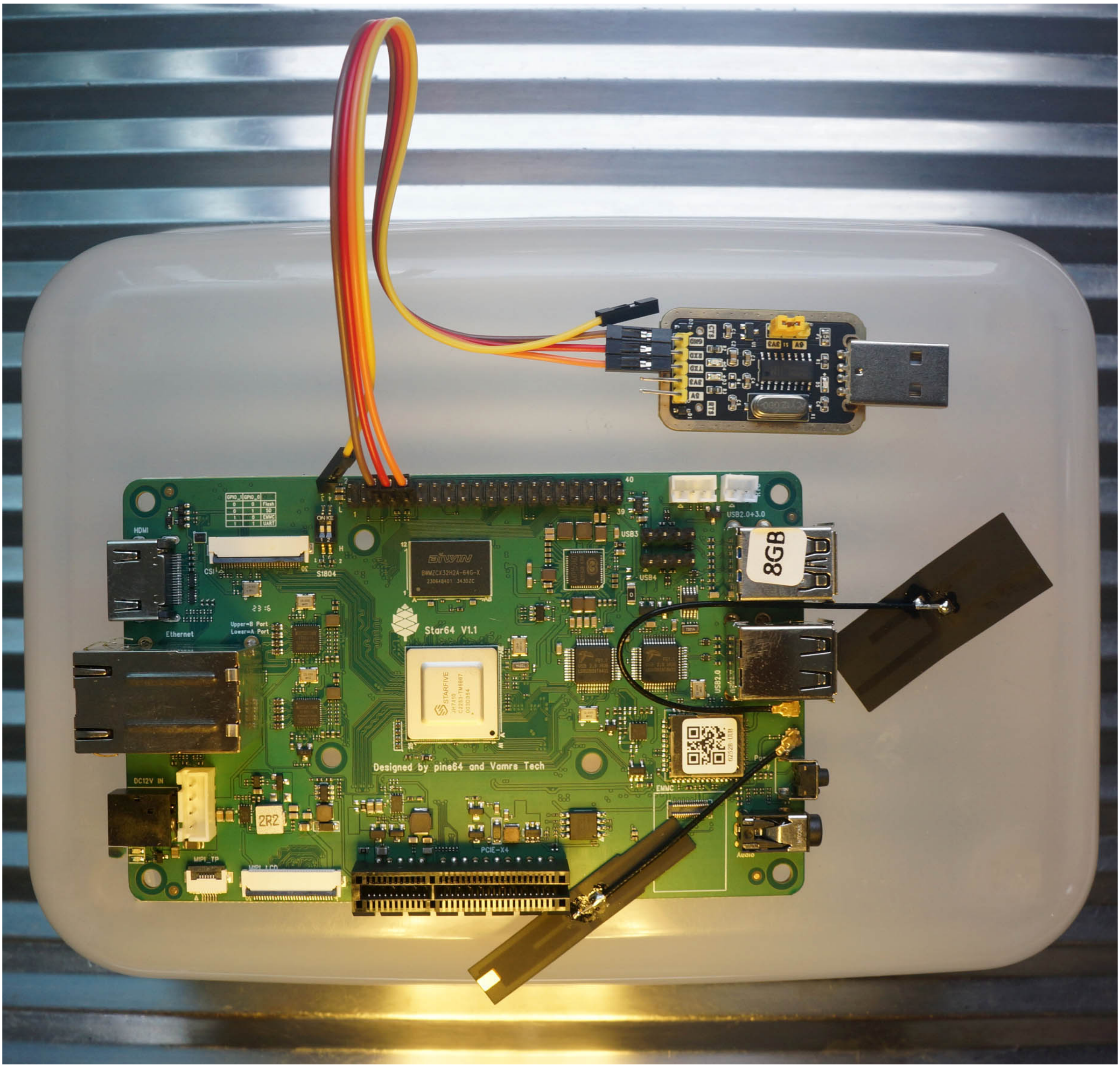
Star64 JH7110 RISC-V SBC: Boot from Network with U-Boot and TFTP

📝 *13 Jul 2023*



Testing a new Operating System like **Apache NuttX RTOS** (or Linux) can get *painfully tedious* on a Single-Board Computer…

Swapping, reflashing and rebooting a MicroSD Card, **again and again and again**!

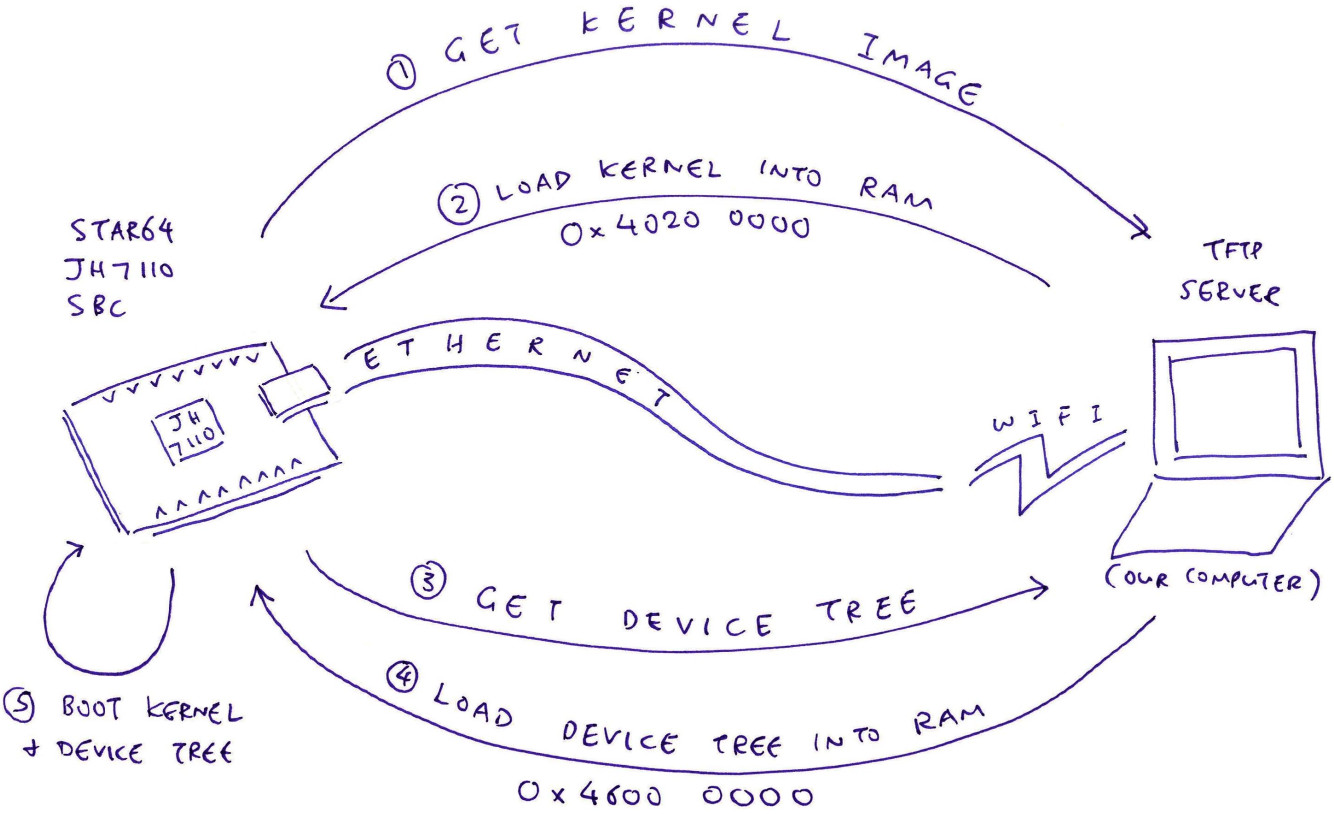
(Like how we tested **NuttX on PinePhone**)

Thankfully there's a better way: Booting NuttX (or Linux) over the **Local Network**, with **U-Boot Bootloader** and **TFTP**!

Today we'll configure TFTP Network Boot on **Pine64 Star64**, the new 64-bit RISC-V Single-Board Computer (SBC).

(Powered by **StarFive JH7110** SoC)

(Watch the **Demo Video** on YouTube)



§1 Boot From Network

The pic above shows our **Grand Plan** for today…

0. We'll install **TFTP Server** on our Computer

   (Which will provide the Kernel Image and Device Tree for Star64)

1. Star64 SBC will fetch the **Kernel Image** from our Computer

   (NuttX or Linux)

2. Our SBC will load the **Kernel into RAM**

   (At RAM Address `0x4020 0000`)

3. Star64 will fetch the **Linux Device Tree** from our Computer

   (NuttX doesn't need it, but we'll do it anyway)

4. Our SBC will load the **Device Tree into RAM**

   (At RAM Address `0x4600 0000`)

5. Our SBC will also fetch and load the **Initial RAM Disk**

   (At RAM Address `0x4610 0000`)

6. Star64 will **boot the Kernel** from RAM, with the Device Tree and Initial RAM Disk

   (NuttX or Linux)

7. We'll configure the SBC to do this **every time it powers on**

   (It will try MicroSD first, before the Network Boot)

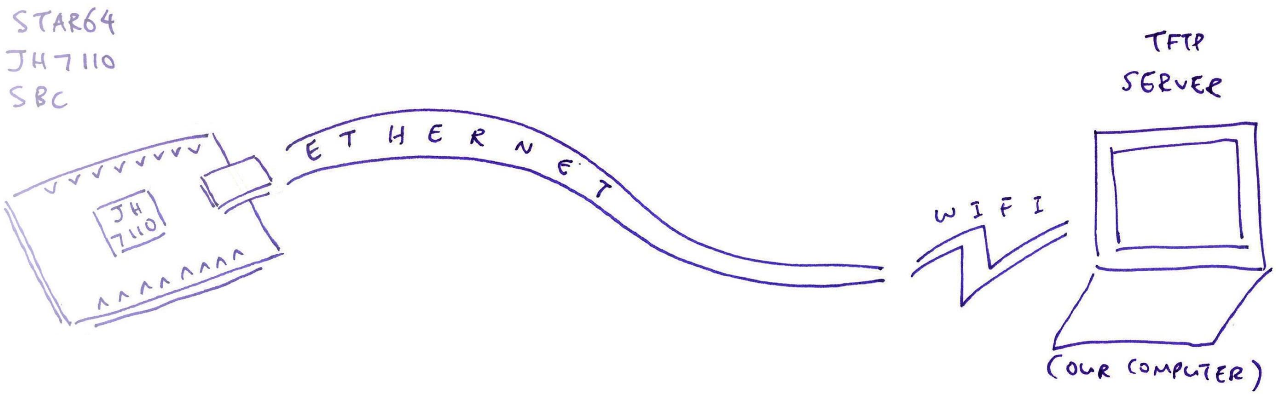
   (Watch the Demo on YouTube)

Do we install anything on our SBC?

Everything we need is already in the **Internal Flash Memory** of our SBC!

Inside our SBC Flash Memory is the **U-Boot Bootloader**. Which normally boots from MicroSD, but can be configured for **Network Boot**.

Let's find out how...



§2 Install TFTP Server

What's this TFTP Server? (Pic above)

That's a simple program (running on our Computer) that handles the **Trivial File Transfer Protocol (TFTP)**.

It dishes out files over the **Local Network** (via UDP not TCP), when requested by our SBC.

Follow these steps to install the `tftpd` **TFTP Server** on our Linux / macOS / Windows Computer...

```
## Install `tftpd` in Rust
cargo install tftpd

## Create a folder for the TFTP Files
mkdir $HOME/tftproot

## Start the TFTP Server. Needs `sudo` because
## Port 69 is a privileged low port.
## Send Duplicate Packets to prevent TFTP Timeouts.
## https://lupyuen.codeberg.page/articles/tftp2#send-everything-twice
sudo $HOME/.cargo/bin/tftpd \
  --duplicate-packets 1 \
  -i 0.0.0.0 \
  -p 69 \
  -d "$HOME/tftproot"

## Or use `nohup` to keep it running continuously
nohup sudo $HOME/.cargo/bin/tftpd --duplicate-packets 1 -i 0.0.0.0 -p 69 -d "$HOME/tftpro
```

(`duplicate-packets` is needed to prevent TFTP Timeouts)

(`xinetd` + `tftpd` might cause TFTP Timeouts)

(`tftp_server` won't work, it only supports localhost)

We should see…

```
Running TFTP Server on 0.0.0.0:69 in $HOME/tftproot

## Later we'll see the dishy files...
## Sending a.txt to 127.0.0.1:57125
##   Sent a.txt to 127.0.0.1:57125
## Sending a.txt to 192.168.x.x:33499
##   Sent a.txt to 192.168.x.x:33499
```

Let's **test the server**…

```
## Create a Test File for TFTP
echo Test123 >$HOME/tftproot/a.txt

## Fetch the Test File over TFTP.
## TODO: Change `192.168.x.x` to our Computer's IP Address
curl -v tftp://127.0.0.1/a.txt
curl -v tftp://192.168.x.x/a.txt
```

(`localhost` won't work because of IPv6, I think)

We should see our **Test File**…

```
* Trying 192.168.x.x:69...
* getpeername() failed with errno 107: Transport endpoint is not connected
* Connected to 192.168.x.x () port 69 (#0)
* getpeername() failed with errno 107: Transport endpoint is not connected
* set timeouts for state 0; Total  300000, retry 6 maxtry 50
...
Test123
```

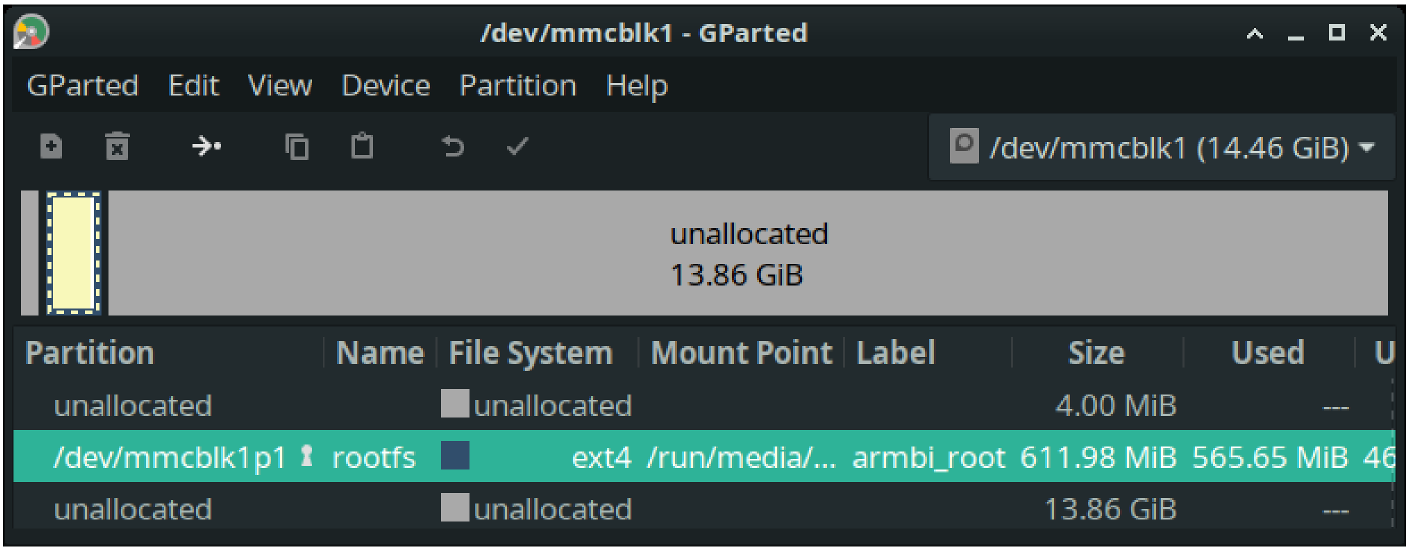
(Ignore the warnings)

Our TFTP Server is up! In olden days we would actually do this…

```
$ tftp 127.0.0.1
tftp> get a.txt
Received 8 bytes in 0.0 seconds
tftp> quit
```

(Just like **FTP**)

But `curl` is so much simpler!



Armbian MicroSD for Star64

§3 Copy Kernel to TFTP Server

How to copy the Kernel to our TFTP Server?

We build **Apache NuttX RTOS** with these steps…

- **"Apache NuttX RTOS for Star64"**

This produces the **NuttX Kernel Image** `nuttx.bin` that we'll copy to our TFTP Folder…

```
## Copy NuttX Binary Image `nuttx.bin` to TFTP Folder
cp nuttx.bin $HOME/tftproot/Image

## Test NuttX Binary Image over TFTP.
## TODO: Change `192.168.x.x` to our Computer's IP Address
curl -v tftp://192.168.x.x/Image

## We should see:
## `Warning: Binary output can mess up your terminal`
```

For Linux: Copy the Linux Kernel File **`Image`** to our TFTP Folder.

What about the Linux Device Tree?

(NuttX won't need it, but let's do it anyway)

For NuttX: Copy the Device Tree **jh7110-visionfive-v2.dtb** from the **StarFive VisionFive2 Software Releases** to our TFTP Folder…

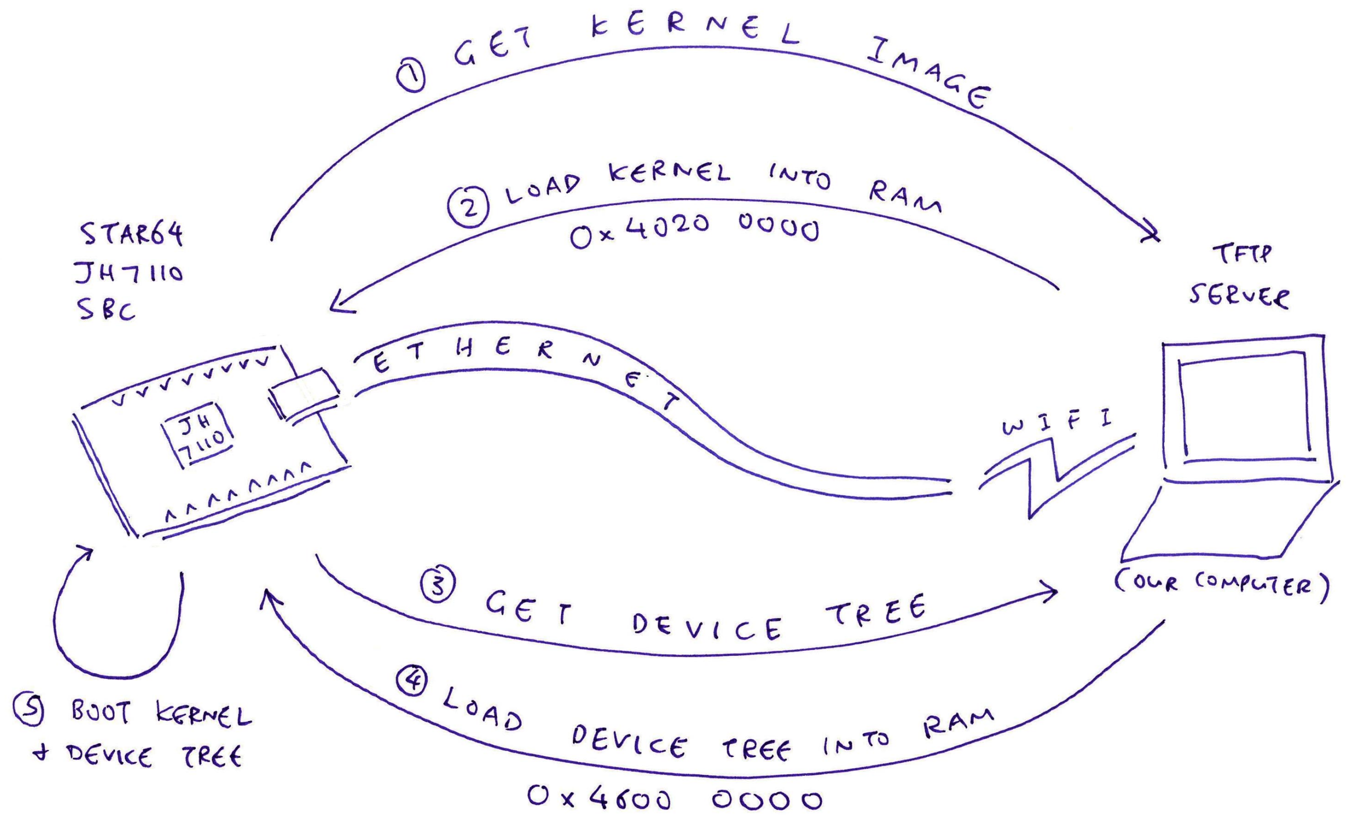
```
## Download the Device Tree for VisionFive2
wget https://github.com/starfive-tech/VisionFive2/releases/download/VF2_v3.1.5/jh7110-vis

## Rename the Device Tree to Star64
cp \
  jh7110-visionfive-v2.dtb \
  jh7110-star64-pine64.dtb

## Copy to TFTP Folder
cp jh7110-star64-pine64.dtb $HOME/tftproot

## Test the Device Tree over TFTP
## TODO: Change `192.168.x.x` to our Computer's IP Address
curl -v tftp://192.168.x.x/jh7110-star64-pine64.dtb

## We should see:
## `Warning: Binary output can mess up your terminal`
```

For Linux: Just copy the Linux Device Tree **jh7110-star64-pine64.dtb** to our TFTP Folder.

Finally we copy the **Initial RAM Disk "initrd"** (NuttX or Linux) to our TFTP Folder…

```
## Copy Initial RAM Disk to TFTP Folder
cp initrd $HOME/tftproot

## Test the Initial RAM Disk over TFTP
## TODO: Change `192.168.x.x` to our Computer's IP Address
curl -v tftp://192.168.x.x/initrd

## We should see:
## `Warning: Binary output can mess up your terminal`
```

Let's test this…



§4 Test U-Boot with TFTP

We’re ready to test U-Boot Bootloader with TFTP!

Connect Star64 to the **Ethernet Wired Network**. (Pic above)

Connect to the **Serial Console** and power up without a MicroSD Card.

Star64 **fails to boot** over the network, but that’s OK…

```
BOOTP broadcast 1
  *** Unhandled DHCP Option in OFFER/ACK: 43
  DHCP client bound to address 192.168.x.x (351 ms)

TFTP from server 192.168.x.x; our IP address is 192.168.x.x
  Filename 'boot.scr.uimg'.

Load address: 0x43900000
  TFTP server died; starting again

Load address: 0x40200000
  TFTP server died; starting again

StarFive #
```

(Source)

That’s because we don’t have a **BOOTP Server** or a **DHCP+TFTP Combo Server**.

Since we have a **Dedicated TFTP Server**, we run these **U-Boot Commands** at the prompt…

```
## Set the TFTP Server IP
## TODO: Change `192.168.x.x` to our Computer's IP Address
setenv tftp_server 192.168.x.x

## Assume Initial RAM Disk is max 16 MB
setenv ramdisk_size 0x1000000

## Load the NuttX Image from TFTP Server
## kernel_addr_r=0x40200000
## tftp_server=192.168.x.x
tftpboot ${kernel_addr_r} ${tftp_server}:Image

## Load the Device Tree from TFTP Server
## fdt_addr_r=0x46000000
## tftp_server=192.168.x.x
tftpboot ${fdt_addr_r} ${tftp_server}:jh7110-star64-pine64.dtb

## Set the RAM Address of Device Tree
## fdt_addr_r=0x46000000
fdt addr ${fdt_addr_r}

## Load Initial RAM Disk over TFTP
## ramdisk_addr_r=0x46100000
## tftp_server=192.168.x.x
tftpboot ${ramdisk_addr_r} ${tftp_server}:initrd

## Boot the NuttX Image with the Initial RAM Disk and Device Tree
## kernel_addr_r=0x40200000
## ramdisk_addr_r=0x46100000
## ramdisk_size=0x1000000
## fdt_addr_r=0x46000000
booti ${kernel_addr_r} ${ramdisk_addr_r}:${ramdisk_size} ${fdt_addr_r}
```

(**tftpboot** explained here)

(**fdt** explained here)

(**booti** explained here)

(See the **U-Boot Settings**)

Our Star64 SBC shall (pic above)…

1. **Fetch the Kernel** over TFTP
2. **Load the Kernel** into RAM
3. **Fetch the Device Tree** over TFTP
4. **Load the Device Tree** into RAM
5. **Load the Initial RAM Disk** into RAM
6. **Boot the Kernel**

Like so…

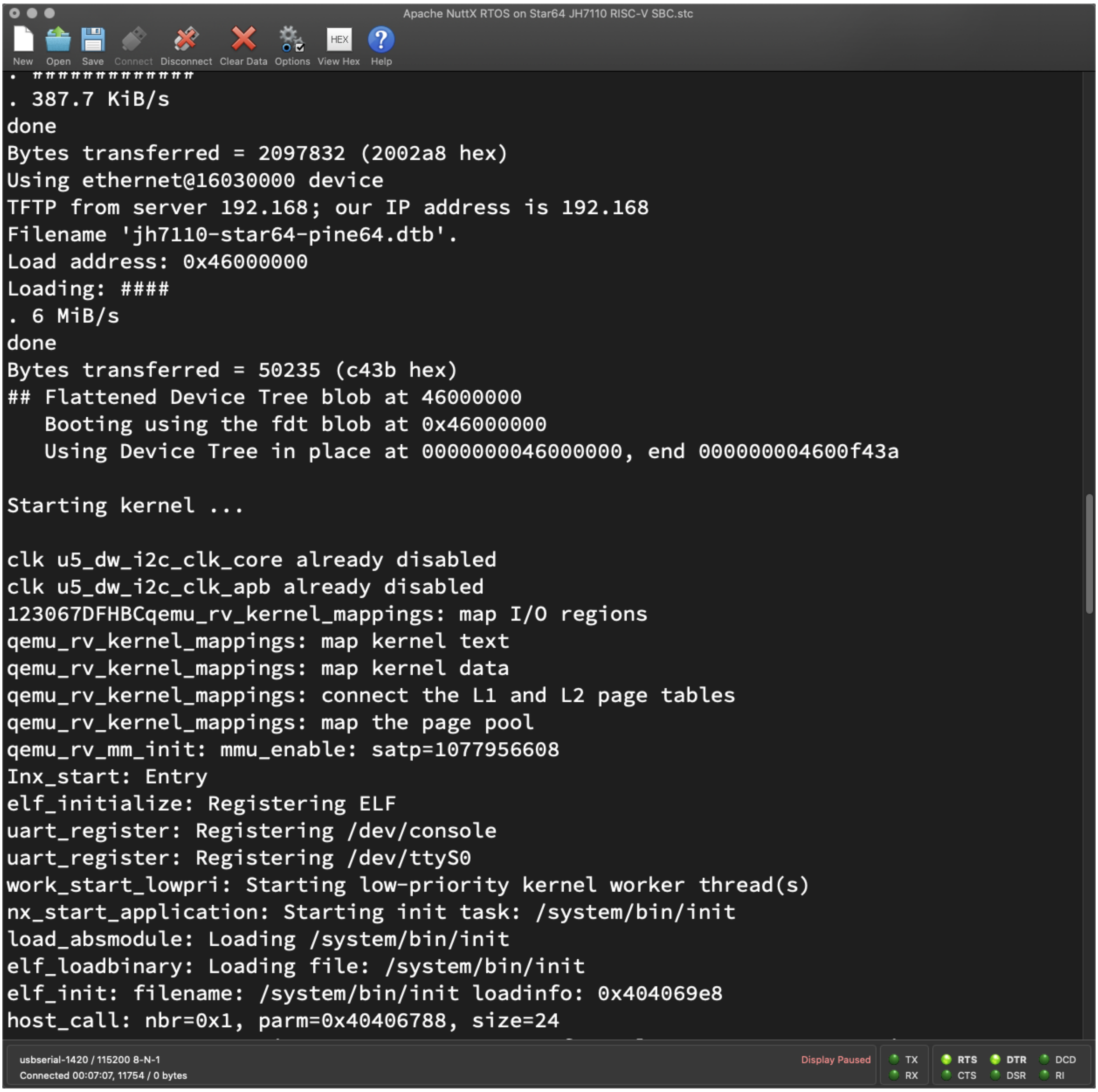
```
$ setenv tftp_server 192.168.x.x

$ setenv ramdisk_size 0x1000000

$ tftpboot ${kernel_addr_r} ${tftp_server}:Image
Filename 'Image'.
Load address: 0x40200000
Loading: 221.7 KiB/s done
Bytes transferred = 2097832 (2002a8 hex)

$ tftpboot ${fdt_addr_r} ${tftp_server}:jh7110-star64-pine64.dtb
Filename 'jh7110-star64-pine64.dtb'.
Load address: 0x46000000
Loading: 374 KiB/s done
Bytes transferred = 50235 (c43b hex)

$ fdt addr ${fdt_addr_r}

$ tftpboot ${ramdisk_addr_r} ${tftp_server}:initrd
Filename 'initrd'.
Load address: 0x46100000
Loading: 189.5 KiB/s done
Bytes transferred = 8020992 (7a6400 hex)

$ booti ${kernel_addr_r} ${ramdisk_addr_r}:${ramdisk_size} ${fdt_addr_r}
Flattened Device Tree blob at 46000000
Booting using the fdt blob at 0x46000000
Using Device Tree in place at 0000000046000000, end 000000004600f43a
```

(Source)

(It might load quicker if we connect our Computer to the **Ethernet Wired Network**, instead of WiFi)

And NuttX (or Linux) boots magically over the Network, no more MicroSD yay!

```
Starting kernel ...
clk u5_dw_i2c_clk_core already disabled
clk u5_dw_i2c_clk_apb already disabled
123067DFAGHBC
```



§5 Configure U-Boot for TFTP

But can we Auto-Boot from Network, every time we power on?

Sure can! The trick is to use the **saveenv** command, which will save the U-Boot Settings into the **Internal Flash Memory**…

```
## Remember the TFTP Server IP.
## TODO: Change `192.168.x.x` to our Computer's IP Address
setenv tftp_server 192.168.x.x
## Check that it's correct
printenv tftp_server
## Save it for future reboots
saveenv

## Assume Initial RAM Disk is max 16 MB
setenv ramdisk_size 0x1000000
## Check that it's correct
printenv ramdisk_size
## Save it for future reboots
saveenv

## Add the Boot Command for TFTP
setenv bootcmd_tftp 'if tftpboot ${kernel_addr_r} ${tftp_server}:Image ; then if tftpboot
## Check that it's correct
printenv bootcmd_tftp
## Save it for future reboots
saveenv

## Test the Boot Command for TFTP, then reboot
run bootcmd_tftp

## Remember the Original Boot Targets
setenv orig_boot_targets "$boot_targets"
## Should show `mmc0 dhcp`
printenv boot_targets
## Save it for future reboots
saveenv

## Add TFTP to the Boot Targets
setenv boot_targets "$boot_targets tftp"
## Should show `mmc0 dhcp  tftp`
printenv boot_targets
## Save it for future reboots
saveenv
```

(See the **U-Boot Settings**)

(See the **Network Boot Log**)

Now Star64 will **Auto-Boot from the Network**, every time we power up! (Pic above)

(Watch the **Demo Video** on YouTube)

(It will try to boot from **MicroSD before Network**)

What if we change our mind?

We can switch back to the **Original Boot Targets**…

```
## Restore the Boot Targets
setenv boot_targets "$orig_boot_targets"
## Should show `mmc0 dhcp`
printenv boot_targets
## Save it for future reboots
saveenv
```

What's boot_targets?

U-Boot Bootloader defines a list of **Targets for Auto-Booting**…

```
## On Power Up: Try booting from MicroSD,
## then from DHCP+TFTP Combo Server
boot_targets=mmc0 dhcp
```

We added **TFTP to the Boot Targets** (pardon the space)…

```
## We added TFTP to the Boot Targets
boot_targets=mmc0 dhcp  tftp
```

Thus U-Boot will execute our TFTP Boot Script **bootcmd_tftp** at startup.

(As explained here)

What's bootcmd_tftp?

bootcmd_tftp expands to this U-Boot Script…

```
## Load the NuttX Image from TFTP Server
## kernel_addr_r=0x40200000
## tftp_server=192.168.x.x
if tftpboot ${kernel_addr_r} ${tftp_server}:Image;
then

  ## Load the Device Tree from TFTP Server
  ## fdt_addr_r=0x46000000
  if tftpboot ${fdt_addr_r} ${tftp_server}:jh7110-star64-pine64.dtb;
  then

    ## Set the RAM Address of Device Tree
    ## fdt_addr_r=0x46000000
    if fdt addr ${fdt_addr_r};
    then

      ## Load the Intial RAM Disk from TFTP Server
      ## ramdisk_addr_r=0x46100000
      if tftpboot ${ramdisk_addr_r} ${tftp_server}:initrd;
      then

        ## Boot the NuttX Image with the Initial RAM Disk and Device Tree
        ## kernel_addr_r=0x40200000
        ## ramdisk_addr_r=0x46100000
        ## ramdisk_size=0x1000000
        ## fdt_addr_r=0x46000000
        booti ${kernel_addr_r} ${ramdisk_addr_r}:${ramdisk_size} ${fdt_addr_r};
      fi;
    fi;
  fi;
fi
```

(See the **U-Boot Settings**)

Which does the same thing as the previous section: Boot NuttX (or Linux) over the Network at startup.

(As explained here)

(Thanks to this article)

Hmmm why do we see TFTP Timeouts?

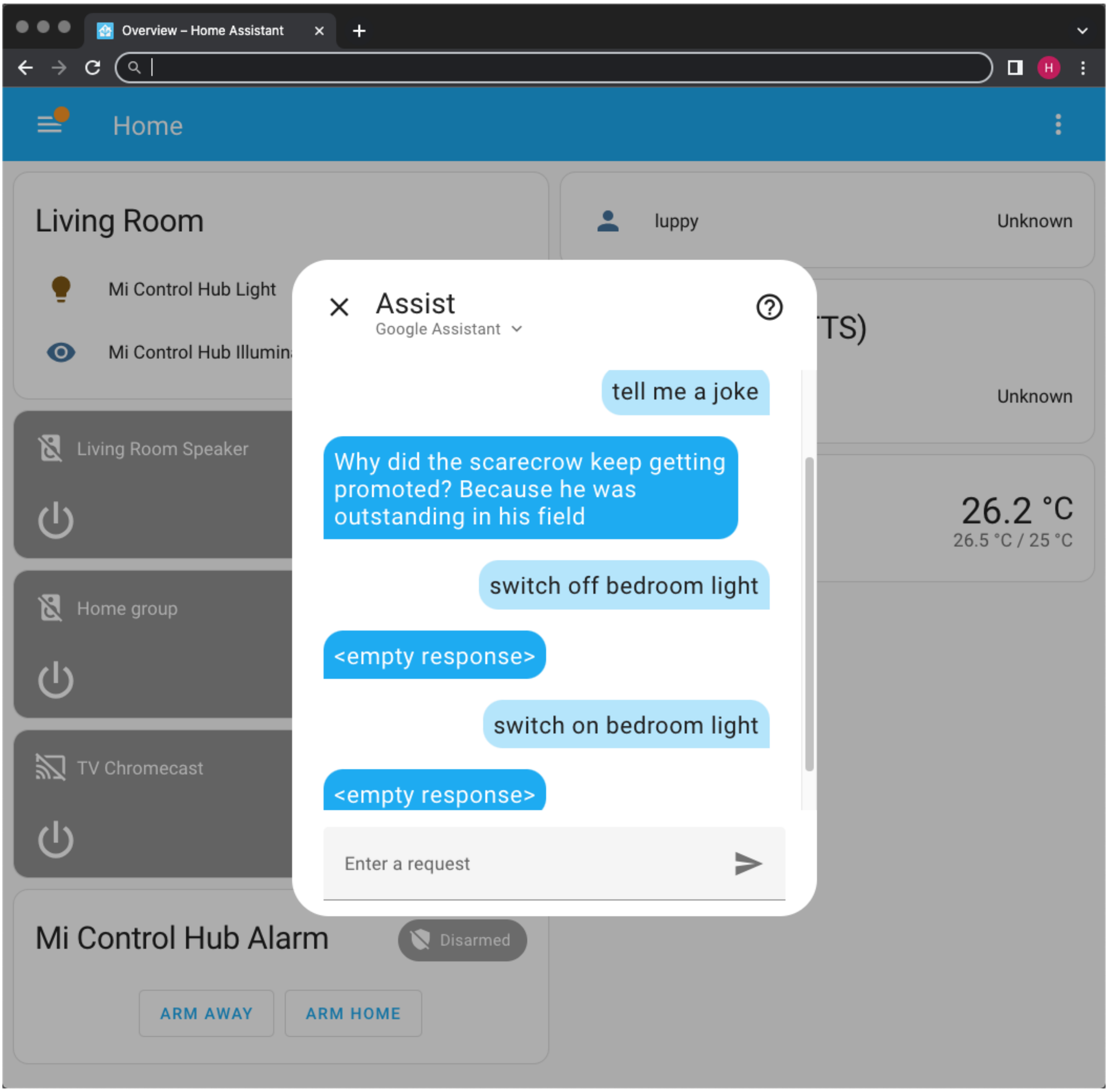
Yeah **frequent TFTP Timeouts** ("T" below) are affecting our NuttX Testing on Star64 JH7110 SBC. Effective Transfer Rate is only 430 kbps!

```
Loading: . ##############T ###################################################
. ####################T #########T ####################################
. 53.7 KiB/s
```

(Source)

Check out the solution here…

- **"Strange Workaround for TFTP Timeout in U-Boot Bootloader (Star64 JH7110 RISC-V SBC)"**



Home Assistant controls our Smart Power Plug

§6 What's Next

With Network Boot running, we're now ready for **Automated Testing of Apache NuttX RTOS** on Star64 SBC!

(With a **Smart Power Plug** and **Home Assistant** to reboot our SBC)

Porting NuttX to Star64 JH7110 becomes so much faster. Stay tuned for updates!

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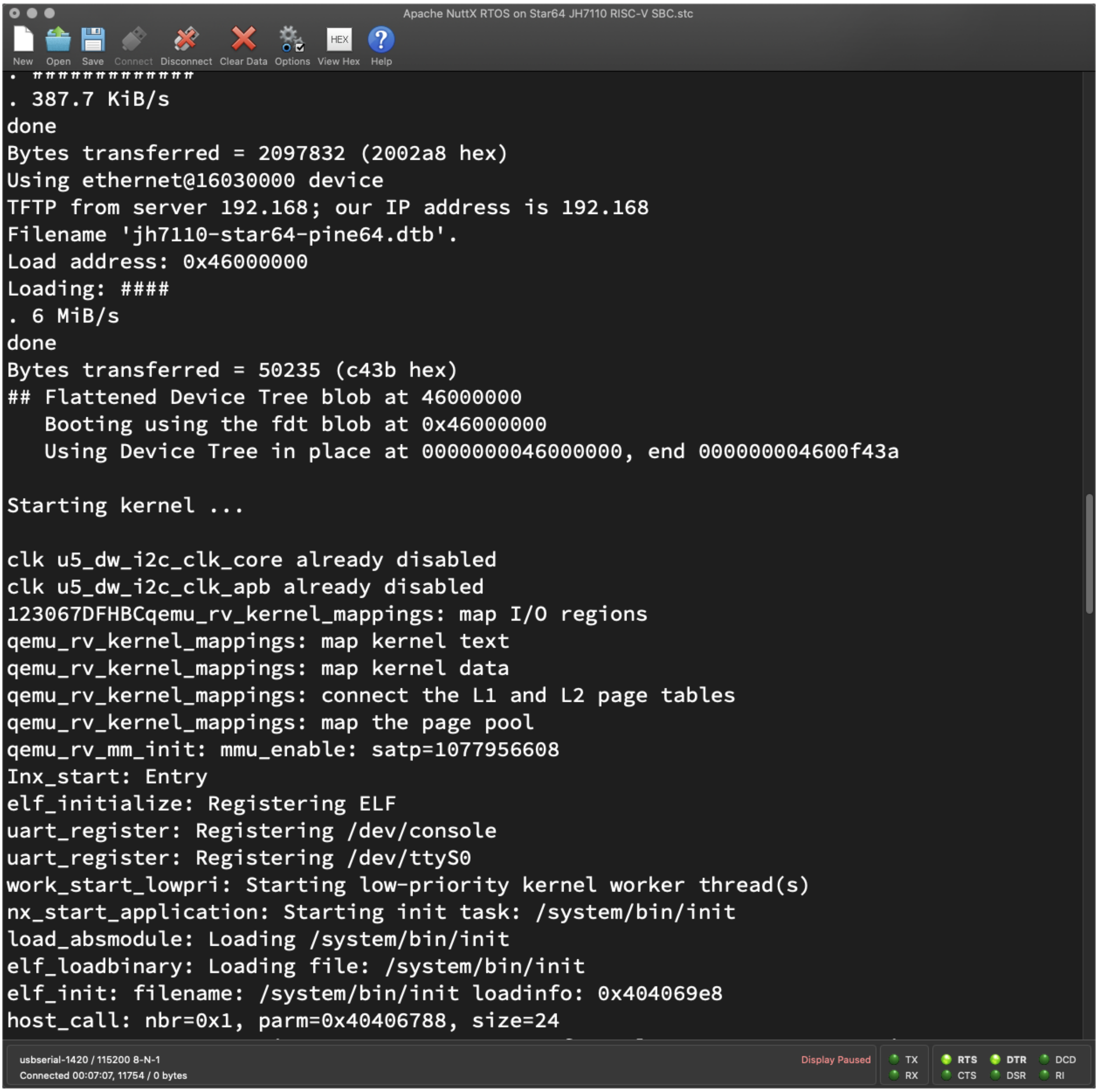
lupyuen.github.io/src/tftp.md



§7 Appendix: Boot Script for U-Boot Bootloader

Earlier we saw boot_targets and bootcmd_tftp. How do they work?

We talked about **boot_targets** and **bootcmd_tftp**…

- **"Configure U-Boot for TFTP"**

Let's figure out how they will **Auto-Boot NuttX** (or Linux) from the Network…

1. At startup, U-Boot Bootloader always executes the **Boot Script** in **bootcmd**.

2. **bootcmd** is set to…

   ```
   ## Load the VisionFive 2 Environment from MMC
   run load_vf2_env;

   ## Load the Boot Environment from MMC
   run importbootenv;

   ## Load the Distro Environment from MMC
   run load_distro_uenv;

   ## Run the `boot2` script (missing)
   run boot2;

   ## For every Boot Target:
   ## Run the Boot Command
   run distro_bootcmd
   ```

   (Source)

   Which executes **distro_bootcmd**

3. **distro_bootcmd** is set to…

   ```
   ## For Every Boot Target...
   for target in ${boot_targets};

     ## Run the Boot Command for the Target
     do run bootcmd_${target};
   done
   ```

   (Source)

4. Previously we changed **boot_targets** to…

   ```
   mmc0 dhcp  tftp
   ```

   (Source)

   Which means U-Boot will execute this sequence…

   - **bootcmd_mmc0**: Try to boot from MicroSD

(See below)

- **bootcmd_dhcp**: Try to boot from DHCP+TFTP Combo Server

  (See below)

- **bootcmd_tftp**: Try to boot from TFTP

5. We saw **bootcmd_tftp** earlier…

   "Configure U-Boot for TFTP"

   It boots NuttX (or Linux) over the Network via TFTP.

And that's how U-Boot Bootloader boots NuttX (or Linux) over the Network at startup!

Note: Don't use the special variable **serverip**, it will change after running **tftpboot**!

§7.1 Boot from MMC0

What's in bootcmd_mmc0?

bootcmd_mmc0 tries to boot from MicroSD…

```
## Set Device Number
devnum=0;

## Boot from MMC
run mmc_boot
```

(Source)

mmc_boot is…

```
if mmc dev ${devnum};
then
  devtype=mmc;
  run scan_dev_for_boot_part;
fi;

mmcbootenv=run scan_mmc_dev;
setenv bootpart ${devnum}:${mmcpart};

if mmc rescan;
then
  run loadbootenv && run importbootenv;
  run ext4bootenv && run importbootenv;

  if test -n $uenvcmd;
  then
    echo Running uenvcmd ...;
    run uenvcmd;
  fi;
fi
```

(Source)

§7.2 Boot from DHCP

What about bootcmd_dhcp?

bootcmd_dhcp tries to boot from DHCP+TFTP Combo Server.

It assumes that the DHCP Server is also a TFTP Server.

(We should probably disable **autoload**)

bootcmd_dhcp is set to…

```
devtype=dhcp;

## Load the Boot Script from DHCP+TFTP Server
## scriptaddr=0x43900000
## boot_script_dhcp=boot.scr.uimg
if dhcp ${scriptaddr} ${boot_script_dhcp};
then
  source ${scriptaddr};
fi;

## Set the EFI Variables
## fdtfile=starfive/starfive_visionfive2.dtb
setenv efi_fdtfile ${fdtfile};
setenv efi_old_vci ${bootp_vci};
setenv efi_old_arch ${bootp_arch};
setenv bootp_vci PXEClient:Arch:00027:UNDI:003000;
setenv bootp_arch 0x1b;

## Load the Kernel Image from DHCP+TFTP Server...
## kernel_addr_r=0x40200000
if dhcp ${kernel_addr_r};
then

  ## Load the Device Tree from the DHCP+TFTP Server
  ## fdt_addr_r=0x46000000
  ## efi_fdtfile=starfive/starfive_visionfive2.dtb
  tftpboot ${fdt_addr_r} dtb/${efi_fdtfile};

  ## Set the RAM Address of Device Tree
  ## fdt_addr_r=0x46000000
  if fdt addr ${fdt_addr_r};
  then

    ## Boot the EFI Kernel Image
    ## fdt_addr_r=0x46000000
    bootefi ${kernel_addr_r} ${fdt_addr_r};
  else

    ## Boot the EFI Kernel Image
    ## fdtcontroladdr=fffc6aa0
    bootefi ${kernel_addr_r} ${fdtcontroladdr};
  fi;
fi;

## Unset the EFI Variables
setenv bootp_vci ${efi_old_vci};
setenv bootp_arch ${efi_old_arch};
setenv efi_fdtfile;
setenv efi_old_arch;
setenv efi_old_vci;
```

(Source)

(**dhcp** explained here)

(**tftpboot** explained here)

(**fdt** explained here)

(**booti** explained here)

We used this as the template for our TFTP Boot Script **bootcmd_tftp**.

§8 Appendix: Commands for U-Boot Bootloader

We talked about the **U-Boot Bootloader** in previous articles…

- **"U-Boot Bootloader for Star64"**
- **"U-Boot Bootloader Log for Star64"**
- **"U-Boot Settings for Star64"**
- **"U-Boot Commands for Star64"**

Below are the **U-Boot Bootloader Commands** mentioned in this article.

We ran "help <command>" to explain the commands…

§8.1 dhcp Command

dhcp - boot image via network using DHCP/TFTP protocol

- **dhcp** [loadAddress] [[hostIPaddr:]bootfilename]

(Source)

§8.2 tftpboot Command

tftpboot - boot image via network using TFTP protocol

- **tftpboot** [loadAddress] [[hostIPaddr:]bootfilename]

(Source)

(Same as **dhcp** Command?)

Note: Don't use the special variable **serverip**, it will change after running **tftpboot**!

§8.3 booti Command

booti - boot Linux kernel 'Image' format from memory

- **booti** [addr [initrd[:size]] [fdt]]

  boot Linux flat or compressed 'Image' stored at 'addr'

The argument ‘initrd’ is optional and specifies the address of an initrd in memory. The optional parameter ‘:size’ allows specifying the size of a RAW initrd.

Currently only booting from gz, bz2, lzma and lz4 compression types are supported. In order to boot from any of these compressed images, user have to set kernel_comp_addr_r and kernel_comp_size environment variables beforehand.

Since booting a Linux kernel requires a flat device-tree, a third argument providing the address of the device-tree blob is required. To boot a kernel with a device-tree blob but without an initrd image, use a ‘-’ for the initrd argument.

(Source)

§8.4 bootefi Command

bootefi - Boots an EFI payload from memory

- **bootefi** <image address> [fdt address]

  boot EFI payload stored at address <image address>.

  If specified, the device tree located at <fdt address> gets exposed as EFI configuration table.

- **bootefi** bootmgr [fdt address]

  load and boot EFI payload based on BootOrder/BootXXXX variables.

  If specified, the device tree located at <fdt address> gets exposed as EFI configuration table.

(Source)

Will it work for NuttX?

Nope it won’t, since NuttX isn’t a UEFI Binary…

```
$ bootefi ${kernel_addr_r} ${fdt_addr_r}
Card did not respond to voltage select! : -110
Card did not respond to voltage select! : -110
No EFI system partition
No UEFI binary known at 0x40200000
```

That’s why we call **booti** to boot NuttX.

§8.5 fdt Command

fdt - flattened device tree utility commands

- **fdt** addr [-c] <addr> [<length>]

  Set the [control] fdt location to <addr>

- **fdt** apply <addr>

Apply overlay to the DT

- **fdt** move <fdt> <newaddr> <length>

  Copy the fdt to <addr> and make it active

- **fdt** resize [<extrasize>]

  Resize fdt to size + padding to 4k addr + some optional <extrasize> if needed

- **fdt** print <path> [<prop>]

  Recursive print starting at <path>

- **fdt** list <path> [<prop>]

  Print one level starting at <path>

- **fdt** get value <var> <path> <prop>

  Get <property> and store in <var>

- **fdt** get name <var> <path> <index>

  Get name of node <index> and store in <var>

- **fdt** get addr <var> <path> <prop>

  Get start address of <property> and store in <var>

- **fdt** get size <var> <path> [<prop>]

  Get size of [<property>] or num nodes and store in <var>

- **fdt** set <path> <prop> [<val>]

  Set <property> [to <val>]

- **fdt** mknode <path> <node>

  Create a new node after <path>

- **fdt** rm <path> [<prop>]

  Delete the node or <property>

- **fdt** header [get <var> <member>]

  Display header info

  get - get header member <member> and store it in <var>

- **fdt** bootcpu <id>

  Set boot cpuid

- **fdt** memory <addr> <size>

  Add/Update memory node

- **fdt** rsvmem print

  Show current mem reserves

- **fdt** rsvmem add <addr> <size>

  Add a mem reserve

- **fdt** rsvmem delete <index>

  Delete a mem reserves

- **fdt** chosen [<start> <end>]

  Add/update the /chosen branch in the tree

  <start>/<end> - initrd start/end addr

Note: Dereference aliases by omitting the leading '/', e.g. fdt print ethernet0.

(Source)