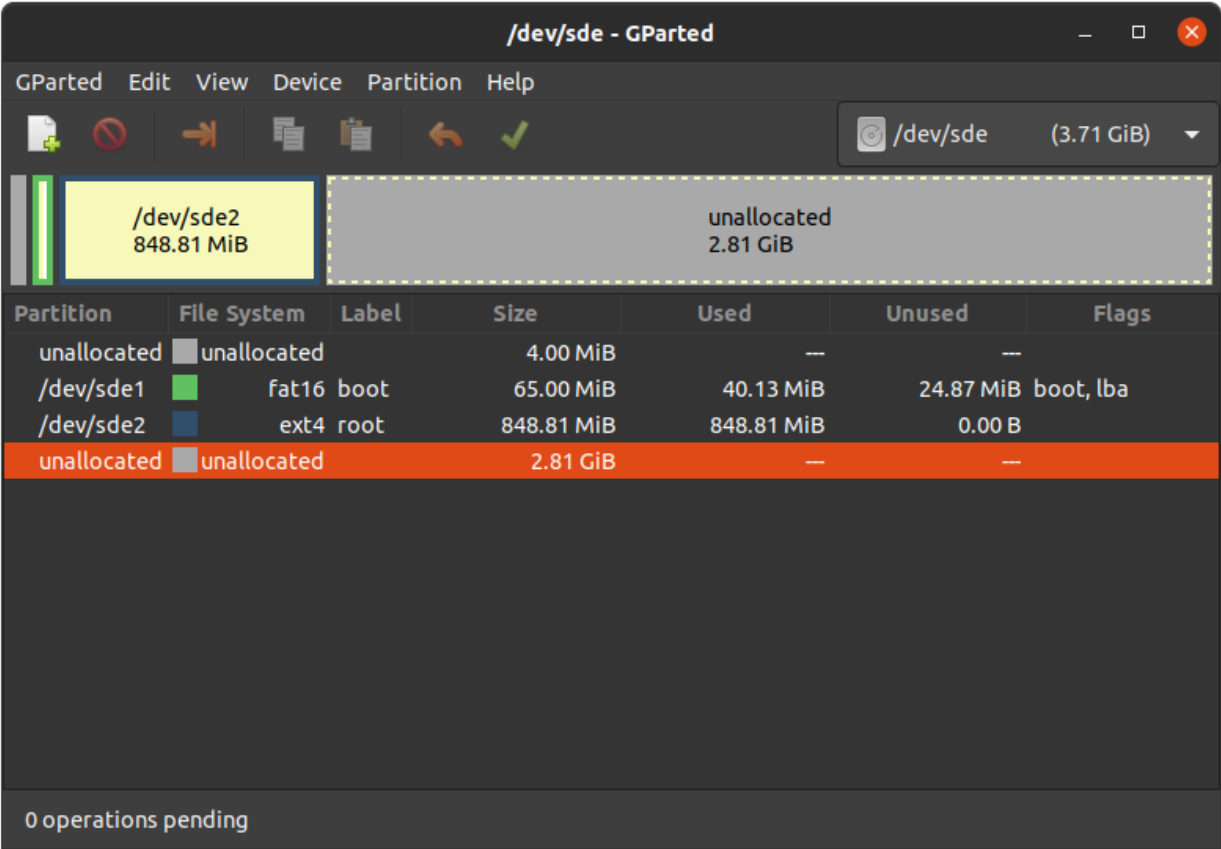
```
host:~$ sudo apt install gparted
```

- Insert the SD card into your host and get the device name:

```
host:~$ dmesg | tail
...
[30436.175412] sd 4:0:0:0: [sdb] 62453760 512-byte logical blocks: (32.0 GB/29.8 GiB)
[30436.179846] sdb: sdb1 sdb2
...
```

- Unmount all SD card partitions.
- 启动 GParted:

```
host:~$ sudo gparted
```

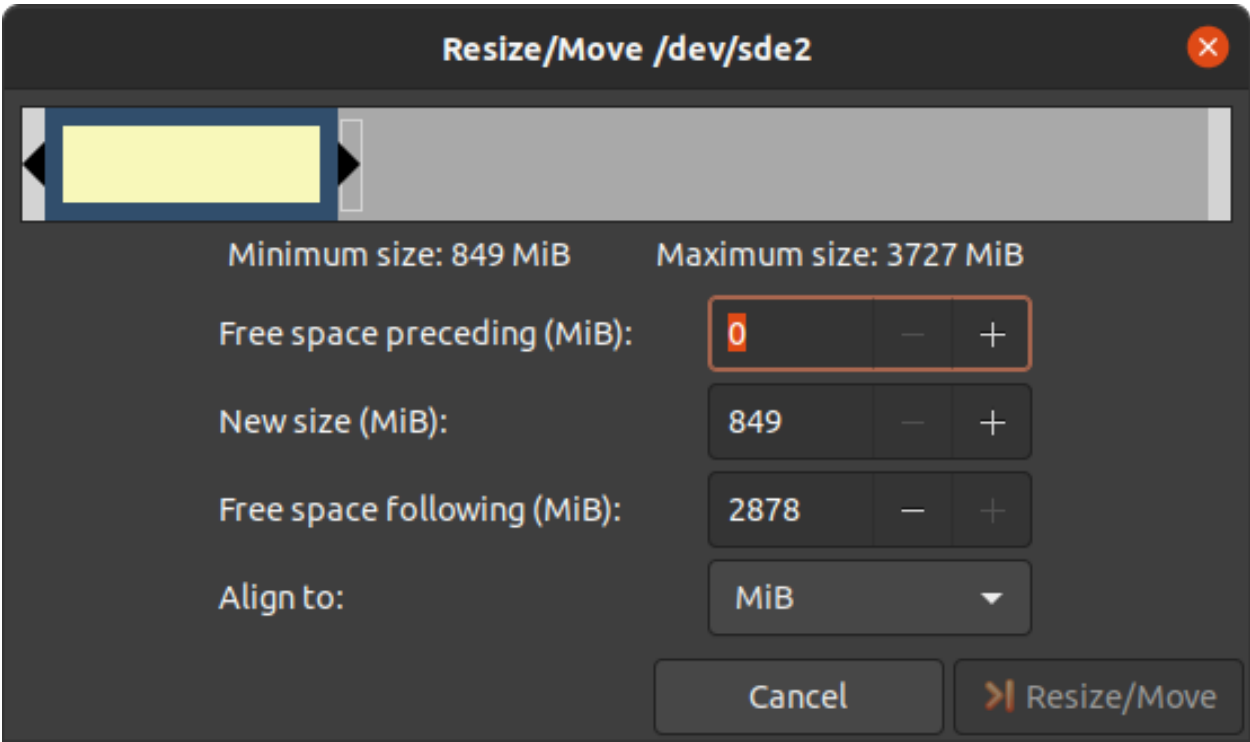
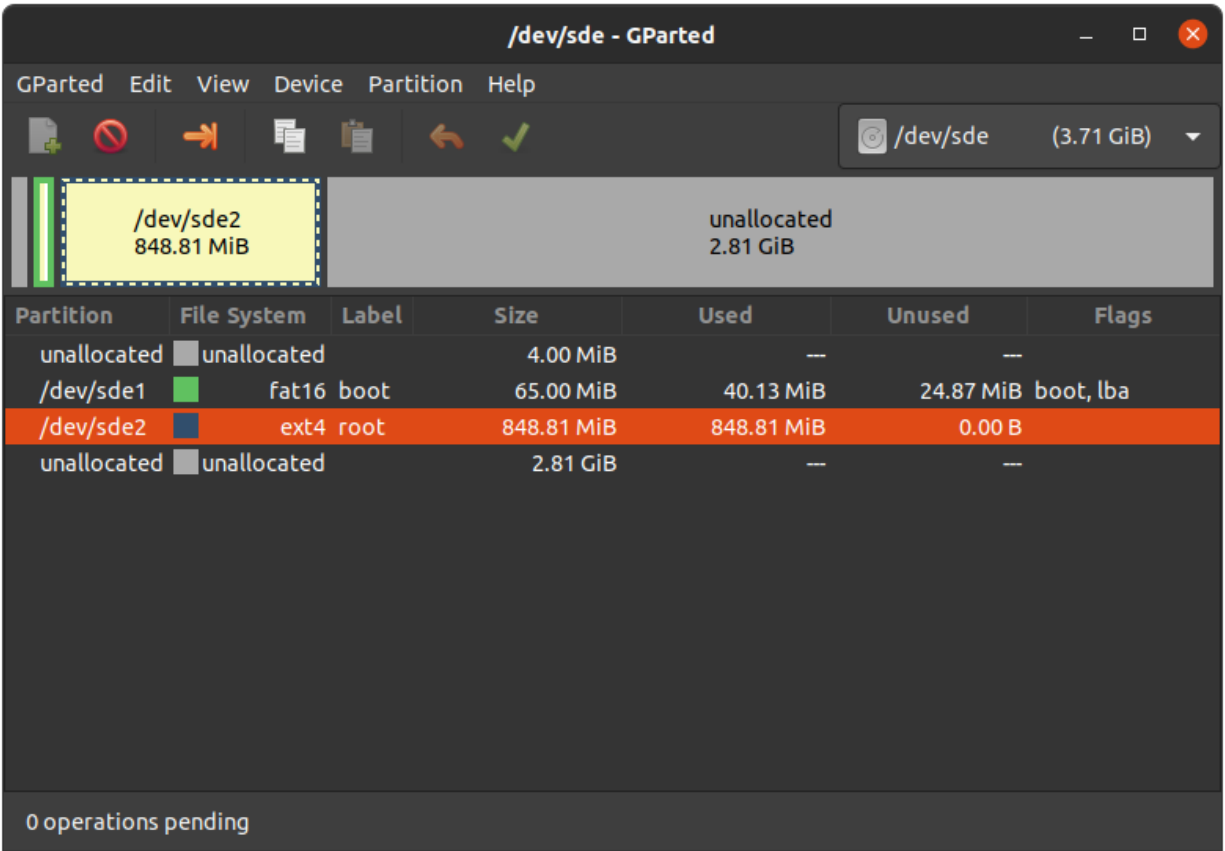


扩展根文件系统

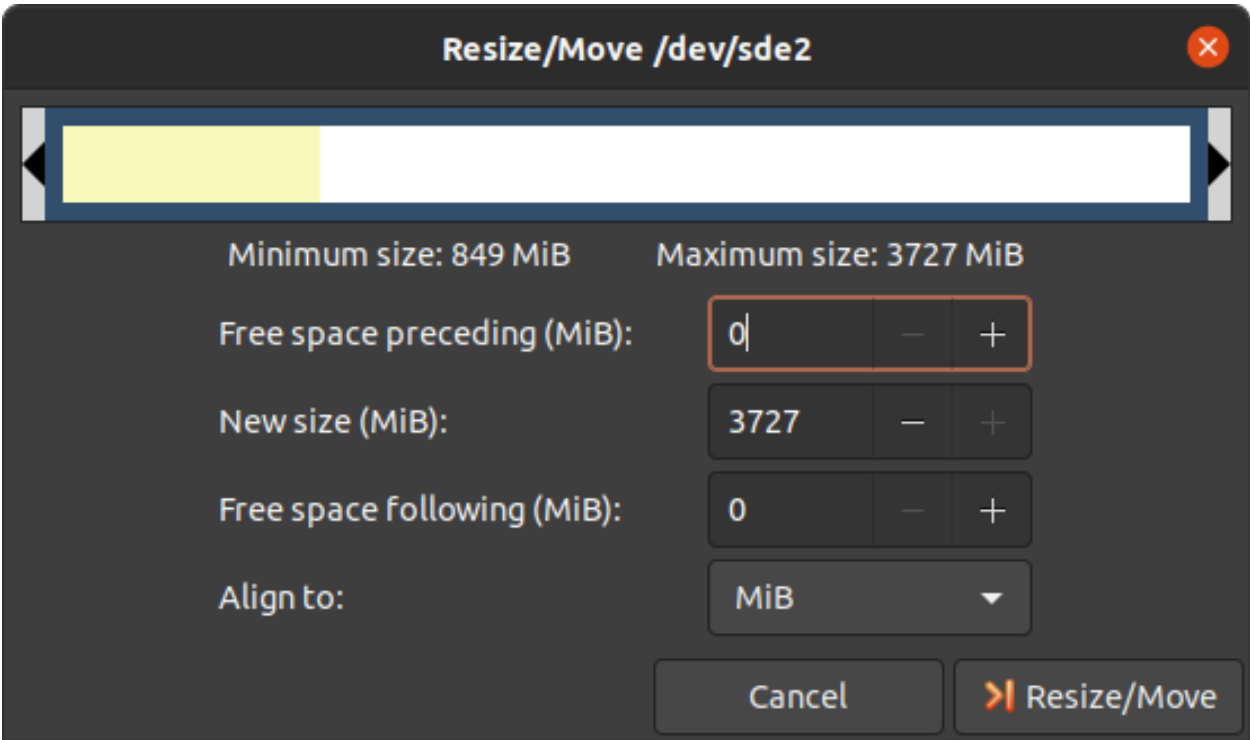
警告

使用 `resize2fs` 版本 1.46.6 及更早版本的 PC 系统（例如 Ubuntu 22.04）无法烧写在 Mickledore 以及更新的 yocto 版本上创建的 `partup` 软件包。这个是因为 `resize2fs` 新增了默认选项而导致的兼容性问题。有关详细信息，请参阅 [发布说明](#)。

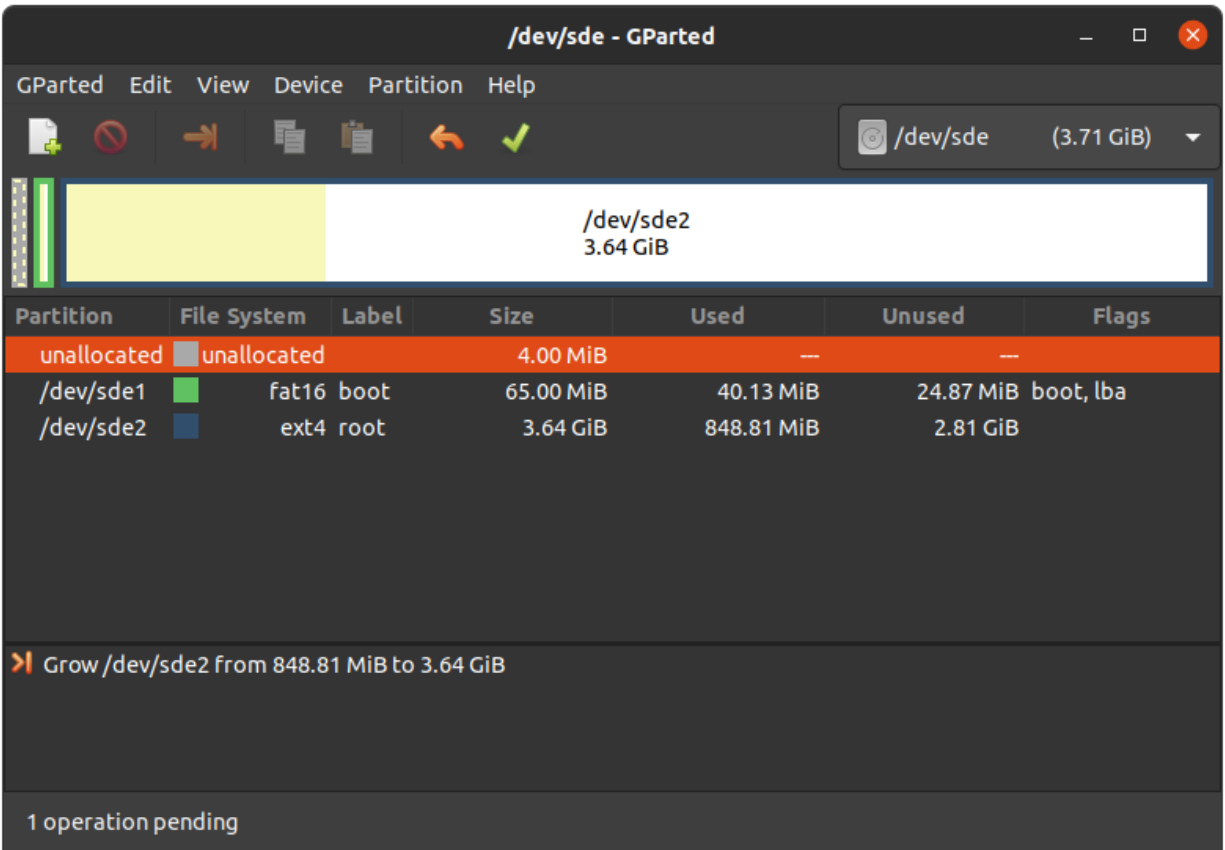
- Choose your SD card device at the drop-down menu on the top right
- 选择 `ext4` 根分区并点击调整大小：



- 您可以根据需要拖动滑块或手动输入大小。



- 通过点击 “Change Size” 按钮确认您的输入。



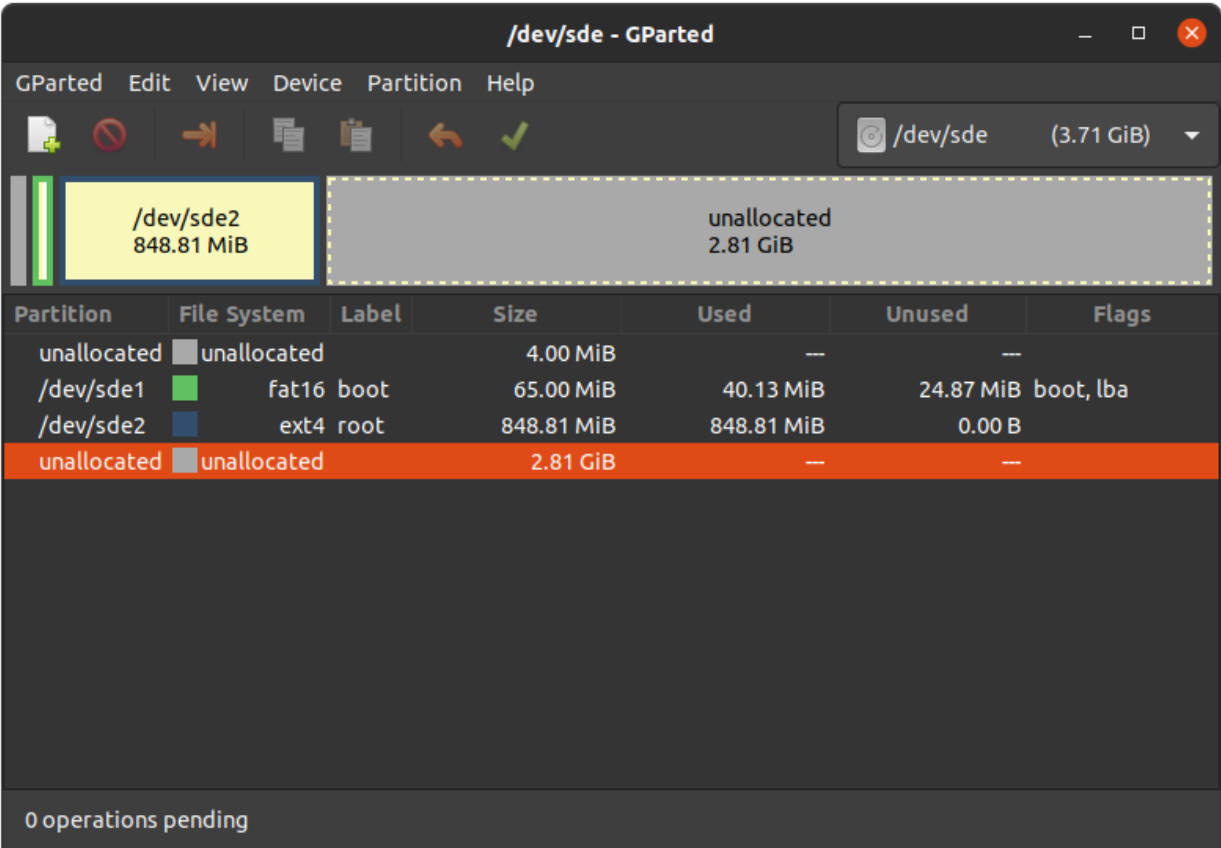
- 要应用您的更改，请按绿色勾号。

- 现在您可以挂载根分区并将 phytec-qt6demo-image-am62lxx-libra-fpsc-1.wic 镜像复制到其中。然后再卸载它：

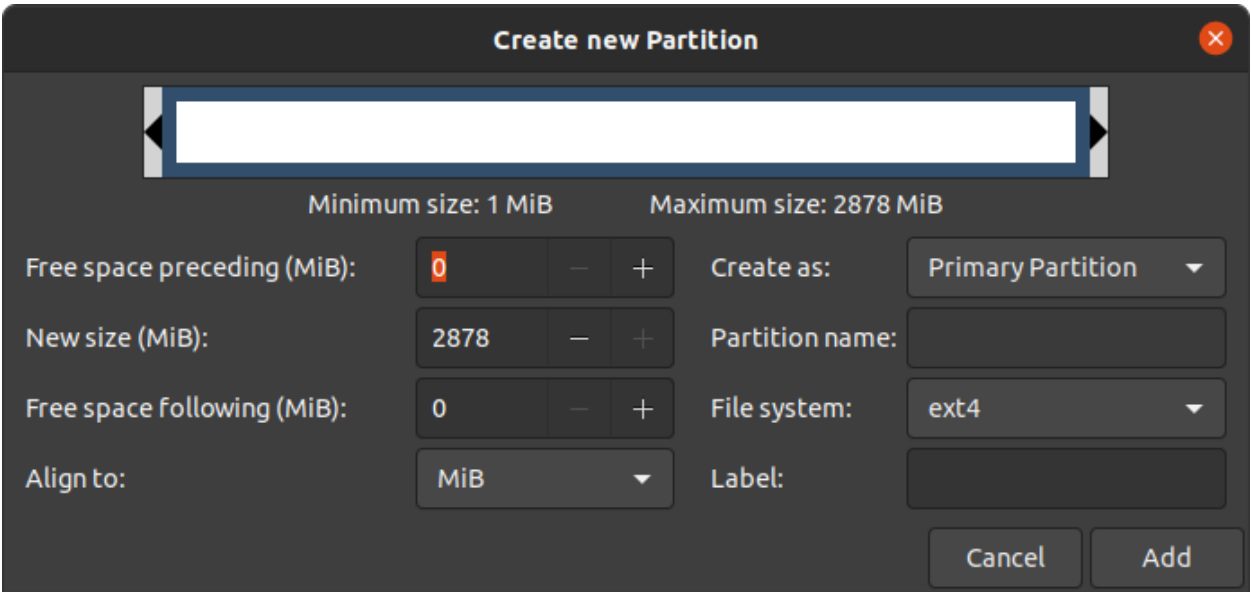
```
host:~$ sudo cp phytec-qt6demo-image-am62lxx-libra-fpsc-1.wic /mnt/ ; sync
host:~$ umount /mnt
```

创建第三个分区

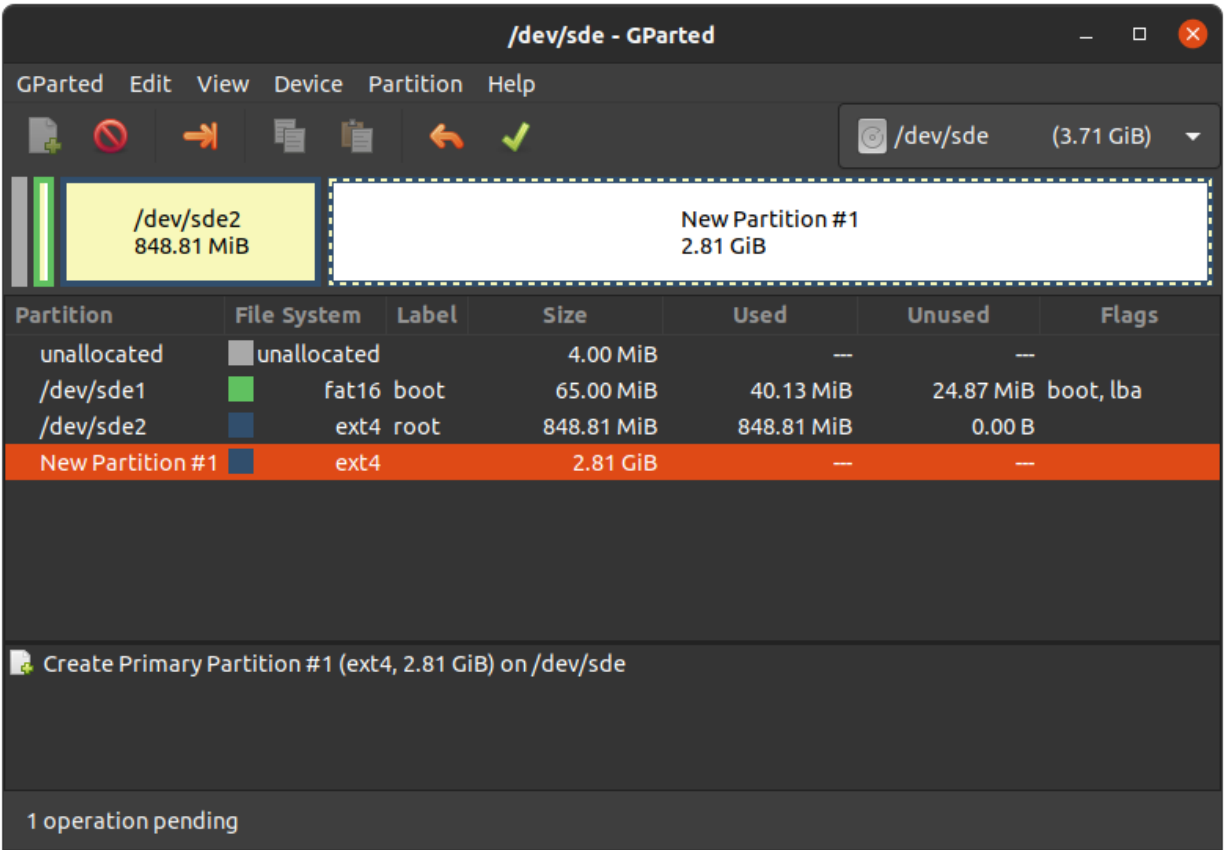
- Choose your SD card device at the drop-down menu on the top right



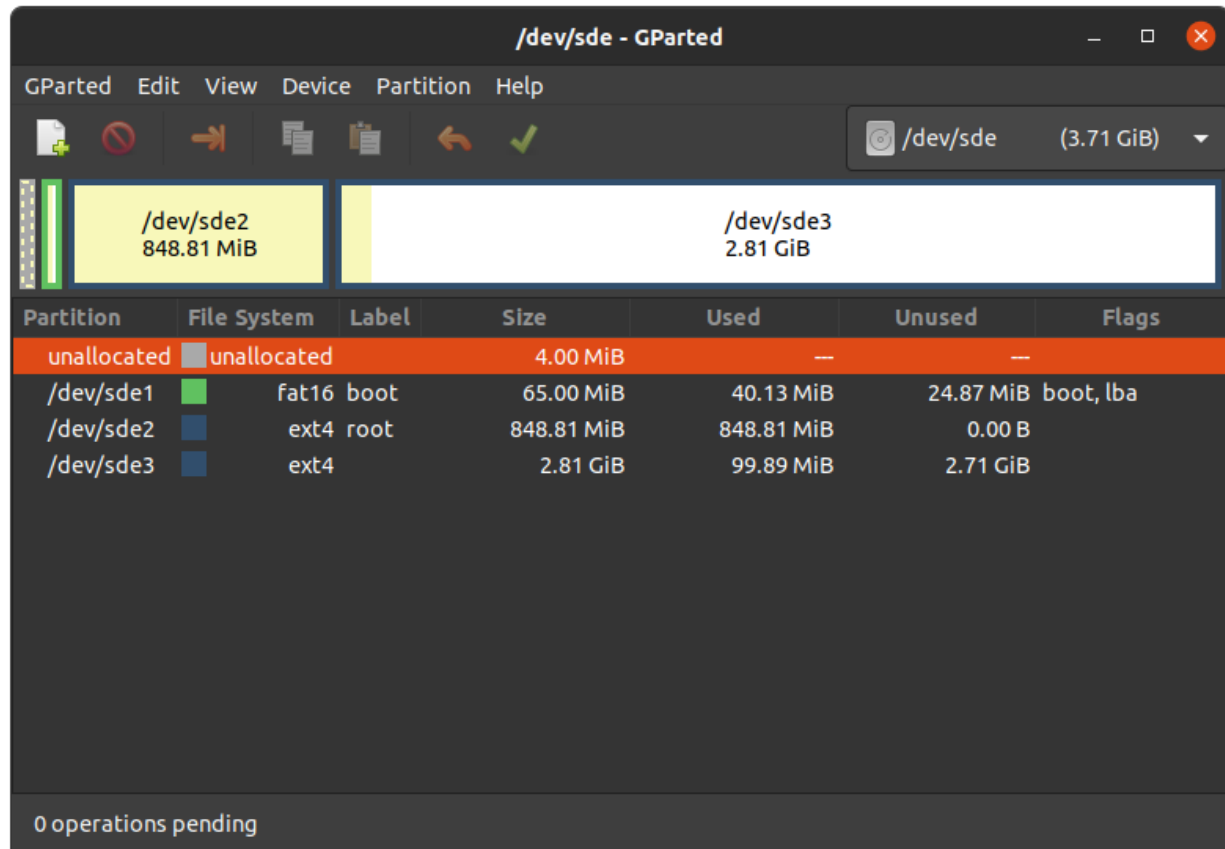
- 选择更大的未分配区域，然后点击”New”：



- 点击”Add”



- 按绿色勾确认更改。



- 现在您可以挂载新的分区并将 phytec-qt6demo-image-am62lxx-libra-fpsc-1.wic 镜像复制到其中。然后卸载它：

```
host:~$ sudo mount /dev/sde3 /mnt
host:~$ sudo cp phytec-qt6demo-image-am62lxx-libra-fpsc-1.wic /mnt/ ; sync
host:~$ umount /mnt
```


6.1 介绍

以下文本简要描述了设备树，关于设备树的相关文档可以在 Linux kernel 文档中找到 (<https://docs.kernel.org/devicetree/usage-model.html>)。

“Open Firmware Device Tree” 或简称设备树 (DT) 是一种用于描述硬件的数据结构和语言。更具体地说，它是一个可由操作系统读取的硬件描述，以便操作系统不需要对 machine 的细节进行硬编码

内核文档是学习设备树的一个非常好的资源。关于设备树数据格式的概述可以在 devicetree.org 的设备树使用页面找到。

6.2 PHYTEC AM62L BSP 设备树概念

以下部分说明了 PHYTEC 配置基于 AM62L 的核心板设备树的一些规则。

6.2.1 设备树结构

- *Module.dtsi* - 文件包括所有安装在核心板上的设备，例如 PMIC 和 RAM。
- *Board.dts* - 包含核心板 dtsi 文件。从 SoC AM62L 引出并在底板使用的设备也包含在此 dts 中。
- *Overlay.dtso* - 根据核心板或底板上可选硬件（例如 SPI 闪存或 PEB-AV-10）的情况来启用/禁用一些功能。

在 Linux 内核的根目录下，我们的 AM62 平台的设备树文件可以在 `arch/arm64/boot/dts/freescale/` 找到。

6.2.2 设备树 Overlay

设备树 Overlay 是可以在启动时合并到设备树中的设备树片段。下面是扩展板的硬件描述。对比源码中的 `include`，overlay 通过覆盖的方式来生效。overlay 也可以根据实际开发板的硬件配置来设置设备树节点状态。设备树 Overlay 与我们 Linux 内核仓库中的其他设备树文件一起放在子文件夹 `arch/arm64/boot/dts/freescale/` 中。

am62lxx-libra-fpsc-1.conf 可用的 overlay 文件有：

```
k3-am62l3-libra-fpsc-lvds-ac209.dtbo
```

可以在 linux 中使用以下命令来列出 FIT 镜像中所有的 overlay 配置

```
host:~$ dumpimage -l /boot/fitImage
```

或者在 u-boot:

```
u-boot=> load mmc ${mmcdev}:1 ${loadaddr} fitImage
u-boot=> iminfo
```

可以在 Linux 或 U-Boot 环境下配置 overlay。overlay 是在引导命令调用后、内核加载之前生效。接下来的部分将更详细地解释配置方法。

设置 \${overlays} 变量

`${overlays}` U-Boot 环境变量包含一个以井号 # 分隔的 overlay 文件列表，这些 overlay 文件将在启动过程中应用。overlays 变量中的 overlay 列表会包含在 FIT 镜像中。在 `$KERNEL_DEVICE_TREE` 这个 Yocto machine 变量中设置的 overlay 文件将自动添加到 FIT 镜像中。

`${overlays}` 变量可以直接在 U-Boot 环境中设置，也可以作为外部 `bootenv.txt` 环境文件的一部分。当希望使用在 U-Boot 环境中手工配置的 overlay 变量，可以配置 `env set no_bootenv 1`，因为 overlay 变量可能在运行启动脚本时被覆盖。默认情况下，`${overlays}` 变量来自位于启动分区的 `bootenv.txt` 文件。您可以在已启动的开发板上从 Linux 读取和写入该文件：

```
target:~$ cat /boot/bootenv.txt
overlays=conf-k3-am62l3-libra-rdk-fpsc-peb-eval-01.dtbo#conf-|dtbo-peb-av-10|
```

更改将在下次重启后生效。如果没有可用的 `bootenv.txt` 文件，可以直接在 U-Boot 环境中设置 overlay 变量。

```
u-boot=> setenv overlays conf-|dtbo-peb-av-10|
u-boot=> printenv overlays
overlays=conf-|dtbo-peb-av-10|
u-boot=> boot
```

如果用户定义了 `${overlays}` 变量，同时存在 `bootenv.txt` 文件，则需要设置 `${no_bootenv}` 变量：

```
u-boot=> setenv no_bootenv 1
u-boot=> setenv overlays conf-|dtbo-peb-av-10|
u-boot=> boot
```

有关环境的更多信息，请参见 U-boot External Environment subsection of the [device tree overlay section](#)。

我们使用 `${overlays}` 变量来描述在运行时无法自动检测的扩展板和摄像头。如果想禁用 `${overlays}` 变量中列出的 overlay，可以在 U-Boot 的环境中将 overlay 变量 unset，并且将 `${no_overlays}` 变量设置为 1。

```
u-boot=> env delete overlays
u-boot=> env set no_bootenv 1
```

如果希望通过 `bootenv.txt` 文件设置除 overlay 之外的 U-Boot 变量并且禁用 overlay，可以从 `bootenv.txt` 文件中删除 overlay 定义行，而不是设置 `no_bootenv`。

不同的 SoM 配置

核心板会自动加载额外的 overlay，以禁用核心板未贴装的组件。通过读取出厂 EEPROM 数据（EEPROM SoM Detection）来实现自动加载对应的 overlay。

核心板型号会决定是否应用设备树 overlay。要在 U-Boot 环境中查询是否会应用某个 overlay，请运行：

```
u-boot=> env print fit_extensions
```

如果没有可用的 EEPROM 数据，则不加载任何设备树 overlay。

要禁止启动时自动加载不同核心板的 overlay，可以在 bootloader 环境中将 `${no_extensions}` 变量设置为 1：

```
u-boot=> setenv no_extensions 1
u-boot=> boot
```

6.2.3 U-boot 外部环境

在 Linux 内核启动时，外部环境 `bootenv.txt` 文本文件将从 MMC 设备的 boot 分区或通过 TFTP 加载。该文件的主要目的是存储 `${overlays}` 变量。这可以针对不同的 machine 在 Yocto 中预定义不同的 overlay 配置。文件的内容在 meta-phytec 中的 Yocto recipe 中的 bootenv 中定义：<https://git.phytec.de/meta-phytec/tree/recipes-bsp/bootenv?h=scarthgap>

该文件中也可以设置其他变量。这些变量将覆盖环境中现有的设置。但只有对 boot 命令后进行计算的变量生效，例如 `${nfsroot}` 或 `${mmcargs}`。在文件中更改其他变量将不会有作用。以网络启动的用法作为示例。

如果无法加载外部环境，启动过程将继续进行，并使用自带的环境变量值。

6.2.4 在 Linux 环境下更改开发板上的 U-boot 环境变量

Libubootenv 是我们镜像中包含的一个工具，用于在开发板 linux 上修改 U-Boot 环境。

使用以下命令打印 U-Boot 环境：

```
target:~$ fw_printenv
```

使用以下命令修改 U-Boot 环境：

```
target:~$ fw_setenv <variable> <value>
```

小心

Libubootenv 会读取配置文件中配置的环境变量。要修改的环境变量会被插入到该文件中，默认情况下使用 eMMC 中存储环境变量。

如果 eMMC 没有被烧写过或者 eMMC 环境被擦除，libubootenv 将无法工作。您应该修改 `/etc/fw_env.config` 文件，以匹配您想要使用的环境源。

To find out which boards and modules are supported by the release of PHYTEC's phyFLEX-AM62L FPSC BSP described herein, visit [our BSP](#) web page and click the corresponding BSP release in the download section. Here you can find all hardware supported in the columns "Hardware Article Number" and the correct machine name in the corresponding cell under "Machine Name".

为了最大化软件的可复用性，Linux 内核提供了一个巧妙的软件架构，软件会根据不同硬件组件来分层。BSP（板级支持包）尽可能地对套件的功能进行模块化。当定制开发板或自定义核心板时，大部分软件配置可以简单的复制粘贴。与具体的开发板相关的内核代码可以在内核代码仓库中的设备树（DT）中找到，路径为 `arch/arm64/boot/dts/freescale/*.dts`。

实际上，软件复用是 Linux 内核最重要的特性之一，尤其是在 ARM 架构中，它必须应对大量复杂且不同的系统级芯片（SoC）。整个开发板的硬件在设备树（DT）中描述，独立于内核镜像。硬件描述在一个单独的二进制文件中，称为设备树二进制文件（Device Tree Blob, DTB）（参见 [device tree](#)）。

请阅读 PHYTEC AM62L BSP 设备树概念部分，以了解我们的 AM62L BSP 设备树模型。

以下部分概述了 AM62L 平台上支持的硬件组件及其对应操作系统驱动程序。客户可以根据自身的需求进行更改。

7.1 AM62L 引脚复用

该 AM62L Soc 包含许多外设接口。为了在保持最大功能性的同时减少封装尺寸和降低整体系统成本，许多 AM62L 引脚可以多路复用为多达八种信号功能。尽管存在许多可能的引脚多路复用组合，但由于时序限制，只有一定数量的组合被称为有效的 IO 集合。这些有效的 IO 集合经过精心挑选，以为用户提供尽可能多的应用场景。

Please refer to our Hardware Manual or the TI AM62L Reference Manual for more information about the specific pins and the muxing capabilities.

IO 集合的配置，也称为复用（muxing），是在设备树中完成的。驱动程序 `pinctrl-single` 读取设备树的节点 `fsl,pins`，并进行引脚复用配置。

The following is an example of the pin muxing of the UART0 device in `k3-am62l3-libra-rdk-fpsc.dtsi`:

```
main_uart0_pins_default: main-uart0-default-pins {
    pinctrl-single,pins = <
        AM62LX_IOPAD(0x01b4, PIN_INPUT, 0)      /* (D13) UART0_RXD */
        AM62LX_IOPAD(0x01b8, PIN_OUTPUT, 0)     /* (C13) UART0_TXD */
    >;
    bootph-all;
};
```

The first argument of the macro AM62LX_IOPAD(pa, val, muxmode) is the pad offset address within the I/O controller (in this example 0x1b4, corresponding UART0_RXD). The second argument (val) specifies the pad configuration, such as input/output and pull-up/pull-down. Third argument (muxmode) selects the functional mux mode for the pad, i.e. which peripheral signal is connected to it. In this case, 0 corresponds to the default mux option for UART0.

The device tree representation for UART0 pinmuxing: <https://github.com/phytec/linux-phytec-ti/tree/v6.12.35-11.01.05-phy/arch/arm64/boot/dts/ti/k3-am62l3-libra-rdk-fpsc.dts#L150>

7.2 RS232

The FPSC Standard supports 3 UART units. On the Libra FPSC, TTL level signals of UART0 (the standard console) and WKUP_UART0 are routed to a FT4232H UART to USB converter expansion. This USB is brought out at USB-C connector X14. UART4 is connected to a multi-protocol transceiver for RS-232 and RS-485, available at pin header connector [X27](#) at the RS-232 level, or at the RS-485 level. The muxing of the used transceivers is done by switch [S5](#) on the baseboard. For more information about the correct setup please refer to the phyFLEX-AM62L FPSC/Libra FPSC Hardware Manual section UARTs. The switch [S5](#) need to be set correctly.

- 以人类可读的格式显示终端的当前设置：

```
target:~$ stty -a
```

- 通过简单的 echo 和 cat，可以测试基本的通信。示例：

```
target:~$ echo 123 > /dev/ttyS1
```

```
host:~$ cat /dev/ttyUSB2
```

The device tree representation for RS232: <https://github.com/phytec/linux-phytec-ti/tree/v6.12.35-11.01.05-phy/arch/arm64/boot/dts/ti/k3-am62l3-libra-rdk-fpsc.dts#L327>

7.3 网络

Libra FPSC-AM62L 提供两个以太网接口。我们的核心板和底板各提供一个千兆以太网接口。

警告

The naming convention of the Ethernet interfaces in the hardware (ETH0 and ETH1) do not align with the network interfaces (end0 and end1) in Linux. So, be aware of these differences:

ETH1 = end0

ETH0 = end1

所有接口都提供一个标准的 Linux 网络端口，可以使用 BSD 套接字接口进行编程。整个网络配置由 systemd-networkd 守护进程管理。相关的配置文件可以在开发板的 `/lib/systemd/network/` 目录中找到，以及在 BSP 中的 `meta-ampliphy/recipes-core/systemd/systemd-conf` 目录中。

IP addresses can be configured within *.network files. The interfaces are configured to static IP as default. The default IP address and netmask for end0 is:

```
end0: 192.168.3.11/24
```

To configure end0 to dynamic IP over DHCP, go to `/lib/systemd/network/*-end0.network` and delete the line:

```
Address=192.168.3.11/24
```

The DT Ethernet setup might be split into two files depending on your hardware configuration: the module DT and the board-specific DT. The device tree set up for the ethernet where the PHY is populated on the SoM can be found here: <https://github.com/phytec/linux-phytec-ti/tree/v6.12.35-11.01.05-phy/arch/arm64/boot/dts/ti/k3-am62l-phycore-fpsc.dtsi#L148> :

The device tree set up for EQOS Ethernet IP core where the PHY is populated on the Libra FPSC can be found here: <https://github.com/phytec/linux-phytec-ti/tree/v6.12.35-11.01.05-phy/arch/arm64/boot/dts/ti/k3-am62l3-libra-rdk-fpsc.dtsi#L213>.

7.3.1 网络配置

U-boot 网络环境

- 要在 bootloader 中查找以太网设置：

```
u-boot=> printenv ipaddr serverip netmask
```

- 在将主机设置为 IP 192.168.3.10 和子网掩码 255.255.255.0 的情况下，开发板应该返回：

```
u-boot=> printenv ipaddr serverip netmask
ipaddr=192.168.3.11
serverip=192.168.3.10
netmask=255.255.255.0
```

- 如果您需要进行任何更改：

```
u-boot=> setenv <parameter> <value>
```

<parameter> 应该是 ipaddr、netmask、gatewayip 或 serverip 中的一个。<value> 将是所选参数的设定值。

- 您所做的更改目前是临时的。要保存这些更改：

```
u-boot=> saveenv
```

在这里，您也可以将 IP 地址更改为 DHCP，而不是使用静态 IP 地址。

- 配置：

```
u-boot=> setenv ip dhcp
```

- 设置 TFTP 和 NFS 的路径。修改可以如下所示：

```
u-boot=> setenv nfsroot /home/user/nfssrc
```

请注意，这些修改只会影响 bootloader 的设置。

小技巧

像 `nfsroot` 和 `netargs` 这样的变量可以被 U-boot 外部环境重新赋值。对于网络启动，外部环境将通过 `tftp` 加载。例如，要在 `bootenv.txt` 文件中设置 `nfsroot` 变量，请在 `tftpboot` 目录修改：

```
nfsroot=/home/user/nfssrc
```

无需在开发板上存储这些信息。请注意，U-boot 外部环境对于像 `ipaddr` 或 `serveraddr` 这样的变量不起作用，因为它们在加载外部环境之前已经被设置完成。

Secondary Ethernet Interface Configuration in U-Boot

By default, U-Boot utilizes the Ethernet PHY located on the module. To use the network connection provided by the PHY on the carrier board, configuration changes are required.

To enable the secondary Ethernet interface in U-Boot, the active Ethernet connection must be adjusted. The IP address configuration in U-Boot may also need modification.

Configure the development host with IP address 192.168.4.10 and netmask 255.255.255.0. The target device must then be configured as follows:

```
u-boot=> setenv ethact eth1
u-boot=> setenv ipaddr 192.168.4.11
```

内核网络环境

- Find the ethernet settings for `end0` in the target kernel:

```
target:~$ ip -statistics address show end0
2: end0: <NO-CARRIER,BROADCAST,MULTICAST,UP> mtu 1500 qdisc mq state UP group default qlen 1000
    link/ether 50:2d:f4:19:d6:33 brd ff:ff:ff:ff:ff:ff
    RX:  bytes  packets  errors  dropped  missed  mcast
         0         0         0         0         0         0
    TX:  bytes  packets  errors  dropped  carrier  collsns
         0         0         0         0         0         0
```

- Temporary adaption of the `end0` configuration:

```
target:~$ ip address add 192.168.3.11/24 dev end0
```

7.4 SD card

The AM62L supports a slot for Secure Digital cards to be used as general-purpose block devices. These devices can be used in the same way as any other block device.

警告

这些设备是热插拔的。然而，您必须确保在设备仍然挂载时不要拔掉它。这可能会导致数据丢失！

After inserting an SD card, the kernel will generate new device nodes in `/dev`. The full device can be reached via its `/dev/mmcblk1` device node. SD card partitions will show up as:

```
/dev/mmcblk1p<Y>
```

<Y> 作为分区编号，从 1 开始计数，直到该设备的最大分区数量。分区可以使用任何类型的文件系统进行格式化，并且可以以标准方式进行处理，例如，可以使用 `mount` 和 `umount` 命令进行分区挂载和卸载。

小技巧

这些分区设备节点要求 SD 卡包含有效的分区表（类似于“硬盘”）。如果没有分区表，则整个设备作为一个文件系统使用（类似于“软盘”）。在这种情况下，必须使用 `/dev/mmcblk1` 进行格式化和挂载。卡始终以可写方式挂载。

DT configuration for the MMC (SD card slot) interface can be found here: <https://github.com/phytec/linux-phytec-ti/tree/v6.12.35-11.01.05-phy/arch/arm64/boot/dts/ti/k3-am62l-phycore-fpsc.dtsi#L272> and <https://github.com/phytec/linux-phytec-ti/tree/v6.12.35-11.01.05-phy/arch/arm64/boot/dts/ti/k3-am62l3-libra-rdk-fpsc.dtsi#L355>

DT configuration for the e.MMC interface can be found here: <https://github.com/phytec/linux-phytec-ti/tree/v6.12.35-11.01.05-phy/arch/arm64/boot/dts/ti/k3-am62l-phycore-fpsc.dtsi#L263>

7.5 e.MMC Devices

PHYTEC modules like phyFLEX-AM62L FPSC are populated with an e.MMC memory chip as the main storage. e.MMC devices contain raw Multi-Level Cells (MLC) or Triple-Level Cells (TLC) combined with a memory controller that handles ECC and wear leveling. They are connected via an SD/MMC interface to the AM62L and are represented as block devices in the Linux kernel like SD cards, flash drives, or hard disks.

The electric and protocol specifications are provided by JEDEC (<https://www.jedec.org/standards-documents/technology-focus-areas/flash-memory-ssds-ufs-emmc/e-mmc>). The e.MMC manufacturer's datasheet is relatively short and meant to be read together with the supported version of the JEDEC e.MMC standard.

PHYTEC currently utilizes the e.MMC chips with JEDEC Version 5.0 and 5.1

7.5.1 扩展 CSD 寄存器

e.MMC devices have an extensive amount of extra information and settings that are available via the Extended CSD registers. For a detailed list of the registers, see manufacturer datasheets and the JEDEC standard.

在 Linux 用户空间中，您可以查询寄存器：

```
target:~$ mmc extcsd read /dev/mmcblk0
```

你将会看到：

```
=====
Extended CSD rev 1.7 (MMC 5.0)
=====

Card Supported Command sets [S_CMD_SET: 0x01]
[...]
```

7.5.2 使能后台操作 (BKOPS)

In contrast to raw NAND Flash, an eMMC device contains a Flash Transfer Layer (FTL) that handles the wear leveling, block management, and ECC of the raw MLC or TLC. This requires some maintenance tasks (for example erasing unused blocks) that are performed regularly. These tasks are called **Background Operations (BKOPS)**.

默认情况下（取决于芯片），后台操作可能会定期执行，也可能不会，他影响读写的最大延迟时间。

The JEDEC Standard has specified a method since version v4.41 that the host can issue BKOPS manually. See the JEDEC Standard chapter Background Operations and the description of registers BKOPS_EN (Reg: 163) and BKOPS_START (Reg: 164) in the eMMC datasheet for more details.

寄存器 BKOPS_EN（寄存器：163）的位 MANUAL_EN（位 0）的含义：

- 值 0：主机不支持手动触发 BKOPS。设备写入性能会受到影响。
- 值 1：主机支持手动触发 BKOPS。当主机不进行设备读写时，它会不时触发 BKOPS。

The mechanism to issue background operations has been implemented in the Linux kernel since v3.7. You only have to enable BKOPS_EN on the eMMC device (see below for details).

JEDEC 标准 v5.1 引入了一种新的自动 BKOPS 功能。它使主机能够定期触发后台操作，因为设备在空闲时会自动启动 BKOPS（请参见寄存器 BKOPS_EN（寄存器：163）中位 AUTO_EN 的描述）。

- 要检查 BKOPS_EN 是否已设置，请执行：

```
target:~$ mmc extcsd read /dev/mmcblk0 | grep BKOPS_EN
```

输出将会是，例如：

```
Enable background operations handshake [BKOPS_EN]: 0x01
#OR
Enable background operations handshake [BKOPS_EN]: 0x00
```

值 0x00 表示 BKOPS_EN 被禁用，设备的写入性能受到影响。值 0x01 表示 BKOPS_EN 被启用，主机将不时发起后台操作。

- 通过以下命令使能 BKOPS_EN：

```
target:~$ target:~$ mmc --help

[...]
mmc bkops_en <auto|manual> <device>
    Enable the eMMC BKOPS feature on <device>.
    The auto (AUTO_EN) setting is only supported on eMMC 5.0 or newer.
    Setting auto won't have any effect if manual is set.
    NOTE! Setting manual (MANUAL_EN) is one-time programmable (unreversible) change.
```

- 要设置 BKOPS_EN 位，请执行：

```
target:~$ mmc bkops_en manual /dev/mmcblk0
```

- 为了确保新设置生效并且内核能够自动触发 BKOPS，请先关闭系统：

```
target:~$ poweroff
```

小技巧

BKOPS_EN 位是一次性可编程的，无法恢复。

7.5.3 可靠写入

有两种不同的可靠写入选项：

1. Reliable Write option for a whole e.MMC device/partition.
2. 单次写的可靠写入方式。

小技巧

Do not confuse e.MMC partitions with partitions of a DOS, MBR, or GPT partition table (see the previous section).

The first Reliable Write option is mostly already enabled on the e.MMCs mounted on the phyFLEX-AM62L FPSC SoMs. To check this on the running target:

```
target:~$ mmc extcsd read /dev/mmcblk0 | grep -A 5 WR_REL_SET
Write reliability setting register [WR_REL_SET]: 0x1f
  user area: the device protects existing data if a power failure occurs during a write operation
  partition 1: the device protects existing data if a power failure occurs during a write operation
  partition 2: the device protects existing data if a power failure occurs during a write operation
  partition 3: the device protects existing data if a power failure occurs during a write operation
  partition 4: the device protects existing data if a power failure occurs during a write operation
  --
Device supports writing EXT_CSD_WR_REL_SET
Device supports the enhanced def. of reliable write
```

如果默认没有启用，可以使用 mmc 工具启用它：

```
target:~$ mmc --help

[...]
mmc write_reliability set <-y|-n|-c> <partition> <device>
  Enable write reliability per partition for the <device>.
  Dry-run only unless -y or -c is passed.
  Use -c if more partitioning settings are still to come.
  NOTE! This is a one-time programmable (unreversible) change.
```

第二个可靠写入方式是命令 CMD23 中的配置位 Reliable Write Request parameter (可靠写入请求参数) (位 31)。自内核版本 v3.0 起，文件系统（例如 ext4 的日志）和用户空间应用程序（如 fdisk 的分区表）会通过内核使用该可靠写功能。在 Linux 内核源代码中，它通过标志 REQ_META 进行处理。

结论：使用挂载选项 data=journal 的 ext4 文件系统在断电情况下是安全的。文件系统检查可以在断电后恢复文件系统，但在断电前刚写入的数据可能会丢失。在各种情况下，都可以恢复文件系统的正常状态。为了确保应用程序文件的正常保存，应用程序中应使用系统函数 fdatasync 或 fsync。

7.5.4 调整 ext4 根文件系统的大小

When flashing the SD card image to e.MMC the ext4 root partition is not extended to the end of the e.MMC. parted can be used to expand the root partition. The example works for any block device such as e.MMC, SD card, or hard disk.

- 获取当前设备大小：

```
target:~$ parted /dev/mmcblk0 print
```

- 输出如下：

```
Model: MMC Q2J55L (sd/mmc)
Disk /dev/mmcblk0: 7617MB
Sect[ 1799.850385] mmcblk0: p1 p2
or size (logical/physical): 512B/512B
Partition Table: msdos
Disk Flags:

Number  Start   End     Size    Type     File system  Flags
  1      4194kB  72.4MB  68.2MB  primary  fat16        boot, lba
  2      72.4MB  537MB   465MB   primary  ext4
```

- 使用 parted 将文件系统分区调整为设备的最大大小：

```
target:~$ parted /dev/mmcblk0 resizepart 2 100%
Information: You may need to update /etc/fstab.

target:~$ parted /dev/mmcblk0 print
Model: MMC Q2J55L (sd/mmc)
Disk /dev/mmcblk0: 7617MB
Sector size (logical/physical): 512[ 1974.191657] mmcblk0: p1 p2
B/512B
Partition Table: msdos
Disk Flags:

Number  Start   End     Size    Type     File system  Flags
  1      4194kB  72.4MB  68.2MB  primary  fat16        boot, lba
  2      72.4MB  7617MB  7545MB  primary  ext4
```

- 将文件系统调整为新的分区大小：

```
target:~$ resize2fs /dev/mmcblk0p2
resize2fs 1.46.1 (9-Feb-2021)
Filesystem at /dev/mmcblk0p2 is mounted on /; on-line resizing required
[ 131.609512] EXT4-fs (mmcblk0p2): resizing filesystem
from 454136 to 7367680 blocks
old_desc_blocks = 4, new_desc_blocks = 57
[ 131.970278] EXT4-fs (mmcblk0p2): resized filesystem to 7367680
The filesystem on /dev/mmcblk0p2 is now 7367680 (1k) blocks long
```

Increasing the filesystem size can be done while it is mounted. But you can also boot the board from an SD card and then resize the file system on the eMMC partition while it is not mounted.

7.5.5 启用伪 SLC 模式

eMMC devices use MLC or TLC (https://en.wikipedia.org/wiki/Multi-level_cell) to store the data. Compared with SLC used in NAND Flash, MLC or TLC have lower reliability and a higher error rate at lower costs.

如果您更喜欢可靠性而不是存储容量，可以启用伪 SLC 模式或 SLC 模式。这个方法采用了增强属性，该属性在 JEDEC 标准中有所描述，可以对设备的一个连续区域设置。JEDEC 标准并未规定增强属性的实现细节和保证，这由芯片制造商自行决定。对于美光（Micron）芯片，增强属性提高了可靠性，但也将容量减半。

警告

在设备上启用增强属性时，所有数据将被丢失。

以下步骤展示了如何启用增强属性。

- First obtain the current size of the eMMC device with:

```
target:~$ parted -m /dev/mmcblk0 unit B print
```

你将收到：

```
BYT;
/dev/mmcblk0:63652757504B:sd/mmc:512:512:unknown:MMC S0J58X;;
```

如您所见，该设备的容量为 63652757504 字节 = 60704 MiB。

- 要获取启用伪 SLC 模式后的设备的大小，请使用：

```
target:~$ mmc extcsd read /dev/mmcblk0 | grep ENH_SIZE_MULT -A 1
```

例如：

```
Max Enhanced Area Size [MAX_ENH_SIZE_MULT]: 0x000764
i.e. 3719168 KiB
--
Enhanced User Data Area Size [ENH_SIZE_MULT]: 0x000000
i.e. 0 KiB
```

这里的最大大小是 3719168 KiB = 3632 MiB。

- 现在，您可以通过输入以下命令为整个设备设置增强属性，例如 3719168 KiB：

```
target:~$ mmc enh_area set -y 0 3719168 /dev/mmcblk0
```

你将获得：

```
Done setting ENH_USR area on /dev/mmcblk0
setting OTP PARTITION_SETTING_COMPLETED!
Setting OTP PARTITION_SETTING_COMPLETED on /dev/mmcblk0 SUCCESS
Device power cycle needed for settings to take effect.
Confirm that PARTITION_SETTING_COMPLETED bit is set using 'extcsd read' after power cycle
```

- 为了确保新设置已生效，请关闭系统：

```
target:~$ poweroff
```

并进行上下电。建议您现在确认设置是否正确。

- 首先，检查 ENH_SIZE_MULT 的值，它必须是 3719168 KiB：

```
target:~$ mmc extcsd read /dev/mmcblk0 | grep ENH_SIZE_MULT -A 1
```

您应该看到：

```
Max Enhanced Area Size [MAX_ENH_SIZE_MULT]: 0x000764
i.e. 3719168 KiB
```

(续下页)

(接上页)

```
--
Enhanced User Data Area Size [ENH_SIZE_MULT]: 0x000764
i.e. 3719168 KiB
```

- 最后，检查设备的大小：

```
target:~$ parted -m /dev/mmcblk0 unit B print
BYT;
/dev/mmcblk0:31742492672B:sd/mmc:512:512:unknown:MMC S0J58X;;
```

7.5.6 擦除设备

It is possible to erase the eMMC device directly rather than overwriting it with zeros. The eMMC block management algorithm will erase the underlying MLC or TLC or mark these blocks as discard. The data on the device is lost and will be read back as zeros.

- After booting from SD card execute:

```
target:~$ blkdiscard -f --secure /dev/mmcblk0
```

选项 `--secure` 确保命令在 eMMC 设备擦除所有块之前会等待。`-f` (强制) 选项强制擦写，当 eMMC 设备包含有效数据分区时需要使用 `-f` 选项。

小技巧

```
target:~$ dd if=/dev/zero of=/dev/mmcblk0 conv=fsync
```

该命令也会擦除设备上的所有信息，但这个命令不利于设备的磨损均衡，并且需要花费更长的时间！

7.5.7 eMMC Boot Partitions

An eMMC device contains four different hardware partitions: user, boot1, boot2, and rpmb.

The user partition is called the User Data Area in the JEDEC standard and is the main storage partition. The partitions boot1 and boot2 can be used to host the bootloader and are more reliable. Which partition the AM62L uses to load the bootloader is controlled by the boot configuration of the eMMC device. The partition rpmb is a small partition and can only be accessed via a trusted mechanism.

此外，User 分区可以分为四个自定义的一般用途分区。对此功能的解释不在本文件涵盖的范围。有关更多信息，请参阅 JEDEC 标准第 7.2 章分区管理。

小技巧

Do not confuse eMMC partitions with partitions of a DOS, MBR, or GPT partition table.

The current PHYTEC BSP does not use the extra partitioning feature of eMMC devices. The U-Boot is flashed at the beginning of the user partition. The U-Boot environment is placed at a fixed location after the U-Boot. An MBR partition table is used to create two partitions, a FAT32 boot, and ext4 rootfs partition. They are located right after the U-Boot and the U-Boot environment. The FAT32 boot partition contains the kernel and device tree.

With eMMC flash storage it is possible to use the dedicated boot partitions for redundantly storing the bootloader. The Bootloader environment still resides in the user area before the first partition. The user

area also still contains the bootloader which the image first shipped during its initialization process. Below is an example, to flash the bootloader to one of the two boot partitions and switch the boot device via userspace commands.

通过用户空间命令

在主机上运行：

```
host:~$ scp <bootloader> root@192.168.3.11:/tmp/
```

The partitions boot1 and boot2 are read-only by default. To write to them from user space, you have to disable `force_ro` in the sysfs.

To manually write the bootloader to the eMMC boot partitions, first disable the write protection:

```
target:~$ echo 0 > /sys/block/mmcblk0boot0/force_ro
target:~$ echo 0 > /sys/block/mmcblk0boot1/force_ro
```

Write the bootloader to the eMMC boot partitions:

```
target:~$ dd if=/tmp/<bootloader> of=/dev/mmcblk0boot0
target:~$ dd if=/tmp/<bootloader> of=/dev/mmcblk0boot1
```

下表是 AM62L SoC 的偏移量：

SoC	User 分区偏移量	Boot 分区偏移量	e.MMC Device
AM62L	32 kiB	0 kiB	/dev/mmcblk0

After that set the boot partition from user space using the `mmc` tool:

(对于'boot0')：

```
target:~$ mmc bootpart enable 1 0 /dev/mmcblk0
```

(对于'boot1')：

```
target:~$ mmc bootpart enable 2 0 /dev/mmcblk0
```

To disable booting from the eMMC boot partitions simply enter the following command:

```
target:~$ mmc bootpart enable 0 0 /dev/mmcblk0
```

To explicitly enable booting from the eMMC user area, run:

```
target:~$ mmc bootpart enable 7 0 /dev/mmcblk0
```

Automatic failover

The ROM loader implements an automatic failover mechanism for eMMC boot partitions. If booting from the primary partition fails, the system automatically attempts to boot from the secondary partition. This failover is indicated by a change in the boot message from **Boot Stage: Primary boot** to **Boot Stage: Secondary boot**. This functionality is limited to boot0 and boot1 partitions and does not apply to the user area.

7.6 SPI 主设备

The AM62L controller has MCSPI and an OSPI controllers included. The MCSPI controller supports four SPI channels with each up to 4 devices. The OSPI controllers supports Single/Dual/Quad/Octal mode data transfer (1/2/4/8 bidirectional data lines).

7.6.1 SPI NOR 烧写

Libra FPSC is equipped with a QSPI NOR Flash which connects to the AM62L's OSPI interface.

From Linux userspace, the NOR Flash partitions are accessible via `/dev/mtd<N>` devices where `<N>` is the MTD device number associated with the NOR flash partition to access. To find the correct MTD device number for a partition, run on the target:

```
root@am62lxx-libra-fpsc-1:~$ mtdinfo --all
Count of MTD devices:      5
Present MTD devices:      mtd0, mtd1, mtd2, mtd3, mtd4
Sysfs interface supported: yes

mtd0
Name:                      ospi.tiboot3
Type:                      nor
Eraseblock size:           131072 bytes, 128.0 KiB
Amount of eraseblocks:     4 (524288 bytes, 512.0 KiB)
Minimum input/output unit size: 1 byte
Sub-page size:             1 byte
Character device major/minor: 90:0
Bad blocks are allowed:    false
Device is writable:        true

mtd1
Name:                      ospi.tispl
Type:                      nor
Eraseblock size:           131072 bytes, 128.0 KiB
Amount of eraseblocks:     16 (2097152 bytes, 2.0 MiB)
Minimum input/output unit size: 1 byte
Sub-page size:             1 byte
Character device major/minor: 90:2
Bad blocks are allowed:    false
Device is writable:        true

mtd2
Name:                      ospi.u-boot
Type:                      nor
Eraseblock size:           131072 bytes, 128.0 KiB
Amount of eraseblocks:     32 (4194304 bytes, 4.0 MiB)
Minimum input/output unit size: 1 byte
Sub-page size:             1 byte
Character device major/minor: 90:4
Bad blocks are allowed:    false
Device is writable:        true

mtd3
Name:                      ospi.env
Type:                      nor
Eraseblock size:           131072 bytes, 128.0 KiB
Amount of eraseblocks:     2 (262144 bytes, 256.0 KiB)
```

(续下页)

(接上页)

```

Minimum input/output unit size: 1 byte
Sub-page size:                  1 byte
Character device major/minor:   90:6
Bad blocks are allowed:         false
Device is writable:             true

mtd4
Name:                           ospi.env.backup
Type:                           nor
Eraseblock size:                131072 bytes, 128.0 KiB
Amount of eraseblocks:          2 (262144 bytes, 256.0 KiB)
Minimum input/output unit size: 1 byte
Sub-page size:                  1 byte
Character device major/minor:   90:8
Bad blocks are allowed:         false
Device is writable:             true

```

它列出了所有 MTD 设备及其对应的分区名称。闪存节点在模块 DTS 中的 SPI 主节点内定义。SPI 节点包含连接到此 SPI 总线的所有设备，在这种情况下只有 SPI NOR Flash。

设备树中 SPI 主节点的定义可以在这里找到：

<https://github.com/phytec/linux-phytec-ti/tree/v6.12.35-11.01.05-phy/arch/arm64/boot/dts/ti/k3-am62l3-libra-rdk-fpsc.dts#L335>

7.7 GPIOs

The Libra FPSC has a set of pins especially dedicated to user I/Os. Those pins are connected directly to AM62L pins and are muxed as GPIOs. They are directly usable in Linux userspace. The processor has organized its GPIOs into nine banks of 16 GPIOs each (up to 144 GPIOs). However, not all GPIOs are pinned out on the Libra FPSC board.

In Linux, the internal GPIO module is exposed as a single GPIO controller, represented by gpiochip0. This controller provides access to all available GPIOs on the device. On the Libra FPSC, this corresponds to 126 GPIO lines in total.

从用户空间访问 GPIO 将使用 libgpiod。它提供了一个库和工具，用于与 Linux GPIO 字符设备进行交互。以下是一些工具的用法示例：

- 检测芯片上的 gpiochips：

```
target:~$ gpiodetect
gpiochip0 [600000.gpio] (126 lines)
```

- GPIO expander

Beside the GPIOs of the AM62L SoC, the Libra FPSC has a GPIO expander, which adds more GPIOs to the system.

```
gpiochip2 [4-0020] (16 lines)
```

DT configuration for the GPIO expander can be found here:

<https://github.com/phytec/linux-phytec-ti/tree/v6.12.35-11.01.05-phy/arch/arm64/boot/dts/ti/k3-am62l3-libra-rdk-fpsc.dts#L274>

- 显示关于 gpiochips 的详细信息，包括它们的名称、consumer、方向、活动状态和附加 flag：

```
target:~$ gpioinfo -c gpiochip0
```

- 读取 GPIO 的值（例如从 gpiochip0 的 GPIO 20）:

```
target:~$ gpioget -c gpiochip0 20
```

- 将 gpiochip0 上的 GPIO 20 的值设置为 0 并退出工具:

```
target:~$ gpiowrite -c gpiochip0 20=0
```

- gpiowrite 的帮助文本显示了可能的选项:

```
target:~$ gpiowrite --help
Usage: gpiowrite [OPTIONS] <line=value>...

Set values of GPIO lines.

Lines are specified by name, or optionally by offset if the chip option
is provided.
Values may be '1' or '0', or equivalently 'active'/'inactive' or 'on'/'off'.

The line output state is maintained until the process exits, but after that
is not guaranteed.

Options:
  --banner           display a banner on successful startup
  -b, --bias <bias>  specify the line bias
                     Possible values: 'pull-down', 'pull-up', 'disabled'.
                     (default is to leave bias unchanged)
  --by-name          treat lines as names even if they would parse as an offset
  -c, --chip <chip>  restrict scope to a particular chip
  -C, --consumer <name> consumer name applied to requested lines (default is 'gpiowrite')
  -d, --drive <drive> specify the line drive mode
                     Possible values: 'push-pull', 'open-drain', 'open-source'.
                     (default is 'push-pull')
  -h, --help         display this help and exit
  -l, --active-low    treat the line as active low
  -p, --hold-period <period>
                     the minimum time period to hold lines at the requested values
  -s, --strict       abort if requested line names are not unique
  -t, --toggle <period>[,<period>]...
                     toggle the line(s) after the specified period(s)
                     If the last period is non-zero then the sequence repeats.
  --unquoted         don't quote line names
  -v, --version      output version information and exit
  -z, --daemonize    set values then detach from the controlling terminal

Chips:
  A GPIO chip may be identified by number, name, or path.
  e.g. '0', 'gpiochip0', and '/dev/gpiochip0' all refer to the same chip.

Periods:
  Periods are taken as milliseconds unless units are specified. e.g. 10us.
  Supported units are 's', 'ms', and 'us'.

*Note*
  The state of a GPIO line controlled over the character device reverts to default
```

(续下页)

(接上页)

when the last process referencing the file descriptor representing the device file exits. This means that it's wrong to run `gpio` set, have it exit and expect the line to continue being driven high or low. It may happen if given pin is floating but it must be interpreted as undefined behavior.

警告

某些 GPIO 用于特殊功能。在使用某个 GPIO 之前，请参考您板子的原理图或硬件手册，以确保该 IO 未被其他功能占用。

7.7.1 通过 sysfs 访问 GPIO

警告

通过 sysfs 访问 GPIO 已经过时了，我们建议使用 `libgpiod`。

默认情况下不再支持通过 sysfs 访问 GPIO。只有手动在内核配置中启用 `CONFIG_GPIO_SYSFS` 后才能支持。要在 `menuconfig` 中使 `CONFIG_GPIO_SYSFS` 可见，必须首先启用选项 `CONFIG_EXPERT`。

You can also add this option for example to the `defconfig` you use in `arch/arm64/configs/` in the linux kernel sources. For our TI based releases, this could be for example `phytec_ti_defconfig`:

```
..
CONFIG_EXPERT=y
CONFIG_GPIO_SYSFS=y
..
```

您也可以创建一个新的 `config` 片段。有关详细信息，请参阅我们的 Yocto Reference Manual。

7.8 ADC

The PHYTEC phyFLEX-AM62L FPSC includes general purpose Analog-to-Digital Converters (ADC) which can be used for interfacing analog sensors.

通过 sysfs 可以读取 ADC 值：

```
target:~$ cat /sys/bus/iio/devices/iio:deviceX/in_voltageY_raw
```

On Libra FPSC the ADC lines are accessible on X73 expansion connector:

ADC 输入	X73 pin
ADC_IN0	3
ADC_IN1	5
ADC_IN2	7
ADC_IN3	9
ADC_IN4	4
ADC_IN5	6
ADC_IN6	8
ADC_IN7	10

备注

On AM62L, only ADC_IN0 to ADC_IN3 are available for use. ADC_IN4 to ADC_IN7 are not connected internally. This limitation also applies to the current/voltage sensing functionality.

Additionally, there is a current and voltage sensing circuitry available on Libra FPSC. It is capable of measuring the input current consumption and supply voltage of the phyFLEX-AM62L FPSC SoM, as well as the Libra FPSC carrier board's 1.8V, 3.3V and 5V power rails.

The current-sensing circuitry uses four INA241A4QDDFRQ1 current-sense amplifiers (gain: 100 V/V), each paired with a 4 mΩ shunt resistor. Their outputs feed the ADC input channels ($V_{ref} = 1.8$ V) through a 1:3 voltage divider. With this configuration, the resulting current resolution is 3.295898 mA/LSB.

The voltage-sensing circuitry uses simple 1:3.46 voltage dividers connected to the ADC input channels ($V_{ref} = 1.8$ V). This yields a voltage resolution of 1.520508 mV/LSB.

Channel Function	ADC Input
SoM current sensing	ADC_IN0
SoM voltage sensing	ADC_IN1
Carrier board 5V rail current sensing	ADC_IN2
Carrier board 5V rail voltage sensing	ADC_IN3
Carrier board 3.3V rail current sensing	ADC_IN4
Carrier board 3.3V rail voltage sensing	ADC_IN5
Carrier board 1.8V rail current sensing	ADC_IN6
Carrier board 1.8V rail voltage sensing	ADC_IN7

Current scaling factor is available as a sysfs parameter `/sys/bus/iio/devices/iio:device1/in_current0_scale`.

The phyFLEX-AM62L FPSC SoM consumption can thus be measured with this simple script:

```
#!/bin/sh
RAW=$(cat /sys/bus/iio/devices/iio:device1/in_current0_raw)
SCALE=$(cat /sys/bus/iio/devices/iio:device1/in_current0_scale)
CURRENT=$(echo "$RAW * $SCALE" | bc -l)
printf "Current: %.3f mA\n" "$CURRENT"
```

备注

Current scaling factor calculation depends on `CONFIG_IIO_RESCALE=y` kernel configuration.

In our BSP we also enable config option `CONFIG_SENSORS_IIO_HWMON=y` which provides hwmon interface to conveniently measure phyFLEX-AM62L FPSC SoM consumption directly via the sysfs parameter:

```
root@yocto-machinename:~$ cat /sys/class/hwmon/hwmon1/curr1_input
415
```

In the example output provided above, the current consumption measured was 415 mA @ 5V.

7.9 LED 灯

如果有任何 LED 灯连接到 GPIO 管脚，您可以通过特定的 LED 驱动程序接口访问它们，而不是使用通用的 GPIO 接口（请参见 GPIO 部分）。您将通过 `/sys/class/leds/` 而不是 `/sys/class/gpio/` 来访问它们。LED 的最大亮度可以从 `max_brightness` 文件中读取。`brightness` 文件将设置 LED 的亮度（取值范围从 0 到 `max_brightness`）。大多数 LED 硬件上不支持调整亮度，所以在所有非零亮度下都会点亮。

下面是一个简单的例子。

要获取所有可用的 LED，请输入：

```
target:~$ ls /sys/class/leds
led-1@ led-2@ led-3@ mmc1::@ mmc2::@
```

The Libra FPSC provides the following LED indicators: led-1, led-2 and led-3.

- 打开 LED 灯：

```
target:~$ echo 255 > /sys/class/leds/led-1/brightness
```

- 关闭 LED：

```
target:~$ echo 0 > /sys/class/leds/led-1/brightness
```

Device tree configuration for the User I/O configuration can be found here: <https://github.com/phytec/linux-phytec-ti/tree/v6.12.35-11.01.05-phy/arch/arm64/boot/dts/ti/k3-am62l3-libra-rdk-fpsc.dts#L251>

7.10 I²C 总线

该 AM62L 包含多个多主支持快速模式的 I²C 模块。PHYTEC 板提供了许多不同的 I²C 设备，这些设备连接到 AM62L 的 I²C 模块。本节描述了我们 Libra FPSC 中集成的一些 I²C 设备的基本设备使用及其设备树 (DT) 表示。

i2c 的设备树节点包含一些设置，例如时钟频率，用于设置总线频率，以及引脚控制设置，包括 `scl-gpios` 和 `sda-gpios`，这些是用于总线恢复的备用引脚配置。

General I²C bus configuration from SoM (e.g. `k3-am62l-phyflex-fpsc.dtsi`): <https://github.com/phytec/linux-phytec-ti/tree/v6.12.35-11.01.05-phy/arch/arm64/boot/dts/ti/k3-am62l-phycore-fpsc.dtsi#L172>

General I²C bus configuration from carrierboard (e.g. `k3-am62l3-libra-rdk-fpsc.dts`) <https://github.com/phytec/linux-phytec-ti/tree/v6.12.35-11.01.05-phy/arch/arm64/boot/dts/ti/k3-am62l3-libra-rdk-fpsc.dts#L233>

7.11 EEPROM

The system features two I2C EEPROM devices distributed across the SoM and carrier board:

On the phyFLEX-AM62L FPSC SoM:

- Board Detection EEPROM
 - Bus: I2C-1
 - Address: 0x50
 - Purpose: Factory configuration for board identification

Device Tree Reference for SoM EEPROMs: <https://github.com/phytec/linux-phytec-ti/tree/v6.12.35-11.01.05-phy/arch/arm64/boot/dts/ti/k3-am62l-phycore-fpsc.dtsi#L249>

And on the Libra FPSC carrier board:

- Board Detection EEPROM
 - Bus: I2C-2
 - Address: 0x51
 - Purpose: Reserved for carrier board identification

Device Tree Reference for Carrier Board: <https://github.com/phytec/linux-phytec-ti/tree/v6.12.35-11.01.05-phy/arch/arm64/boot/dts/ti/k3-am62l3-libra-rdk-fpsc.dts#L238>

7.11.1 I2C EEPROM access

警告

The first 1024 (0x400) bytes of the EEPROM area (bus: I2C-1 addr: 0x50) should not be erased or overwritten. As this will influence the behavior of the bootloader. The board might not boot correctly anymore.

EEPROM reading and writing in U-Boot

In U-Boot the `i2c` command can be used for EEPROM read and write operations.

First set the correct I2C bus, where the EEPROM is connected. `<bus-no>` is the I2C bus number of the EEPROM.

```
u-boot=> i2c dev <bus-no>
```

To read and print the first 32 bytes from EEPROM execute. `<addr>` is the I2C address of the EEPROM.

```
u-boot=> i2c md <addr> 0x00 0x20
```

To read the first 32 bytes from EEPROM into memory (loadaddr) execute:

```
u-boot=> i2c read <addr> 0x00 0x20 $loadaddr
```

To write 0xff to the 32 bytes at offset 0x100 execute:

```
u-boot=> i2c mw <addr> 0x100 0xff 0x20
```

To write 32 bytes to offset 0x100 to EEPROM from memory (loadaddr) execute:

```
u-boot=> i2c write $loadaddr <addr> 0x100 0x20
```

EEPROM reading and writing in Linux

Reading and writing can also be done via sysfs in Linux. For this, find the correct path in sysfs first. It follows this logic: `/sys/class/i2c-dev/i2c-<bus-no>/device/<bus-no>-<addr>/eeprom` `<bus-no>` is the bus number of the EEPROM `<addr>` is the address of the EEPROM in 4 digits hex.

To read and print the EEPROM content as a hex number, execute:

```
target:~$ hexdump -C <eeprom-sysfs-path>
```

or:


```
target:~$ dd if=<eeprom-sysfs-path> | od -x
```

To fill the EEPROM with zeros leaving out the EEPROM data use:

```
target:~$ dd if=/dev/zero of=<eeprom-sysfs-path> seek=1 bs=256
```

7.11.2 EEPROM SoM 检测

The I2C EEPROM, populated on the phyFLEX-AM62L FPSC, is addressable over I2C address 0x50 on bus 1. PHYTEC uses this 32 byte data area to store information about the SoM. This includes PCB revision and mounting options.

The EEPROM data is read at a very early stage during startup. It is used to select the correct RAM configuration. This makes it possible to use the same bootloader image for different RAM sizes and choose the correct DTS overlays automatically.

警告

The first 1024 (0x400) bytes of the EEPROM area (bus: I2C-1 addr: 0x50) should not be erased or overwritten. As this will influence the behavior of the bootloader. The board might not boot correctly anymore.

使用 API 修订版 2 数据格式烧写的核心板将在早期启动阶段打印出有关模块的信息。

7.11.3 恢复 EEPROM 数据

The hardware introspection data is pre-programmed on the EEPROM data spaces. If you accidentally delete or overwrite this data, please contact our support team.

7.12 RTC

RTC 可以通过 `/dev/rtc*` 访问。由于 PHYTEC 板通常有多个 RTC，因此可能会有多个 RTC 设备文件。

- 要找到 RTC 设备的名称，可以通过以下方式读取其 sysfs 条目：

```
target:~$ cat /sys/class/rtc/rtc*/name
```

- 例如，你将得到：

```
rtc-rv3028 0-0052
snvs_rtc 30370000.snvs:snvs-rtc-lp
```

小技巧

这将列出所有实时时钟 (RTC)，包括非 I²C 接口的 RTC。如果存在设备树/aliases 条目，Linux 会根据这些条目分配 RTC 设备 ID。

日期和时间可以通过 `hwclock` 工具和 `date` 命令进行操作。要显示目标上设置的当前日期和时间：

```
target:~$ date
Thu Jan  1 00:01:26 UTC 1970
```

使用日期命令更改日期和时间。日期命令以以下语法设置时间：“YYYY-MM-DD hh:mm:ss (+|-)hh:mm”：

```
target:~$ date -s "2022-03-02 11:15:00 +0100"
Wed Mar  2 10:15:00 UTC 2022
```

备注

您的时区（在此示例中为 +0100）可能会有所不同。

使用 date 命令并不会改变实时时钟（RTC）的时间和日期，因此如果我们重启开发板，这些更改将会被丢弃。要写入 RTC，我们需要使用 hwclock 命令。使用 hwclock 工具将当前的日期和时间（通过 date 命令设置）写入 RTC，然后重启开发板以检查更改是否已应用到 RTC 上：

```
target:~$ hwclock -w
target:~$ reboot
.
.
.
target:~$ date
Wed Mar  2 10:34:06 UTC 2022
```

要从实时时钟（RTC）设置系统时间和日期，请使用：

```
target:~$ date
Thu Jan  1 01:00:02 UTC 1970
target:~$ hwclock -s
target:~$ date
Wed Mar  2 10:45:01 UTC 2022
```

7.12.1 RTC 唤醒 alarm

可以从实时时钟（RTC）发出中断以唤醒系统。该格式使用 Unix 纪元时间，即自 1970 年 1 月 1 日 UTC 午夜以来的秒数。要在从挂起到 RAM 状态后的 4 分钟唤醒系统，请输入：

```
target:~$ echo "+240" > /sys/class/rtc/rtc0/wakealarm
target:~$ echo mem > /sys/power/state
```

备注

内部唤醒 alarm 时间将被向上舍入到下一个分钟，因为 alarm 功能不支持秒。

7.12.2 RTC 参数

实时时钟（RTC）具有一些功能，可以通过 hwclock 工具进行读取和设置。

- 我们可以通过以下方式检查 RTC 支持的功能：

```
target:~$ hwclock --param-get features
The RTC parameter 0x0 is set to 0x71.
```

这个值的含义在内核中进行了编码，每个位的定义为：

```
#define RTC_FEATURE_ALARM          0
#define RTC_FEATURE_ALARM_RES_MINUTE 1
#define RTC_FEATURE_NEED_WEEK_DAY  2
#define RTC_FEATURE_ALARM_RES_2S   3
#define RTC_FEATURE_UPDATE_INTERRUPT 4
#define RTC_FEATURE_CORRECTION      5
#define RTC_FEATURE_BACKUP_SWITCH_MODE 6
#define RTC_FEATURE_ALARM_WAKEUP_ONLY 7
#define RTC_FEATURE_CNT             8
```

- 我们可以通过以下方式检查 RTC BSM (Backup Switchover Mode 备份切换模式):

```
target:~$ hwclock --param-get bsm
The RTC parameter 0x2 is set to 0x1.
```

- 我们可以通过以下方式设置 RTC BSM:

```
target:~$ hwclock --param-set bsm=0x2
The RTC parameter 0x2 will be set to 0x2.
```

BSM 位的定义为:

```
#define RTC_BSM_DISABLED  0
#define RTC_BSM_DIRECT    1
#define RTC_BSM_LEVEL     2
#define RTC_BSM_STANDBY   3
```

小技巧

您应该将 BSM 模式设置为 DSM 或 LSM, 以便在初始电源不可用时, RTC 可以切换到备用电源。请查看 **RV-3028** RTC 的 Datasheet, 以了解 LSM (电平切换模式) 和 DSM (直接切换模式) 这两个定义的工作模式。

DT representation for I²C RTCs: <https://github.com/phytec/linux-phytec-ti/tree/v6.12.35-11.01.05-phy/arch/arm64/boot/dts/ti/k3-am62l-phycore-fpsc.dtsi#L257>

And the additions on the carrierboard: <https://github.com/phytec/linux-phytec-ti/tree/v6.12.35-11.01.05-phy/arch/arm64/boot/dts/ti/k3-am62l3-libra-rdk-fpsc.dts#L228>

7.13 USB 主控制器

The USB controller of the AM62L SoC provides a low-cost connectivity solution for numerous consumer portable devices by providing a mechanism for data transfer between USB devices with a line/bus speed of up to 480 Mbit/s (High-Speed 'HS'). The USB subsystem has two independent USB controller cores. Both cores are capable of acting as a USB peripheral device or a USB host. Each is connected to a USB 2.0 PHY.

BSP 支持大容量存储设备 (优盘) 和键盘。其他与 USB 相关的设备驱动程序必须根据需要在内核配置中启用。由于 udev, 所有连接的存储设备都会获得唯一的 ID, 并可以在 `/dev/disk/by-id` 中找到。这些 ID 可以在 `/etc/fstab` 中用于以不同的方式挂载不同的 USB 存储设备。

DT representation for USB Host: <https://github.com/phytec/linux-phytec-ti/tree/v6.12.35-11.01.05-phy/arch/arm64/boot/dts/ti/k3-am62l3-libra-rdk-fpsc.dts#L382>

7.14 CAN FD

The Libre FPSC has two CAN interfaces supporting CAN FD. They are supported by the Linux standard CAN framework which builds upon then the Linux network layer. Using this framework, the CAN interfaces behave like an ordinary Linux network device, with some additional features special to CAN. More information can be found in the Linux Kernel documentation: <https://www.kernel.org/doc/html/latest/networking/can.html>

备注

The switches S6 and S7 are switching the 120 Ohm bus termination resistors. For proper functionality of the CAN FD interface, the bus needs to be terminated. If no external bus termination resistors are mounted, the switches S6 (for CAN FD1) and S7 (for CAN FD2) need to be set to ON.

- 使用:

```
target:~$ ip link
```

to see the state of the interfaces. The two CAN interfaces should show up as main_mcan0 and main_mcan1.

- To get information on main_mcan0, such as bit rate and error counters, type:

```
target:~$ ip -d -s link show main_mcan0
```

The information for main_mcan0 will look like:

```
4: main_mcan0: <NOARP,UP,LOWER_UP,ECHO> mtu 72 qdisc pfifo_fast state UP mode DEFAULT group default_
↪qlen 10
    link/can promiscuity 0 allmulti 0 minmtu 0 maxmtu 0
    can <FD> state ERROR-ACTIVE (berr-counter tx 0 rx 0) restart-ms 0
        bitrate 800000 sample-point 0.800
        tq 12 prop-seg 39 phase-seg1 40 phase-seg2 20 sjw 10 brp 1
        m_can: tseg1 2..256 tseg2 2..128 sjw 1..128 brp 1..512 brp_inc 1
        dbitrate 800000 dsample-point 0.800
        dtq 50 dprop-seg 9 dphase-seg1 10 dphase-seg2 5 dsjw 2 dbrp 4
        m_can: dtseg1 1..32 dtseg2 1..16 dsjw 1..16 dbrp 1..32 dbrp_inc 1
        clock 80000000
        re-started bus-errors arbit-lost error-warn error-pass bus-off
            0          0          0          0          0          0          numtxqueues 1 numrxqueues_
↪1 gso_max_size 65536 gso_max_segs 65535 tso_max_size 655
    RX: bytes packets errors dropped missed mcast
        0          0          0          0          0          0
    TX: bytes packets errors dropped carrier collsns
        0          0          0          0          0          0
```

输出包含一组标准参数，这些参数也适用于以太网接口，因此并非所有参数对于 CAN 都是相关的（例如 MAC 地址）。以下输出参数包含有用的信息：

can0	接口名称
NOARP	CAN 无法使用 ARP 协议
MTU	最大传输单元
RX packets	接收的数据包数量
TX packets	发送的数据包数量
RX bytes	接收字节数
TX bytes	发送字节数
errors...	总线错误统计信息

The CAN configuration is done in the systemd configuration file `/lib/systemd/network/11-main_mcan.network`. For a persistent change of (as an example, the default bitrates), change the configuration in the BSP under `./meta-ampliphy/recipes-core/systemd/systemd-conf/11-main_mcan.network` in the root filesystem and rebuild the root filesystem.

```
[Match]
Name=main_mcan*

[CAN]
BitRate=800000
DataBitRate=800000
FDMode=yes
```

比特率也可以手动更改，例如，设置为灵活比特率（flexible bitrate）：

```
target:~$ ip link set main_mcan0 down
target:~$ ip link set main_mcan0 txqueuelen 10 up type can bitrate 500000 sample-point 0.75 dbitrate
↪4000000 dsample-point 0.8 fd on
```

您可以使用 `cansend` 发送消息，或使用 `candump` 接收消息：

```
target:~$ cansend main_mcan0 123#45.67
target:~$ candump main_mcan0
```

要生成用于测试目的的随机 CAN 流量，请使用 `cangen`：

```
target:~$ cangen
```

`cansend --help` 和 `candump --help` 提供了关于选项和用法的帮助信息。

警告

mcp2518fd SPI 到 CAN FD 只支持从 125kB/s 开始的波特率。可以选择更慢的速率，但可能无法正常工作。

Device Tree CAN configuration of k3-am62l3-libra-rdk-fpsc.dts: <https://github.com/phytec/linux-phytec-ti/tree/v6.12.35-11.01.05-phy/arch/arm64/boot/dts/ti/k3-am62l3-libra-rdk-fpsc.dts#L306>

7.15 视频

7.15.1 视频与 Gstreamer

默认情况下，BSP 安装了一个示例视频，路径为 `/usr/share/qtpy/videos/`。可以使用以下命令之一开始视频播放：

```
target:~$ gst-launch-1.0 playbin uri=file:///usr/share/qtphy/videos/caminandes_3_llamigos_720p_vp9.webm
```

- 或者:

```
target:~$ gst-launch-1.0 -v filesrc location=/usr/share/qtphy/videos/caminandes_3_llamigos_720p_vp9.webm !  
└─> decodebin name=decoder decoder. ! videoconvert ! waylandsink
```

- 或者:

```
target:~$ gst-play-1.0 /usr/share/qtphy/videos/caminandes_3_llamigos_720p_vp9.webm --videosink waylandsink
```

7.16 显示

The Libra FPSC supports up to 3 different display outputs. The following table shows the required extensions and devicetree overlays for the different interfaces. For the alpha release, we have included overlay for powertip,ac209 LVDS display. The name can be found on the back of the display.

备注

Currently only LVDS1 (onboard LVDS) is supported

接口	扩展板	设备树 overlay
LVDS1	Libra FPSC	k3-am62l3-libra-fpsc-lvds-ac209.dtbo

The default interface is LVDS1 (onboard LVDS).

7.16.1 Qt Demo

使用 phytec-qt6demo-image 时, Weston 会在启动时启动。我们的 Qt6 DEMO 应用程序名为 “qtphy”, 可以通过以下方式停止:

```
target:~$ systemctl stop qtphy
```

- 要重新开始 Demo, 请运行:

```
target:~$ systemctl start qtphy
```

- 要禁用 Demo 的自动启动, 请运行:

```
target:~$ systemctl disable qtphy
```

- 要启用 Demo 的自动启动, 请运行:

```
target:~$ systemctl enable qtphy
```

- Weston 可以通过以下方式停止:

```
target:~$ systemctl stop weston
```

备注

在关闭 Weston 之前，必须先关闭 Qt Demo。

7.16.2 背光控制

如果 LCD 连接到 PHYTEC 开发板，可以通过 Linux 内核的 sysfs 接口控制其背光。系统中所有可用的背光设备可以在文件夹 `/sys/class/backlight` 中找到。读取相应的文件并向其写入数据可以控制背光。

备注

一些具有多显示的开发板在 `/sys/class/backlight` 有多个背光控制。比如：backlight0 和 backlight1

- 例如，要获取最大亮度级别（max_brightness），请执行：

```
target:~$ cat /sys/class/backlight/backlight/max_brightness
```

有效的亮度值范围是 0 到 `<max_brightness>`。

- 要获取当前亮度级别，请输入：

```
target:~$ cat /sys/class/backlight/backlight/brightness
```

- 写入文件 brightness 以更改亮度：

```
target:~$ echo 0 > /sys/class/backlight/backlight/brightness
```

例如，关闭背光。

有关所有文件的文档，请参见 <https://www.kernel.org/doc/Documentation/ABI/stable/sysfs-class-backlight>。

Device tree description of LVDS-0 can be found here: <https://github.com/phytec/linux-phytec-ti/tree/v6.12.35-11.01.05-phy/arch/arm64/boot/dts/ti/k3-am62l3-libra-fpsc-lvds-ac209.dtso#L16>

7.17 电源管理

7.17.1 CPU 核心管理

AM62L SoC 在芯片上拥有多个处理器核心。例如，AM62L 具有 2 个 ARM 核，这些核可以在运行时单独开启和关闭。

- 要查看系统中所有可用的核心，请执行：

```
target:~$ ls /sys/devices/system/cpu -l
```

- 这将显示，例如：

```
cpu0      cpu1      cpufreq
[...]
```

这里系统有四个处理器核心。默认情况下，系统中所有可用的核心都被启用，以获得最佳性能。

- 要关闭某个核，请执行：

```
target:~$ echo 0 > /sys/devices/system/cpu/cpu1/online
```

作为确认，您将看到：

```
[ 110.505012] psci: CPU1 killed
```

现在核心已关闭电源，并且该核心上不再安排任何进程。

- 您可以使用 `top` 命令查看核心和进程的图形概览：

```
target:~$ htop
```

- 要重新启用核心，请执行：

```
target:~$ echo 1 > /sys/devices/system/cpu/cpu1/online
```

7.18 热管理

7.18.1 内核

Linux 内核集成了热管理功能，能够监测芯片 (SoC) 温度，降低 CPU 频率，控制风扇，通知其他驱动程序减少功耗，并在最坏的情况下关闭系统 (<https://www.kernel.org/doc/Documentation/thermal/sysfs-api.txt>)。

本节描述了如何在 AM62L SoC 平台上使用热管理内核 API。AM62 具有用于 SoC 的内部温度传感器。

- 当前温度可以以毫摄氏度为单位读取：

```
target:~$ cat /sys/class/thermal/thermal_zone0/temp
```

- 例如，你将得到：

```
49530
```

This translates to 49.53°C

There can be a number of trip points registered by the thermal kernel driver:

表 1: Type of trip points

Type	描述
pas-sive	Mitigate heat by scaling down performance without active cooling.
active	Implement more aggressive cooling methods to prevent the system from reaching critical temperatures.
hot	Signals a state where the system is getting warm but hasn't reached critical levels yet.
criti-cal	Protect the hardware from potential damage due to extreme temperatures by forcing shutdown.

Number of trip points, their type and values differ depending on the CPU variant and CPU grade. For example:

```
target:~$ cat /sys/class/thermal/thermal_zone0/trip_point*
2000
125000
critical
```


This is a critical trip point which will cause the system to shutdown when the temperature reaches 125°C. The kernel thermal management uses these trip points to trigger events and change the cooling behavior. The following thermal policies (also named thermal governors) are available in the kernel:

表 2: Type of thermal governors

Governor	描述
step_wise	Default on most SoCs. Increases/decreases cooling device state step by step as temperature crosses trip points.
bang_bang	Simple on/off control: turns cooling device fully on above threshold, fully off below.
user_space	Userspace daemon controls cooling states via sysfs. Kernel only reports temperatures.
fair_share	Distributes cooling demand proportionally among available cooling devices.
power_allocat	More advanced: allocates cooling power budget dynamically (uses power models).

7.19 看门狗

PHYTEC AM62L 模块包含一个硬件看门狗，当系统挂起时能够重置开发板。看门狗在 U-Boot 中默认启动，超时时间为 60 秒。因此，即使在早期内核启动过程中，看门狗也已经开始运行。Linux 内核驱动程序控制看门狗，并确保它有被踢到。本节将解释如何使用 systemd 在 Linux 中配置看门狗，以避免系统挂起和重启期间的情况。

7.19.1 Systemd 中的看门狗支持

Systemd 从版本 183 开始支持硬件看门狗。

- 要启用看门狗支持，需要通过启用选项来配置 `/etc/systemd/` 中的文件 `system.conf` 文件：

```
RuntimeWatchdogSec=60s
ShutdownWatchdogSec=10min
```

`RuntimeWatchdogSec` 定义了看门狗的超时时间，而 `ShutdownWatchdogSec` 定义了系统重启时的超时时间。有关 systemd 下硬件看门狗的更多详细信息，请访问 <http://0pointer.de/blog/projects/watchdog.html>。更改将在重启后生效，或者运行：

```
target:~$ systemctl daemon-reload
```