

Zynq UltraScale+ MPSoC Quick Emulator User Guide

QEMU

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Revision History

The following table shows the revision history for this document.

Date	Version	Revision
10/19/2016	2016.3	Added Chapter 5, Co-Simulating With QEMU .
05/25/2016	2016.1	Changed version to match software release.
05/05/2016	2.0	Replaced Table 2-1. <ul style="list-style-type: none"> • Updated support on AXI Interconnect features. • Updated ARMv8 EL2 support. • Updated ARMv8 Crypto instructions to “supported”. Updated PetaLinux link. Added a new procedure, Building QEMU from Source in Chapter 3. Removed RedHat command from Building QEMU from Source. Added EEPROM in Chapter 3. Added Using TightVNC and RealVNC in Chapter 3. Added Networking Options in Chapter 3. Adding New Devices to the Design in Chapter 5.
11/18/2015	1.0	Initial public release.

Table of Contents

Chapter 1: Using QEMU for Zynq UltraScale+ MPSoC

What is QEMU?	5
Documentation and Support Scope	5

Chapter 2: Getting Started with QEMU

QEMU for Zynq MPSoC Model Roadmap	6
Installing PetaLinux	9

Chapter 3: QEMU Quick Reference Card

Quick Reference	10
QEMU Command Line Reference Manual	11

Chapter 4: Using XSDB with QEMU

Introduction	34
Connecting QEMU	34
Limitations	36

Chapter 5: Co-Simulating With QEMU

Remote-Port	37
libsystemctlm-soc	37
Co-Simulating with QEMU	38

Chapter 6: Creating Boot Images on QEMU

Introduction	40
Using an SD for Boot (SD Boot Tutorial)	41
Using QSPI for Boot	42
Using NAND for Boot	43
Using TFTP for Boot	44
SD-Card Partitioning and Loading an Ubuntu-core File System	44
Adding New Devices to the Design	46

Appendix A: Additional Resources and Legal Notices

Xilinx Resources	47
Solution Centers	47
Documentation Navigator and Design Hubs	47
References	48
Please Read: Important Legal Notices	49

Using QEMU for Zynq UltraScale+ MPSoC

What is QEMU?

Xilinx provides a Quick EMUlator (QEMU) for software developers targeting the Zynq® UltraScale+™ MPSoC development platform. This system-emulation-model runs on an Intel-compatible Linux host system. To use this system emulation model you must be familiar with:

- Zynq UltraScale+ MPSoC device architecture
- GDB for remote debugging QEMU
- Generation of guest software application using Xilinx® PetaLinux and SDK tools
- Device trees

This document provides the basic information to familiarize, use, and debug software with QEMU.

Documentation and Support Scope

Within each package, Xilinx documents only those devices for which bare-metal drivers exist and have been tested.

Users might find additional device models by diving into the QEMU model itself (for example, using the `info mtree` command on the QEMU Console).

Getting Started with QEMU

QEMU for Zynq MPSoC Model Roadmap

The following table summarizes the status of elements of the QEMU model according to the delivery.

Table 2-1: QEMU Roadmap

Description	QEMU Status
Application Processing Units	
ARM interrupt controller (GIC v2)	Yes
ARMv8 (A53) implementation. Quad Core.	Little Endian only
ARM v8 EL0 support	AArch64 and AArch32
ARM v8 EL1 support	AArch64 and AArch32
ARM v8 EL2 support	AArch64
ARM v8 EL3 support	AArch64
ARMv8 Crypto instruction support	Supported
Vector Floating Point (VFP) support	As maintained by mainline. No formal acceptance criteria to feature.
SIMD support	As maintained by mainline. No formal acceptance criteria to feature.
Realtime Processing Units	
Dual core Cortex-R5	Incomplete coverage of system register set, little endian only
Dual core R5 CPU run-time configuration	Static dual core, no parallel/lock transitioning. No lock step fault capability
Fault Handling	No ECC or fault injection capabilities
Tightly coupled Memories	No R5 local view. Only globally accessible TCM memory region is accessible. Flat memory only, no control register implementation.
Interrupt controller	Yes
SLCRs	Very limited functionality. Only dummy registers, except SD <code>is MMC</code> control.

Description (Cont'd)	QEMU Status (Cont'd)
PMU	
IPI	Limited Connectivity specific to PMU functionality
Global Registers	Yes
PMU Microblaze	Yes
PMU Interrupt Controller	Yes
I/O Peripherals and Devices	
I/O Peripherals	Not all peripherals are implemented. Some standard peripherals are slight variations on the actual cores configuration-wise.
Cadence Gigabit Ethernet Controller	1588 not supported
SD Host Controller Interface (v3.0)	Yes
SD Card model	no SDXC
ONFi compliant NAND flash device modelpwd	Partial model of ANFC command set. Limited selection of parts. Limited ONFi 3.0 features.
QSPI controller (excludes Linear and Generic)	Yes
QSPI linear region	No XIP. Slow emulation performance
QSPI NOR flash devices	Incomplete but reasonable selection of parts including many modern QSPI capable devices.
UART Controller	Yes
SPI controller	Master mode only
I2C controller	Master mode only
DDR	Simple flat RAM model, no ECC
CAN	No
XADC	No
GPIO	Limited functionality: connects to remote port.
MDIO and Ethernet PHY	Dummy models, show link up on requested PHY using MDIO
USB	No
SATA	Yes
PCI	No
Display Ports	
DP model	AUX Communication. DPCP: DisplayPort Configuration Information. EDID.
DPDMA	Yes

Description (Cont'd)	QEMU Status (Cont'd)
2 Layers	Yes
Alpha Blending	Yes
Audio	With some unexpected behavior
Dynamic resolution changes	Yes
Multiple Pixel formats	Not all
Mali GPU	No
AMBA AXI Bus	
AMBA/AXI bus interconnect system	Simple bus model, no AXI/AMBA-specific features (such as MIDs). Master IDs and Trustzone (secure versus non-secure) transactions supported.
Bus quality of service monitoring and control	N/A
On Chip Memory	Yes
AXI Performance Monitor (APM) ATM AXI Trace Monitor (ATM)	N/A
Additional Zynq UltraScale+ MP SoC Capabilities	
XMPU	Does not return Slave error; CPU does not recognize asynchronous aborts on failed accesses.
XPPU	Does not return Slave error; CPU does not recognize asynchronous aborts on failed accesses.
SMMU	Only supports 64-bit page tables
Clock/reset controllers for low-power and high power domains.	Limited feature set specific to CPU functionality
Interprocessor Interrupt controller	Yes
PL-based AMS block	N/A
Miscellaneous QEMU Non-IP Related Feature	
Ability to boot multiple software in different CPUs.	Yes
Create QEMU Machine models from Linux device tree binaries (DTBs).	Limited to QEMU maintained DTBs only. IPI/HSI generated DTBs unsupported.
FPDDMA	No FCI and no rate-control
LPDDMA	No FCI and no rate-control
Timers and Clock Generators	
Triple Timer Counter	Yes
SWDT, WDT	No
Si570/71	I2C device. Dummy emulation of clock generator.

Installing PetaLinux

QEMU comes with the Xilinx® PetaLinux Tools Installer for the Zynq® UltraScale+™ MPSoC platform. See the PetaLinux documentation [Ref 7] for installation instructions.



TIP: Use `which qemu-system-aarch64` to know where QEMU binary is installed after PetaLinux paths are set.

Launch QEMU Using PetaLinux Commands

QEMU is integrated with the PetaLinux workflow.

To use QEMU with a PetaLinux project, create and build a PetaLinux project for the Zynq UltraScale+ MPSoC platform and use the PetaLinux boot flow to boot Linux on QEMU, as follows:

```
petalinux-create -t project -s <${DOWNLOAD_DIR}/zynqmp-<version>-final.bsp
```

QEMU Quick Reference Card

Quick Reference

This is a basic template for Zynq® UltraScale+™ MPSoC device QEMU command lines:

```
qemu-system-aarch64 -M arm-generic-fdt -nographic -dtb <hw-dtb> \
  -device loader,file=<progam.elf>,cpu=<cpu-id> \
  -device loader,addr=<cpu-reset-register-addr>,data=<value>,data-len=4 \
  [-boot mode=<boot-mode-id>] \
  [-drive file=<image-path>, if=<( sd | mtd | pflash )>, format=raw,\
  index=<index_num> ]
```

The following table lists the options and descriptions for QEMU commands.

Table 3-1: QEMU Commands and Descriptions

Option	Description
-device loader, file=<progam.elf>, cpu=<cpu-id>	Specify the software to run (in ELF format).
-device loader, addr=<cpu-reset-register-addr>, data=<value>, data-len=4	Release CPU from reset.
-boot mode=<boot-mode-id>	Specify the boot mode pins.
-drive file=<image-path>, if=<[sd mtd pflash]>, format=raw, index=<index_num>	Specify files for persistent storage media (SD, QSPI or NAND respectively). <index_num> specifies the respective controller for each media type.
-M arm-generic-fdt -nographic -dtb <hw-dtb>	Standard options. <hw-dtb> is the QEMU machine description.

Standalone Hello World Example

This example runs a “Hello-world” ELF file on an A53 processor. Substitute the `hello_world.elf` with the location your target software, as follows:

```
qemu-system-aarch64 -nographic -M arm-generic-fdt \
  -dtb qemu-arm.dtb \
  -device loader,file=./hello_world.elf,cpu=0 \
  -device loader,addr=0xf01a0104,data=0x8000000e,data-len=4
```

QEMU Command Line Reference Manual

This section provides details of QEMU command line options. The following sections detail boot, network, serial, storage, and miscellaneous command line options.

Using Extra QEMU Command Line Arguments with PetaLinux

The `petalinux-boot --qemu` command has an argument `--qemu-args` that lets you specify extra QEMU command line arguments.

Some of the optional arguments specified in the section can be passed to the PetaLinux QEMU using this switch.



IMPORTANT: *Do not specify the standard, boot, or network options to `petalinux-boot`; those options are handled transparently by the application.*

QEMU Boot Options

```
[ -device loader, (file=<file_name>|data=<value>,data-len=4), \
[addr=<value>], [cpu=<value>], [force-raw=true] ] ...
```

This (repeatable) argument configures the QEMU machine for boot. The boot options perform the following tasks:

- Loads software or data into RAM sections
- Sets the CPU entry points
- Releases CPUs from reset

By default, the six ARM CPUs (four cores of Cortex-A53 and two cores of Cortex-R5) are in reset by their respective reset controllers when no software is loaded. You can use a combination of `-device loader` arguments to load software and setup the CPUs.

There are two basic modes for the loader argument: *file mode* and *single transaction mode*. Specify one mode only. The following subsections describe these modes.

File Mode

In file mode, the loader accepts a file as data to load. The file can be in any format and is passed using the `file=<file_name>` sub-option.

If the file is an ELF or a U-Boot image, the file is parsed and the sections loaded into memory as specified by the image; otherwise, the file is assumed as a raw image and loaded accordingly as an image into memory.

Specify the address for loading raw images with the `addr=<value>` argument. The address default is 0. The address is ignored if the file is an ELF or U-Boot image.

Optionally, you can specify a CPU using the `cpu=<value>` sub-option.

If specified, the CPU has a set entry point.

- For ELFs and U-Boot images, the address is set as specified by the image.
- For raw images, the entry point is set to the start address.
- If you do not specify a CPU, the bus for CPU0 loads images, but no program entry point is set. See [CPU Enumeration, page 13](#) for more details on the meaning of `<value>`.

There are cases where you might want to treat an ELF or a U-Boot image as a raw data image (particularly useful for testing bootloaders with ELF or U-Boot capability).

You can pass the `force-raw=true` sub-option to instruct the loader to treat the image as raw in this case.

You must specify the `addr`; in this case and the section information in the ELF or U-Boot image are ignored.

Single Transaction Mode

In single transaction mode, a single bus transaction occurs.

- `data addr` and `data-len` must be specified.
 - `data-len` must equal 4 (corresponding to a single 4-bit transaction).
 - `addr` must be aligned to 4-bits.

Before the initial system reset, the QEMU performs the specified bus transaction. The initial system reset might clear the value set by the single transaction when the transaction accesses the I/O peripherals. As a work-around, key registers interpret bit 31 (usually reserved) as an indicator to not reset that particular register when resetting this system. This is useful for releasing CPU resets from the command line.

The registers that support bit-31 `reset-ignore` are:

- `CRF.RST_FPD_APU`
- `CRL.RST_LPD_TOP`
- `PMU_LOCAL.LOCAL_RESET`
- `RPU.RPU_GLBL_CNTL`

Optionally, you can specify a CPU using the `cpu=<value>` sub-option.

The single transaction occurs from the perspective of the specified CPU. If you do not specify a CPU, then the system assumes CPU0.

See the *Zynq UltraScale+ MPSoC Registers Users Guide* (UG1087) [Ref 6] for more information about registers.

CPU Enumeration

The `cpu=<value>` argument interprets value are shown in the following table:

Table 3-2: CPU Enumeration Values

Value	CPU
0	A53-0
1	A53-1
2	A53-2
3	A53-3
4	R5-0
5	R5-1

ADVANCED: If you edit the `/cpus dtb` node, these enumerations change. The enumerations of the CPUs matches the DTS `/cpus` node ordering.

Hot Loading

You can use the loader at runtime to load new software into an already running system. This is accessible from the QEMU monitor. See the [Non-Graphical I/O Option, page 17](#) for information on accessing the monitor.

From the monitor, you can stop the emulation using the `stop` command:

```
(qemu) stop
```

You can then use the loader to add new software or release CPUs from reset. The syntax is:

```
(qemu) device_add loader, (file=<file>|data=<value>,data len=4), \
[addr=<value>], [cpu=<value>], [force-raw=true]
```

All sub-options are the same as described in the previous section. The emulation can then be resumed (with the new memory and CPU state from the loading operations) using the following `c` command:

```
(qemu) c
```

Multiple-Architecture QEMU

A multiple architecture (Multi-Arch) QEMU is special concept in which more than one instance of QEMU of completely a different architecture can communicate and can run together using socket communication.

- This version of QEMU supports running the ARM® (Cortex-A53s and Cortex-R5s) and the Microblaze™ device power management unit (PMU).
- The multi-architecture version of QEMU needs different device tree binaries (DTB)s, than what is necessary for single-architecture (Single-Architecture).

Multi-Architecture DTB

- `zynqmp-qemu-multiarch-arm.dtb`: DTB for the `qemu-system-aarch64`
- `zynqmp-qemu-multiarch-pmu.dtb`: DTB for `qemu-system-microblazeel`

Single-Arch DTB

- `zynqmp-qemu-arm.dtb`: DTB for `qemu-system-aarch64`
 - `-machine-path` `[/qemu-tmp]`
 - `-machine-path` takes any folder path as argument, and QEMU uses that area for creating sockets and parallel communication. This is a mandatory argument for using Multiple-Architecture.

See the *Zynq UltraScale+ MPSoC Software Developer User Guide* (UG1137) [Ref 1] for steps on running QEMU with ARM and PMU.

QEMU Command Examples

The following table provides command examples.

Table 3-3: Command Examples and Descriptions

Description	Command
Load an ELF onto Cortex-A53-0.	<code>-device loader, file=./hello_world.elf,cpu=0</code>
Release Cortex-A53-0 from reset.	<code>-device loader,addr=0xfd1a0104, data=0x8000000e,data-len=4</code>
Load a binary DTB into RAM at a specific address (no CPU entry point will be set).	<code>-device loader,file=./Image, addr=0x0008000</code>

Table 3-3: Command Examples and Descriptions (Cont'd)

Description	Command
Load an ELF to RAM (no CPU entry point will be set).	<code>-device loader, file=./foo.elf</code>
Load an ELF to Cortex-A53-0 from the monitor in an already running system.	<pre>(qemu) stop (qemu) device_add loader, file=./foo.elf, cpu=0 (qemu) device_add loader, addr=0xfd1a0104, data=0x8000000e, data-len=4 (qemu) c</pre>

Using Single Transactions to Unlock CPUs

You can unlock CPUs by writing into system configuration registers using single transactions. The A53-0,1,2,3 reset register is `CRF_APB.RST_FPD_APU`.

The following table lists the arguments that can unlock certain CPU combinations.

Table 3-4: Single Transaction Unlock Arguments

Argument	Command
A53-0	<code>-device loader addr=0xfd1a0104, data=0x8000000e, data-len=4</code>
A53-1	<code>-device loader addr=0xfd1a0104, data=0x8000000d, data-len=4</code>
A53-2	<code>-device loader addr=0xfd1a0104, data=0x8000000b, data-len=4</code>
A53-3	<code>-device loader addr=0xfd1a0104, data=0x80000007, data-len=4</code>
All A53	<code>-device loader addr=0xfd1a0104, data=0x80000000, data-len=4</code>

Similarly the R5-0, 1 reset register is `CRL_APB.RST_LPD_TOP`. As R5-0 and R5-1 can work in split-mode or lockstep mode, split-mode/lock-step requires extra configuration for R5, which is done using register `RPU.RPU_GLBL_CNTL`.

Table 3-5: Cortex-R5 Registers and Commands

Register	Command
R5-0 (split mode)	<pre>-device loader, addr=0xff5e023c, data=0x80008fde, data-len=4 -device loader, addr=0xff9a0000, data=0x80000218, data-len=4</pre>
R5-1 (split mode)	<pre>-device loader, addr=0xff5e023c, data=0x80008fdd, data-len=4 -device loader, addr=0xff9a0000, data=0x80000218, data-len=4</pre>
Both R5 (split mode)	<pre>-device loader, addr=0xff5e023c, data=0x80008fdc, data-len=4 -device loader, addr=0xff9a0000, data=0x80000218, data-len=4</pre>
Lockstep Mode	<code>-device loader, addr=0xff5e023c, data=0x80008fde, data-len=4</code>

See the *Zynq UltraScale+ MPSoC Registers Users Guide* (UG1087) [Ref 6] for more information.

Hardware Specification

```
-M arm-generic-fdt ( -hw-dtb | -dtb ) <file> ...
```

These arguments are required for all supported boot flows.

The `-M` argument to QEMU specifies the QEMU machine to create. In this case, you are selecting the `arm-generic-fdt` machine option, which tells QEMU to parse a device tree binary (or DTB) for machine generation.

QEMU automatically creates CPUs and peripherals for each node in the device tree it has a corresponding device model for (QEMU has a library of known DTS compatible strings).

The `-dtb` or `-hw-dtb` argument specifies the DTB describing the system.

The corresponding DTB is available in a PetaLinux project (either fully built or the Lightweight for-standalone build) at:

```
<proj_path>/images/linux/zynqmp-qemu-arm.dtb
```

Or:

```
<proj_path>/pre-built/linux/images/zynqmp-qemu-arm.dtb
```

ADVANCED: DTSs for QEMU are available in the following directory:

```
<project_directory>/subsystems/linux/configs/device-tree.
```

Example

```
qemu-system-aarch64 -nographic -M arm-generic-fdt \
-dtb ./images/linux/zynqmp-qemu-arm.dtb
```

-dtb vs -hw-dtb

For Linux Kernel boots, QEMU supports a flow where different DTBs are used for machine generation and Linux Kernel boot. In this flow, both `-dtb` and `-hw-dtb` are specified on the command line.

The `-hw-dtb` is used for machine generation and `-dtb` is passed to the Linux Kernel (using a memory buffer). For standalone, flows these two arguments are fully interchangeable; specify only one or the other.



CAUTION! *In a PetaLinux flow the QEMU DTB is different from the kernel system.dtb.*

QEMU DTS are different for single and multi-architecture models.

- Single-arch : `zynqmp-qemu-arm.dtb`
- Multi-arch : `zynqmp-qemu-multiarch-arm.dtb`,
`zynqmp-qemu-multiarch-pmu.dtb`

Non-Graphical I/O Option

`-nographic`

By default, QEMU attempts to create a display for user I/O. This option instructs the QEMU that there is no need for a display and I/O is serial.

QEMU attaches the invoking terminal to the serial port in this case (in the default use cases, this is `UART0`). See [Serial Options, page 24](#) for more information and choices.

In this mode, the QEMU monitor (a command line interface for sending control commands to QEMU) is multiplexed on `stdio`. To switch between the serial port and the monitor, use the following command:

`CTRL-a c`

Boot Mode

`-boot mode=<value>`

This command line argument select the value of boot mode pins. The following table lists the supported boot modes.

Table 3-6: Boot Mode IDs and Descriptions

Boot Mode ID	Boot Mode
0	JTAG (QEMU does not support JTAG debugging, but you can use JTAG boot mode to test FSBL without it performing boot handoff.)
1	QSPI24
2	QSPI32
3	SD0/EMMC0
4	NAND
5	SD1/EMMC1
6	EMMC0

Storage Media

Several disk and storage media interfaces are modeled. You can pass each to a regular file(s) to use for stored data. QEMU updates the files so the data can be persistent across multiple sessions.

Argument Format

The format is:

```
-drive file=<image-path>, if=(mtd|sd|pflash), format=raw, index=<value>[, readonly]
```

The argument allows specification of extra options such as marking the file as read-only.

The argument can also be used to specify the index of the device, allowing specifying files for devices in an order-independent way. The following table lists the supported storage media.

Table 3-7: Supported Storage Media

	Description	Format	Size
QSPI LCS	Dual Parallel QSPI lower-chip-select or Single mode QSPI.	if=mtd,index=0	64MB
QSPI UCS	Dual Parallel QSPI upper-chip-select or Single mode QSPI.	if=mtd,index=1	64MB
SPI0 CS0	4x SPI flashes attached to SPI controller 0	if=mtd,index=2	1MB
SPI0 CS1		if=mtd,index=3	1MB
SPI0 CS2		if=mtd,index=4	1MB
SPI0 CS3		if=mtd,index=5	1MB
SPI1 CS0	4x SPI flashes attached to SPI controller 1	if=mtd,index=6	1MB
SPI1 CS1		if=mtd,index=7	1MB
SPI1 CS2		if=mtd,index=8	1MB
SPI1 CS3		if=mtd,index=9	1MB
SD0	SD card attached to SD controller 0	if=sd,index=0	512MB
SD1	SD card attached to SD controller 1	if=sd,index=1	512MB
EMMC0	EMMC attached to SDHC0	if=sd,index=2	512MB
EMMC1	EMMC attached to SDHC1	if=sd,index=3	512MB
NAND	NAND flash attached to NAND controller CS=0	if=pflash,index=0	4.7GB
NAND	NAND flash attached to NAND controller CS=1	if=pflash,index=1	4.7 GB

QSPI

QSPI is modeled with 2x Micron n25q512a11 parts (64MB each) parts. The SPI flashes connect in a dual-parallel arrangement. The file size for each should match exactly 64MB.

If you are using only a single mode QSPI, then only one QSPI argument is needed.

For each, if an image is not provided QEMU still models the flash, but initializes with `NULL` data and discards the data after QEMU exists. Data can be written and read back within a single session in this case.

Flash Striper Utility

In parallel mode, that the QSPI data passes in for each flash is unique to that flash chip. Because the QSPI controller implements bit-striping in dual parallel mode, a special utility is needed to take a single QSPI data image and format into the two images. The syntax is as follows:

```
flash_strip_bw <input> <out1> <out0>
```

where:

- `<input>` is a 128MB image.
- `<out0>` and `<out1>` are the two 64MB images passable to the `-mtdblock` arguments for QSPI.



IMPORTANT: `flash-strip-bw` is done the reverse order to QEMU.

The reverse is also possible, taking the two striped images and converting them back to a single 64MB image as shown in the following command:

```
flash_unstrip_bw <output> <in1> <in0>
```

Building the Flash Striper

Compile for your host with the following commands:

```
SOURCE=flash_stripe.c
gcc $SOURCE -o flash_strip_bw -DFLASH_STRIP_BW
gcc $SOURCE -o flash_unstrip_bw -DUNSTRIP -DFLASH_STRIP_BW
```

The Flash Strip utility is available as a part of the `qemu_utilities`.

The following table lists the supported SPI Flash models.

Table 3-8: Supported QSPI Flash Models

Vendor	Flash Models
Atmel	at25fs010, 25fs040, at25df041a, at25df321a, at25df641, at26f004, at26df081a, at26df161a, at26df321, at45db081d
EON -- en25xxx	en25f32, en25p32, en25q32b, en25p64, en25q64
GigaDevice	gd25q32, gd25q64
Intel/Numonyx -- xxxs33b	160s33b, 320s33b, 640s33b n25q064
Macronix	mx25l2005a, mx25l4005a, mx25l8005, mx25l1606e, mx25l3205d, mx25l6405d, mx25l12805d, mx25l12855e, mx25l25635e, mx25l25655e
Micron	n25q032a11, n25q032a13, n25q064a11, n25q064a13, n25q128a11, n25q128a13, n25q256a11, n25q256a13, n25q512a11, n25q512a1
Spansion -- single (large) sector size only, at least for the chips listed here (without boot sectors)	s25sl032p, s25sl064p, s25fl256s0, s25fl256s1, s25fl512s, s70fl01gs, s25sl12800, s25sl12801, s25fl129p0, s25fl129p1, s25sl004a, s25sl008a, s25sl016as, s25sl032a, s25sl064a, s25fl016k, s25fl064k
Winbond -- w25x "blocks" are 64k, "sectors" are 4KiB	w25x10, w25x20, w25x40, w25x80, w25x16, w25x32, w25q32, w25q32dw, w25q64, w25q80, w25q80b, w25q256
Numonyx	25q128
SST	sst25vf040b, sst25vf080b, sst25vf016b, sst25vf032b, sst25wf512, sst25wf010, sst25wf020, sst25wf040, sst25wf080
ST Microelectronics	m25p05, m25p10, m25p20, m25p40, m25p80, m25p16, m25p32, m25p64, m25p128, n25q032, m45pe10, m45pe80, m45pe16, m25pe20, m25pe80, m25pe16, m25px32, m25px32-s0, m25px32-s1, m25px64

SPI

The SPI controllers each have 4x SST25WF080 1MB SPI flashes connected. The image size should match exactly 1MB.

For each SPI Flash, if an image is not provided QEMU still models the flash, but initializes with NULL data and discards the data after QEMU exits. Data can be written and read back within a single session in this case.

NAND

QEMU emulates a single MT29F32G08ABCDBJ4 NAND flash part attached to the NAND controller.

If an image is not provided, QEMU models the flash, but initializes with `NULL` data and discards the data after QEMU exists. Data can be written and read back within a single session in this case.

QEMU requires that NAND storage images be in a special format (to account for out-of-band (OOB) data). A special utility is needed to take an image and format it for QEMU NAND. The input data is laid-out as the in-band data and OOB data is set to all-ones, interspersed with the in-band data as expected by QEMU.

```
qemu-nand-creator 16384 1216 256 1048 672 < <input>
```

The output file is approximately 4.7GB in this case. 16384 (16k) specifies the page size of the NAND part. This is a sparse file which occupies 1.5G on disk.

Building the Nand Creator

```
gcc qemu-nand-creator.c -o qemu-nand-creator
```

See QEMU utilities for `qemu-nand-creator.c`.

SD

QEMU models an SD card for `-drive file=<file_path>, if=sd` with `index 2,3`.

The SD card model in QEMU is generic and does not attempt to model a specific physical part. The size of the input file initializes the size of the emulated SD card. Only 512MB SD images are officially supported, although powers of two around that order of magnitude will work.



IMPORTANT: *SDXC (>32GB) sizes do not work.*

If an SD argument is not specified, no SD card is modeled, the corresponding SD slot is ejected.

Note: This is different from the SPI and NAND, where if there is no argument those modes still model a physical device.

EMMC

QEMU will model an EMMC card for `-drive file=<file_path>,if=sd` with index 2, 3. EMMC connects to respective host interface controllers, based on the `slcr` settings.

The size of the input file initializes the size of the emulated MMC card. Only 512MB images are supported, although powers of two, around that order of magnitude, will work.

EEPROM

QEMU models EEPROMS connected to I2C. A backend file can be passed as follows:

```
-drive file=<file_path>,if=mtdev with index 10, 11, 12, 13.
```

Users can find the information on which I2C controller eeproms are connected in respective board DTS.

Passing Bootable Images

Boot images are passed to the QEMU using the command line with the storage media options. This is useful for testing, or testing with, FSBL or U-Boot bootloaders. See the Bootgen documentation in the *Zynq UltraScale+ MP SoC Software Developers Guide* [Ref 1] for how to create the bootable images.

See the [Example, page 16](#) command for a comprehensive suite of examples for bootable image commands.

Chardev Options

```
-chardev backend, id=id [,options]
```

The `-chardev` arguments lets you create a character device. This can be thought of as a file descriptor that routes text from inside QEMU to outside QEMU. The `-chardev` arguments consists of three main parts:

1. The output
2. If the `chardev` is muxable
3. The ID of this `chardev`

Character Device Option Examples

```

-chardev null,id=id[,mux=<on|off>]
-chardev socket,id=id[,host=host],port=port,[to=to],[ipv4],[ipv6]\
,[nodelay],[reconnect=seconds],[server],[nowait][,telnet]\
,[reconnect=seconds] [mux=<on|off>] (tcp)

-chardev socket,id=id,path=path[,server][,nowait][,telnet]\
,[reconnect=seconds],[mux=<on|off>] (unix)

-chardev udp,id=id[,host=host],port=port[,localaddr=localaddr]\
,[localport=localport],[ipv4],[ipv6],[mux=on|off]

-chardev msmouse,id=id, [mux=on|off]

-chardev vc,id=id[[,width=width][,height=height]][[,cols=cols]\
,[rows=rows]] ,mux=on|off]

-chardev ringbuf,id=id,[size=size]

-chardev file,id=id,path=path,[mux=on|off]

-chardev pipe,id=id,path=path[,mux=on|off]

-chardev pty,id=id[,mux=on|off]

-chardev stdio,id=id[,mux=on|off][,signal=on|off]

-chardev serial,id=id,path=path[,mux=on|off]

-chardev tty,id=id,path=path[,mux=on|off]

-chardev parallel,id=id,path=path[,mux=on|off]

-chardev parport,id=id,path=path[,mux=on|off]
    
```

STDIO

The following is an example chardev:

```
-chardev stdio,mux=on,id=terminal
```

In this case anything sent to the chardev is redirected to the standard I/O. This chardev supports muxing and is called `terminal`.

Server (TCP Socket)

The following is an example of using chardev to connect to a server:

```
-chardev socket,id=terminal,host=localhost,port=4444,mux=on
```

The server can be `nc`, in this case use:

```
nc -k -l localhost 4444
```

Socket (UNIX Socket)

The following is an example of connecting to a standard UNIX socket:

```
-chardev socket,id=output,path=/tmp/socket,mux=on
```

The socket can be created by nc by using:

```
nc -k -lU /tmp/socket
```

pty

The following is an example of connecting to a pseudo-terminal:

```
chardev pty,id=output,mux=on
```

There is no wait on this chardev to get connected to pty. You can open pty c with any serial terminal: Minicoy, putty, screen.

```
screen /dev/pty/188
```

QEMU puts out on which pty it is connected .

```
"char device redirected to /dev/pts/188 (label IO-base)"
```

Serial Options

```
-serial <arg>
```

By default, the QEMU connects the invoking terminal to UART0 to provide user I/O (see [Non-Graphical I/O Option, page 17](#) for more information.)

You can override this behavior by providing at least one explicit `-serial` argument.

You can specify up to two `-serial` arguments:

- The first one (for example, first positional argument) specifies the connection for UART0
- The second for UART1

The following table lists the supported values for <arg>:

Table 3-9: Serial Arguments and Effects

<arg>	Effects
/dev/null	Disconnect this particular serial.
mon:stdio	Connect this serial and monitor to the terminal.
stdio	Connect this serial to terminal.
telnet::<port>,server,nowait	Create a localhost telnet server on <port> for the serial connection. It can be accessed by: telnet localhost <port>.
chardev: dev	Connects serial to a backend; for example, to a socket, pipe, or terminal.

Serial Command Examples

The following are some of the common non-default serial setups.

- Disconnect all serials: `-serial /dev/null -serial /dev/null`
- Connect UART1 to the terminal and ignore UART0: `-serial /dev/null -serial mon:stdio`
- Connect UART0 to terminal and UART1 to telnet: `-serial mon:stdio -serial telnet::1234,server,nowait`
- Connect UART0 to chardev socket: `-serial chardev:terminal`

Note: `terminal` is the chardev device ID. See details the [Chardev Options, page 22](#).

Monitor Options

- `-monitor`: specifies where to send the QEMU monitor. Generally, this is sent to the standard I/O which can be done with the following command:

```
-monitor chardev:terminal
```

Networking Options

```
-net nic -net user -tftp <directory>
```

This connects GEM0 to a virtual network, with a TFTP server hosting the argument directory. The TFTP server IP is 10.0.2.2. The guest software can configure the machine to an IP on the same subnet (for example 10.0.2.4) and communicate. The following command connects all four GEMs in the zynqmp to a virtual network:

```
-nt nic -net nic -net nic -net user
```

See the QEMU public documentation for more comprehensive listing of QEMU networking options.

Port Redirection

Adding the following command makes every packet in/out of host-port to redirect to target-port of guest. For example, to get connected to guest using telnet, one can redirect the port 23 of guest to any free port of the host.

```
-redir tcp:<host-port>:<guest-ip>:<target-port>
```

Example:

```
-redir tcp:1440:10.0.2.15:23
```

Tap Mode (Requires Sudo)

Tap network is similar to bridge network; it allows the guest to communicate with host DHCP and DNS. This makes it also a real device on a network.

Unlike user mode, in tap mode, networking guest is directly accessible without any port redirection/forwarding. The following is an example:

```
-net nic -net nic -net nic -net nic -net tap,downscript=no
```

Before running QEMU ensure that you have the `qemu-ifup` script available in `/etc/`. Follow the instructions in this [link](#) to set up tap network.

Debug Options

- QEMU Arguments: Enabling and using the GDB stub:

```
-gdb tcp::<host_name>:<port> -S
```

Where:

- `-gdb`: Creates a GDB stub on the local host at the specified port.
- `-S`: Causes the emulation to start in the pause state. This allows you to attach a debugger before software starts executing. You can attach your GDB to QEMU as follows: `(gdb) target remote :<port>`

On the GDB host, use the GDB that corresponds to your build toolchain; for example:

- `aarch64-none-elf-gdb` or `aarch64-linux-gnu-gdb` for debugging A53 code.

Or:

- `arm-none-eabi-gdb` for R5 software.

QEMU emulation can be resumed using a `continue` in GDB, as shown in the following command:

```
(gdb) c
```

Breakpoints can be inserted as normal. Either symbolic function names, file lines, or text memory addresses can be used. See the *ARM Information Center* [Ref 14] for more information.

Debug-Related Monitor Commands

You can use a range of QEMU monitor commands to access helpful debug information and perform some basic operations. The following are a few of the more commonly used options. See [Non-Graphical I/O Option, page 17](#) for information on accessing the monitor.

- Stopping and resuming the VM:

```
(qemu) stop
```

```
(qemu) c
```

These commands stop and resume the emulation, respectively.

If QEMU is started with the `-s` argument, you can use the `c` command to commence emulation.

Display Options

The QEMU display option emulates a virtual monitor for the display applications.



IMPORTANT: *To make use of the Display option, do not pass the `-nographic` argument in the command line; it restricts the ability to create a display console.*



CAUTION! *PetaLinux QEMU does Not include SDL support for Display Monitor Emulation, It is recommended that you build QEMU from source with SDL enabled. See [Building QEMU from Source, page 33](#).*

The following command option, when passed on the QEMU command line, creates a VNC session through which you can view the display console:

```
-vnc <hostname>:<display>
```

For example, the command `-vnc localhost:1` connects to a VNC session using VNC viewer on `localhost:1`, where 1 represents the display ID. In this way you can have *n* number of display monitors open.

Using TightVNC and RealVNC

In both TightVNC and RealVNC you can open the monitor using following command:

```
vncviewer localhost:<display id>
```

To open monitor for a different server, enable port forwarding using the following command:

```
ssh <target-host> -L <localhost-port>:localhost:<target-host-port>
```

For example, if the QEMU display id is 1, it should map to TCP port 5901. Then, run the port forwarding command as follows:

```
ssh qemu-host -L 5901:localhost:5901
```

Now use the same vncviewer command to open the display.



IMPORTANT: *RealVNC does not directly work. Follow the workaround in the following [link](#).*

Listening on a VNC Session

You can connect to a display at any time using the `-vnc <hostname>:<display>` command; however, if you need the QEMU to wait until it is connected to a VNC session, configure the QEMU to work with a *listening* VNC session.

```
-vnc <hostname>:<tcp port number>,reverse
```

For example, `-vnc localhost:5501,reverse`, will be able to connect to a listening VNC session with `display-id 1`.

Note: The TCP port number for display ID 1 maps as $5500+d$, where d is the display ID.

Running the VNC viewer with `-listen 1` results in the host listening for connections on the VNC session with display 1.

Listing and Selecting CPUs in the System

From the QEMU Monitor Console, use the following commands:

```
(qemu) info cpus  
(qemu) cpu <value>
```

Where:

- The `info cpus` lists out the CPUs in the system and indicated the currently selected CPU. In a normal setup there are six CPUs: 4 x A53 and 2 x R5. QEMU has the concept of a currently selected CPU with respect to some monitor commands. This is very similar to GDBs concept of a currently selected thread.
- Change the selected CPU using the `cpu <value>` command; where `<value>` is a number from 0 to 5 that corresponds to the QEMU CPU indexes.
- CPUs with an asterisk (*) are currently selected.

See [CPU Enumeration, page 13](#) for information on how QEMU CPU indexes match the Zynq UltraScale+ MPSoC platform CPUs.

Inspecting CPU State

```
(qemu) info registers
```

The `info registers` command dumps out useful information about the current CPU (such as registers and current EL) For R5 CPUs. R15 is the program counter.

See the ARM Architecture reference manuals for the meaning of specific pieces of information.

Inspecting Physical Memory

```
(qemu) ( xp | x ) <addr>  
(qemu) memsave <addr> <length> <file>
```

Use these commands to dump memory data. The `x` or `xp` command can be used to read a single address:

- `xp`: (qemu) `xp 0x1234F00D`
 - `x` uses virtual addresses for the currently selected cpu
 - `xp` uses physical addresses
- The `memsave` command saves a buffer of specified length (`<length>`) and address (`<addr>`) to a file specified by `<file>`, where `<file>` is the data buffer as raw binary data.

For example: (qemu) `memsave 0xc0ae1a80 16384 dumpmem.logbuf`

Linux Kernel Logbuf Extraction

The following instructions are directly applicable to booting Linux Zynq® UltraScale+™ MPSoC QEMU. There is more information available at [Linux Kernel Logbuf Extraction \[Ref 18\]](#).

Examples for Single Arch

This section provides some example complete fully elaborated QEMU command lines. Substitute particular arguments to suite your application as needed. See the *Command Line Argument Manual* for further details of each options. For each command, it is assumed the current working directory is a PetaLinux project root.

You can run the commands without a PetaLinux project but file paths of boot components will need to be adjusted.

See [Storage Media, page 18](#) as required for details on how to generate storage media files for QSPI, NAND, and SD.

FSBL as an Application on A53-0

In each of the following examples, FSBL is run as the application; however, these command line formats are applicable to other standalone software. Substituting the FSBL ELF file for another standalone application is valid.

A53-0 FSBL in JTAG Mode

```
qemu-system-aarch64 -M arm-generic-fdt -nographic \  
-dtb ./images/linux/zynqmp-qemu-arm.dtb \  
-device loader,file=./images/linux/zynqmp_a53_fsbl.elf,cpu=0 \  
-device loader,addr=0xfd1a0104,data=0x8000000e,data-len=4
```

A53-0 FSBL in QSPI Boot Mode (Single)

```
qemu-system-aarch64 -M arm-generic-fdt -nographic \  
-dtb ./images/linux/zynqmp-qemu-arm.dtb \  
-device loader,file=./images/linux/zynqmp_a53_fsbl.elf,cpu=0 \  
-device loader,addr=0xfd1a0104,data=0x8000000e,data-len=4 \  
-drive file=qemu_qspi.bin,if=mtd,format=raw,index=0\  
-boot mode=1
```

A53-0 FSBL in QSPI Boot Mode (Dual Parallel)

```
qemu-system-aarch64 -M arm-generic-fdt -nographic \  
-dtb ./images/linux/zynqmp-qemu-arm.dtb \  
-device loader,file=./images/linux/zynqmp_a53_fsbl.elf,cpu=0 \  
-device loader,addr=0xfd1a0104,data=0x8000000e,data-len=4 \  
-drive file=qemu_qspi_high.bin,if=mtd,format=raw,index=0\  
-drive file=qemu_qspi_low.bin,if=mtd,format=raw,index=1\  
-boot mode=1
```

A53-0 FSBL in SD Boot Mode

```
qemu-system-aarch64 -M arm-generic-fdt -nographic \
-dtb ./images/linux/zynqmp-qemu-arm.dtb \
-device loader,file=./images/linux/zynqmp_a53_fsbl.elf,cpu=0 \
-device loader,addr=0xfd1a0104,data=0x8000000e,data-len=4 \
-drive file=qemu_sd.img,if=sd,format=raw,index=0\
-boot mode=3
```

A53-0 FSBL in NAND Boot Mode

```
qemu-system-aarch64 -M arm-generic-fdt -nographic \
-dtb ./images/linux/zynqmp-qemu-arm.dtb \
-device loader,file=./images/linux/zynqmp_a53_fsbl.elf,cpu=0 \
-device loader,addr=0xfd1a0104,data=0x8000000e,data-len=4 \
-drive file=qemu_nand.bin,if=pflash,format=raw,index=0\
-boot mode=4
```

FSBL as an Application on R5-0

In each of the following examples, FSBL is run as the application. These command line format are however applicable to other standalone software. Substituting the FSBL ELF file for another standalone application is valid.

R5-0 FSBL in JTAG Mode

```
qemu-system-aarch64 -M arm-generic-fdt -nographic \
-dtb ./images/linux/zynqmp-qemu-arm.dtb \
-device loader,file=zynqmp_r5_fsbl.elf,cpu=4 \
-device loader,addr=0xff5e023c,data=0x80008fde,data-len=4 \
-device loader,addr=0xff9a0000,data=0x80000218,data-len=4
```

R5-0 FSBL in QSPI Boot Mode (Single)

```
qemu-system-aarch64 -M arm-generic-fdt -nographic \
-dtb ./images/linux/zynqmp-qemu-arm.dtb \
-device loader,file=zynqmp_r5_fsbl.elf,cpu=4 \
-device loader,addr=0xff5e023c,data=0x80008fde,data-len=4 \
-device loader,addr=0xff9a0000,data=0x80000218,data-len=4 \
-drive file=qemu_qspi.bin,if=mtd,format=raw,index=0\
-boot mode=1
```

R5-0 FSBL in QSPI Boot Mode (Dual Parallel)

```
qemu-system-aarch64 -M arm-generic-fdt -nographic \
-dtb ./images/linux/zynqmp-qemu-arm.dtb \
-device loader,file=zynqmp_r5_fsbl.elf,cpu=4 \
-device loader,addr=0xff5e023c,data=0x80008fde,data-len=4 \
-device loader,addr=0xff9a0000,data=0x80000218,data-len=4 \
-drive file=qemu_qspi_high.bin,if=mtd,format=raw,index=0 \
-drive file=qemu_qspi_low.bin,if=mtd,format=raw,index=1\
-boot mode=1
```

R5-0 FSBL in SD Boot Mode

```
qemu-system-aarch64 -M arm-generic-fdt -nographic \
-dtb ./images/linux/zynqmp-qemu-arm.dtb \
-device loader,file=zynqmp_r5_fsbl.elf,cpu=4 \
-device loader,addr=0xff5e023c,data=0x80008fde,data-len=4 \
-device loader,addr=0xff9a0000,data=0x80000218,data-len=4 \
-drive file=qemu_sd.img,if=sd,format=raw,index=0 \
-boot mode=3
```

R5-0 FSBL in NAND Boot Mode

```
qemu-system-aarch64 -M arm-generic-fdt -nographic \
-dtb ./images/linux/zynqmp-qemu-arm.dtb \
-device loader,file=zynqmp_r5_fsbl.elf,cpu=4 \
-device loader,addr=0xff5e023c,data=0x80008fde,data-len=4 \
-device loader,addr=0xff9a0000,data=0x80000218,data-len=4 \
-drive file=qemu_nand.bin,if=nand,format=raw,index=0 \
-boot mode=4 -if=pflash
```

R5 Lockstep FSBL

Only one example is provided for lock step, although all boot modes are valid. See the previous example command line arguments for storage media and boot mode that could be applied to this command line. This specific example is JTAG boot mode:

```
qemu-system-aarch64 -M arm-generic-fdt -nographic \
-dtb ./images/linux/zynqmp-qemu-arm.dtb \
-device loader,file=zynqmp_r5_fsbl.elf,cpu=4 \
-device loader,addr=0xff5e023c,data=0x80008fde,data \
-len=4
```

Running PMU and ARM QEMU

The following examples runs two instances of QEMU, one emulating the PS part of Cortex-A53s and Cortex-R5s and another is the PMU in a Microblaze™ device.

Note: DTBs used for single and present multiarch model are different.

1. Setup the ARM instance by typing the following commands:

```
qemu-system-aarch64-M arm-generic-fdt -nographic \
-dtb <proj>/pre-built/linux/images/zynqmp-qemu-multiarch-arm.dtb \
-machine-path <any-folder-path> -gdb tcp::9000
```

2. Setup a PMU instance by typing the following commands:

```
qemu-system-microblazeel-M microblaze-fdt -nographic \
-dtb <proj>/pre-built/linux/images/zynqmp-qemu-multiarch-pmu.dtb \
-kernel <proj>/pre-built/linux/images/pmu_rom_qemu_sha3.elf \
-machine-path <any-folder-path> -gdb tcp::9005
```

After these two steps are complete, connect the ARM QEMU using the XSDB `connect` command. See [Building QEMU from Source in Chapter 3](#) for more information.

Building QEMU from Source

QEMU source code is available on the *github* link [Ref 16]. The following are the build steps:

1. Clone QEMU, and update the sub-modules, `dtc` and `pixman`.



IMPORTANT: *Make sure to install the build dependencies before starting the build.*

- For Ubuntu, use `apt-get build-dep qemu`.

Its recommended to do an out-of-tree build.

2. Make an empty folder outside of the `source` folder, and change into the new folder.
3. Run the following `configure` command:

```
<QEMU_SOURCE_PATH>/configure
--target-list="aarch64-softmmu,microblazeel-softmmu,arm-softmmu" \
  --enable-debug \
  --force-internal-fdt \
  --extra-cflags="-DXILINX_SPIPS_ERR_DEBUG=2 \
    -DM25P80_ERR_DEBUG=2 \
    -DNAND_ERR_DEBUG=1 \
    -DARASAN_NFC_ERR_DEBUG=1 \
    -DSDHC_DEBUG \
    -DFDT_GENERIC_UTIL_ERR_DEBUG=2 \
    -DCADENCE_GEM_ERR_DEBUG \
    -DCONFIG_FDT " \
  --disable-werror \
  --enable-fdt \
  --enable-sdl
```

4. Run `make -j16`.

QEMU binaries are available at:

- `<build_path>/aarch64-softmmu/qemu-system-aarch64`
- `<build_path>/microblazeel-softmmu/qemu-system-microblazeel`

You might need to install additional libraries based on your configuration inputs.

Using XSDB with QEMU

Introduction

The Xilinx® system debugger (XSDB) lets you download and debug application on the QEMU platform.

Using the XSDB, you can do the following:

- Download and run a bare-metal application ELF
 - Suspend and resume a processor
 - Debug using breakpoints
 - Read and write registers
-

Connecting QEMU

XSDB connects to QEMU GDB by using remote ports.

While passing arguments to load and run QEMU running, attach a GDB client by appending the option: `-gdb tcp::<port-num>` to QEMU command line.

The following is the total command:

```
qemu-system-aarch64 -M arm-generic-fdt -nographic \  
-dtb ./images/linux/zynqmp-qemu-arm.dtb -gdb tcp::1440
```

Note: Port number is not specific; it can be any free port.

With QEMU running, connect the QEMU using the XSDB `gdbremote` command shown in the following command line:

```
gdbremote connect <hostname>:<port-num>
```

Note: The `hostname` can be `localhost` or the name of the server or an IP address upon which QEMU is running.

Downloading and Running with XSDB

Download and run with XSDB on available targets by selecting a target and loading an ELF. The `targets` or `ta` command shows the available targets (processors) on board.

For example, the command lists all the targets as shown:

```
xsdb% ta
1 GdbClient (xhdl3763:6678)
2 p1
3 Cortex-A53 #0 (Suspended)
4 Cortex-A53 #1 (Suspended)
5 Cortex-A53 #2 (Suspended)
6 Cortex-A53 #3 (Suspended)
7 p2
8 Cortex-R5 #0 (Suspended)
9 Cortex-R5 #1 (Suspended)
```

- `ta <target-number>`: Connects to the respective targets.

Note: These are not the same numbers that QEMU uses for CPUs internally.

- `dow <elf file path>`: Downloads the specified ELF and sets the PC value to the corresponding targets .

Note: Before downloading and running ELF's, take the processors out of reset. This requires a few more commands to get started. The following table shows the processor, command, and address to provide.

Table 4-1: Processors Out of Reset Command

Processor	Command and Address
Cortex-A53	<code>mwr 0xfda0104 0</code>
Cortex-R5	<code>mwr 0xff5e023c 0x00008fde</code> <code>mwr 0xff9a0000 0x00000218</code>

Stopping and Starting Execution

- `con`: Start a command execution.
- `stop`: Stop a command execution.

Using Breakpoints

You can add, list and remove breakpoints using the following commands:

- `bpadd`: Set a breakpoint.
 - Example: `bpadd -addr &<function-name>/<address>`
- `bplist`: Lists all breakpoints.
- `bpremove`: Remove Breakpoint.
 - Example: `bpremove <breakpoint number>`

For more information on using breakpoints see the "XSDB" topic in the *Xilinx Software Development Kit help* [Ref 2].

Reading and Writing to Memory Registers

You can read and write to the memory of the peripherals and the DDR and OCM memory in the debugger using the `mrd` and `mwr` commands.

Note: Stop the processors when performing memory operations.

Commands

- `mrd <addr>`: Read memory
- `mwr <addr> <value>`: Write to memory

Limitations

- Reset of processors command is not supported. Instead, QEMU can be restarted or use `system_reset` in the QEMU monitor.
- PL bitstream loading is not supported as shown in XSDB help .
- Changing memory maps is not supported.
- JTAG is not supported.

Co-Simulating With QEMU

The Xilinx® QEMU can connect to external simulators in order to simulate larger and mixed simulator systems. This functionality allows you to model the Processing System (PS) in QEMU and the Programmable Logic (PL) design in an RTL or SystemC simulator. It also allows you to connect multiple QEMU instances to each other. These processes are all connected through a communication protocol called Remote-Port (RP).

Remote-Port

QEMU connects to external simulators through Remote-Port. Remote-Port is a protocol/framework that uses sockets and shared-memory to communicate transactions and synchronize time between simulators.

libsystemctlm-soc

You do not need to interface directly with Remote-Port. Xilinx provides abstractions for SystemC/TLM-2.0 that encapsulate your SystemC/TLM-2.0 module, allowing it to connect to remote QEMU instances. These modules use Remote-Port. SystemC/TLM-2.0 users can, therefore, treat QEMU as any other standard SystemC/TLM-2.0 module.

These abstractions can be found in the libsystemctlm-soc repository [\[Ref 19\]](#).

For an example of wrapping your SystemC application, see the SystemC/TLM-2.0 co-simulation demo [\[Ref 20\]](#).

SystemC/TLM-2.0 Co-Simulation Demo

This demo is written using standard, compliant SystemC/TLM-2.0 APIs. You can run the demo on any SystemC/TLM-2.0 simulator that is compliant with Accellera Systems Initiative (ASI) industry standard specifications. This demo was tested and verified with Accellera's open source reference implementation of the simulator.

The SystemC/TLM-2.0 co-simulation demo [\[Ref 20\]](#) provides an example project that demonstrates how to use libsystemctlm-soc to connect custom SystemC/TLM-2.0 and RTL models to QEMU.

The examples in this demo show how QEMU models the PS aspect of both Zynq-7000 devices and Zynq® UltraScale+ devices while SystemC/TLM-2.0 and RTL models can be used to model the custom PL logic.

Co-Simulating with QEMU

Generating Required Device Trees

You need to instruct QEMU to co-simulate with other simulators. This can be done by editing the hardware device tree passed into QEMU via the `-hw-dtb` option. For more information on this process, see the QEMU wiki [Ref 10] and the device tree repository [Ref 21].

Extra Command Line Options

`-machine-path` - Specifies a directory where QEMU creates shared memory files and named UNIX sockets.

`-sync-quantum` - Specifies the TLM synchronization quantum in nanoseconds (only used if `-icount` is enabled).

`-icount` - Enables virtual instruction counter with 2^N clock ticks per instruction; enables aligning the host and virtual clocks or disables real-time cpu sleeping.

Useful starting values for `icount`:

- Zynq UltraScale+ MPSoC devices: 1
- Zynq-7000 devices: 7

As you lower the `sync-quantum`, the modeling speed decreases, but the accuracy increases. A general starting value is 100000.

Example Extra Options

```
-icount 1 -sync-quantum 100000
```

Example QEMU Command

```
qemu-system-aarch64 -M arm-generic-fdt -nographic \  
-dtb <path to dtb build form qemu-devicetrees repo> \  
-device loader,file=<proj_dir>images/linux/bl31.elf,cpu=0 \  
-device loader,addr=0xfd1a0104,data=0x8000000e,data-len=4 \  
-device loader,file=<proj_dir>/images/linux/u-boot.elf \  
-tftp images/linux/ -machine-path <soc_dir> -icount 1 \  
-sync-quantum 100000
```

Note: Use the same sync-quantum number for the other simulators.

Example Simulator Command

When the command shown in the previous example runs successfully, QEMU waits for the SystemC/TLM-2.0 connection on the socket that was created in the directory supplied by the `-machine-path` argument. You need to use the same socket path when running the SystemC application.

```
./demo-app unix:<socket path> <sync-quantum number>
```

For more information on building and running the SystemC demo application see the SystemC/TLM-2.0 co-simulation demo [\[Ref 20\]](#).

Creating Boot Images on QEMU

Introduction

This section details some end-to-end image generation and QEMU boot flows.

The standard FSBL, ATF, U-Boot, and Linux boot flow is the example in each case.

This specific use case is similar to PetaLinux, and you can access it more simply using the PetaLinux tool suite. This section details the lower-level tools available for complex boot flows should they be required for greater customization.

This section does not cover building the boot products. See the *Zynq® UltraScale+™ MPSOC Software Developers Guide* (UG1137) [Ref 1] for information on how to build the following:

- FSBL
- U-Boot
- ARM trusted firmware (ATF)
- Linux image (Kernel plus RAM disk)
- Device tree binary (DTB)

Note: (This is different from the hardware DTB that is passed to QEMU command lines.)

It is assumed all of these boot products are available. You can build all of the listed images in a standard PetaLinux project.

In the example, FSBL, ATF (b131.e1f), U-Boot runs on an A53 as shown in the BIF file. U-boot loads the Kernel onto A53.

The following run commands point to the `<proj_dir>/images/linux/` folder for all the boot products. You can also use a pre-built area.

Using an SD for Boot (SD Boot Tutorial)

Creating a Binary File from Bootgen

1. Create a binary file (.bin) for the FSBL, ATF, and U-Boot using Bootgen.

Bootgen accepts a BIF file, which contains the information about image paths and on which cores to run.

The following is the BIF file (myimg.bif):

```
the_ROM_image:
{
  [fsbl_config] a53_x64
  [bootloader] ron_a53_fsbl.elf
  [destination_cpu=a53-0]bl31.elf
  [destination_cpu=a53-0]u-boot.elf
}
```

2. Use the following command to generate the BIN file is:

```
bootgen -image myimg.bif -r -w -o i BOOT.BIN
```



TIP: Use `bootgen -bif_help` for more info of BIF parameters.

3. Create the SD image:

```
dd if=/dev/zero of=qemu_sd.img bs=128M count=1
mkfs.vfat -F 32 qemu_sd.img
mcopy -i qemu_sd.img BOOT.BIN ::/
mcopy -i qemu_sd.img Image ::/
mcopy -i qemu_sd.img system.dtb ::/
```

4. Boot the image on QEMU:

```
qemu-system-aarch64 -M arm-generic-fdt -nographic \
-device loader,file=<proj_dir>/images/linux/ron_a53_fsbl.elf,cpu=0 \
-dtb <proj_dir>/images/linux/zynqmp-qemu-arm.dtb \
-device loader,addr=0xfd1a0104,data=0x8000000e,data-len=4 \
-drive file=qemu_sd.img,if=sd,format=raw,index=0 \
-boot mode=3
```

Note: Even though the FSBL is packed in the SD image, it should be passed over the command line as a runnable ELF because QEMU does not contain the boot ROM.

Using QSPI for Boot

Creating the Binary File from Bootgen

1. Create a binary file (.bin) to boot FSBL ATF, and U-Boot using Bootgen.

Bootgen accepts a BIF file, which contains the information about image paths and on which cores to run.

The following is the BIF file (myimg.bif):

```
the_ROM_image:
{
  [fsbl_config] a53_x64
  [bootloader] zynqmp_a53_fsbl.elf
  [destination_cpu=a53-0]bl31.elf
  [destination_cpu=a53-0]u-boot.elf
  [destination_cpu=a53-0,offset=0x140000]Image
  [destination_cpu=a53-0,offset=0x100000]system.dtb
}
```

2. Issue the following command to generate the BIN file:

```
bootgen -image myimg.bif -r -w -o i BOOT.BIN
```

3. Create the QSPI boot image(s) for either or both single flash mode and dual parallel mode.

Single Flash Mode

```
dd if=/dev/zero of=qemu_qspi.bin bs=64M count=1
dd if=BOOT.BIN of=qemu_qspi.bin bs=1 seek=0 conv=notrunc
```

Dual Parallel Mode

```
dd if=/dev/zero bs=128M count=1 of=qemu_qspi_tmp.bin
dd if=BOOT.BIN of=qemu_qspi_tmp.bin bs=1 seek=0 conv=notrunc
flash_strip_bw qemu_qspi_tmp.bin qemu_qspi_low.bin qemu_qspi_high.bin
```

4. Boot either the single or dual image(s) on QEMU.

Single Flash Mode

```
qemu-system-aarch64 -M arm-generic-fdt -nographic \
-dtb <proj_dir>/images/linux/zynqmp-qemu-arm.dtb \
-device loader,file=<proj_dir>/images/linux/zynqmp_a53_fsbl.elf,cpu=0 \
-device loader,addr=0xfd1a0104,data=0x8000000e,data-len=4 \
-drive file=qemu_qspi.bin,if=mtd,format=raw,index=0 \
-boot mode=1
```

Dual Parallel Mode

```

qemu-system-aarch64 -M arm-generic-fdt -nographic \
-dtb <proj_dir>/images/linux/zynqmp-qemu-arm.dtb \
-device loader,file=<proj_dir>/images/linux/zynqmp_a53_fsbl.elf,cpu=0 \
-device loader,addr=0xfd1a0104,data=0x8000000e,data-len=4 \
-drive file=qemu_qspi_high.bin,if=mtd,format=raw,index=0 \
-drive file=qemu_qspi_low.bin,if=mtd,format=raw,index=1
-boot mode=1
    
```



TIP: See the Storage Media for more information on `flash_strip_bw`.

Using NAND for Boot

Creating a Binary File from Bootgen

1. Create a binary file (.bin) to boot FSBL, ATF, and U-Boot using Bootgen.

Bootgen accepts a BIF file, which should contain the info about image paths and which cores on which they should run. The following is the BIF file (`myimg.bif`):

```

the_ROM_image:
{
  [fsbl_config] a53_x64
  [bootloader] ron_a53_fsbl.elf
  [destination_cpu=a53-0]bl31.elf
  [destination_cpu=a53-0]u-boot.elf
  [destination_cpu=a53-0,offset=0x140000]Image
  [destination_cpu=a53-0,offset=0x100000]system.dtb
}
    
```

2. Use the following command to generate the BIN file:

```
bootgen -image myimg.bif -r -w -o i BOOT.BIN
```

3. Create the NAND boot image(s):

```
qemu-nand-creator 16384 1216 256 1048 672 < BOOT.BIN
```



CAUTION! These steps create a 4GB image file. This is required as QEMU emulated 4GB NAND Flash.



TIP: See the Storage Media for more information on `qemu-nand-creator`.

4. Use the following command to run the NAND image on QEMU:

```
qemu-system-aarch64 -M arm-generic-fdt -nographic \  
-dtb images/linux/zynqmp-qemu-arm.dtb \  
-device loader,file=<proj_dir>/images/linux/zynqmp_a53_fsbl.elf,cpu=0 \  
-device loader,addr=0xfd1a0104,data=0x8000000e,data-len=4 \  
-drive file=qemu_nand.bin,if=pflash,format=raw,index=0\  
-boot mode=4
```

Using TFTP for Boot

In the normal JTAG boot mode, `petalinux-build` command has the required images in the `images/linux/` directory (or) a prebuilt path (for example: `pre-built/linux/images/`).

1. Point QEMU to the `./images/linux` directory for `tftp` boot.
2. Use the following command for TFTP boot.

```
qemu-system-aarch64 -M arm-generic-fdt -nographic \  
-dtb <proj_dir>/images/linux/zynqmp-qemu-arm.dtb \  
-device loader,file=<proj_dir>/images/linux/bl31.elf,cpu=0 \  
-device loader,addr=0xfd1a0104,data=0x8000000e,data-len=4 \  
-device loader,file=<proj_dir>/images/linux/u-boot..elf \  
-tftp images/linux/
```



IMPORTANT: *The /TFTP folder should contain the Image and the `system.dtb`.*



TIP: *Image Creation Steps for SD and EMMC are the same.*

SD-Card Partitioning and Loading an Ubuntu-core File System

The following are the steps to create an SD card image.

1. Create a dummy container using `qemu-img`. The `qemu-img` is a utility used to create disk images for using with QEMU. It comes with Ubuntu packages and is also packaged with PetaLinux tools.

```
qemu-img create <Image name> <size>
```

For example: The command, `qemu-img create sd.img 2G`, creates a 2G raw disk, with no partitions present.

2. Create the network back end with `qemu-nbd` and `nbd-client`.

The `qemu-nbd` command creates a disk network block server making it an network block device, so that it can be connected with `nbd-client`.

For example:

- `qemu-nbd -p 4444 sd.img &` makes a network block device server, instructing the client to use port 4444 to connect.
 - `nbd-client localhost 4444 /dev/nbd0` connects to the created network block server. It can be accessed using the `/dev/nbd0` node.
3. Create partitions using `fdisk`, a text-based tool used to create partitions on a disk.

Also, you could use `gparted`, a GUI-based partitioning tool.

`fdisk /dev/nbd0` connects to the block device.

4. Create partitions, mostly two primary partitions are required.
- One is bootable partition for keeping `BOOT.BIN`, `Image`, and the `system.dtb`.
 - Another is the partition for `rootfs`.

A bootable flag can be toggled using `fdisk`. Ensure that there is least 100Mb in the bootable partition to have enough space.

5. Write the partition table and exit.
6. Format the partitions. Always format the bootable partition using FAT file systems. The second partition can be `ext2/ext4`.

For example:

`mkfs.vfat -F 32 /dev/nbd0p1` formats the first partitions using FAT.

`mkfs.ext4 /dev/nb0p2` formats the second partition using `ext4`.

7. Mount the partitions and copy the necessary files. Load the `Image` file without `initramfs`, by de-selecting the **[]Initial RAM filesystem and RAM disk (initramfs/initrd) support** option located in **General Setup** in **menuconfig**.

Note: This step in not required if performing `switch-root`.

8. Extract the `ubuntu-core` available for arm64 in to the second partition.



TIP: *The `ubuntu-core` is located on the [Ubuntu-Core release page](#).*

9. Un-mount the partition and disconnect the `nbd` connection using the following command: `nbd-client-d /dev/nbd0`.
10. Ensure that the `bootargs` points to appropriate device for root, which is the following:
`root=/dev/mmcblk0p2 rw rootfstype=ext4`.

Adding New Devices to the Design

QEMU has limited device models; you can use the device model if it is available in QEMU source by directly adding the bindings into the device tree.

The following is an example of adding a SI57X I2c controlled clock generator to one of the I2C buses:

```
&i2cswitch{
i2c@3 {
    #address-cells = <1>;
    #size-cells = <0>;
    reg = <3>;
    si570_21 clock-generator@5e {
        compatible = "silabs,si57x";
        reg = <0x5d>;
        temperature-stability=<50>;
    };
};

};
```

The compatible string is QEMU device, `TYPE_NAME`.

- `reg` represents the I2C address of the slave.
- `temperature-stability` is the property that the device expects to be set before device initialization happens.

See the `Property` structure in the device model to know what properties must be added.

An example of the `Property` structure for SI570 is as follows:

```
static Property si57x_properties[] = {
    DEFINE_PROP_UINT16("temperature-stability", Si57xState, temp_stab,
        TEMP_STAB_50PPM),
    DEFINE_PROP_END_OF_LIST(),
};
```

Additional Resources and Legal Notices

Xilinx Resources

For support resources such as Answers, Documentation, Downloads, and Forums, see [Xilinx Support](#).

Solution Centers

See the [Xilinx Solution Centers](#) for support on devices, software tools, and intellectual property at all stages of the design cycle. Topics include design assistance, advisories, and Vivado Design Suite Documentation

Documentation Navigator and Design Hubs

Xilinx® Documentation Navigator provides access to Xilinx documents, videos, and support resources, which you can filter and search to find information. To open the Xilinx Documentation Navigator (DocNav):

- From the Vivado IDE, select **Help > Documentation and Tutorials**.
- On Windows, select **Start > All Programs > Xilinx Design Tools > DocNav**.
- At the Linux command prompt, enter `docnav`.

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- In the Xilinx Documentation Navigator, click the **Design Hubs View** tab.
- On the Xilinx website, see the [Design Hubs](#) page.

Note: For more information on Documentation Navigator, see the [Documentation Navigator](#) page on the Xilinx website.

References

Zynq Documentation

1. *Zynq UltraScale+ MPSoC Software Developers Guide* ([UG1137](#))
2. *Xilinx Software Developer Kit Help* ([UG782](#)) (Includes XSDB)
3. *OS and Libraries Document Collection* ([UG643](#))
4. *Xilinx Third-Party Licensing Guide* ([UG763](#))
5. *UltraScale Architecture and Product Overview* ([DS890](#))
6. *Zynq UltraScale+ Registers User Guide* ([UG1087](#))
7. [PetaLinux Tools](#)
8. [Vivado Design Suite Documentation](#)
9. [UltraScale Architecture Video Tutorials](#)

Wiki Sites and GIT Hub Resources

10. [QEMU Wiki](#)
11. [Zynq MPSoC XEN Wiki](#)
12. [GNU FTP](#)
13. [Zynq MPSoC Non-Secure Boot](#) and [Zynq MPSoC Secure Boot](#)
14. [ARM Information Center](#)
15. [Using GIT](#)
16. [GIT Hub](#)
17. [OpenAMP Wiki](#)
18. [QEMU Linux Kernel Logbuf Extraction](#)
19. [libsystemctlm-soc Repository](#)
20. [SystemC/TLM 2.0 Co-simulation Demo](#)
21. [Device Tree Repository](#)

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