# DEC RL01/RL02 DISK-DRIVE EMULATOR

## + Cloner + Reader + (Writer)

## User Manual for the DE10-Nano board

## *Version 2.8E*


**DE10-Nano board with interface**
**SoC/HPS environment: Cyclone V FPGA + ARM Cortex-A9 CPU.**

**Emulates up to 4 RL01/RL02 drives simultaneously**
**Supports mixed environment of emulated + real RL drives**
**Access to 16 x 4 RL01/RL02 configurations sets**
**Support .DSK data format**
**Open FPGA-SoC-Linux environment**
**SoC/HPS based disk emulator for the DEC RL01 and RL02 disk drives**

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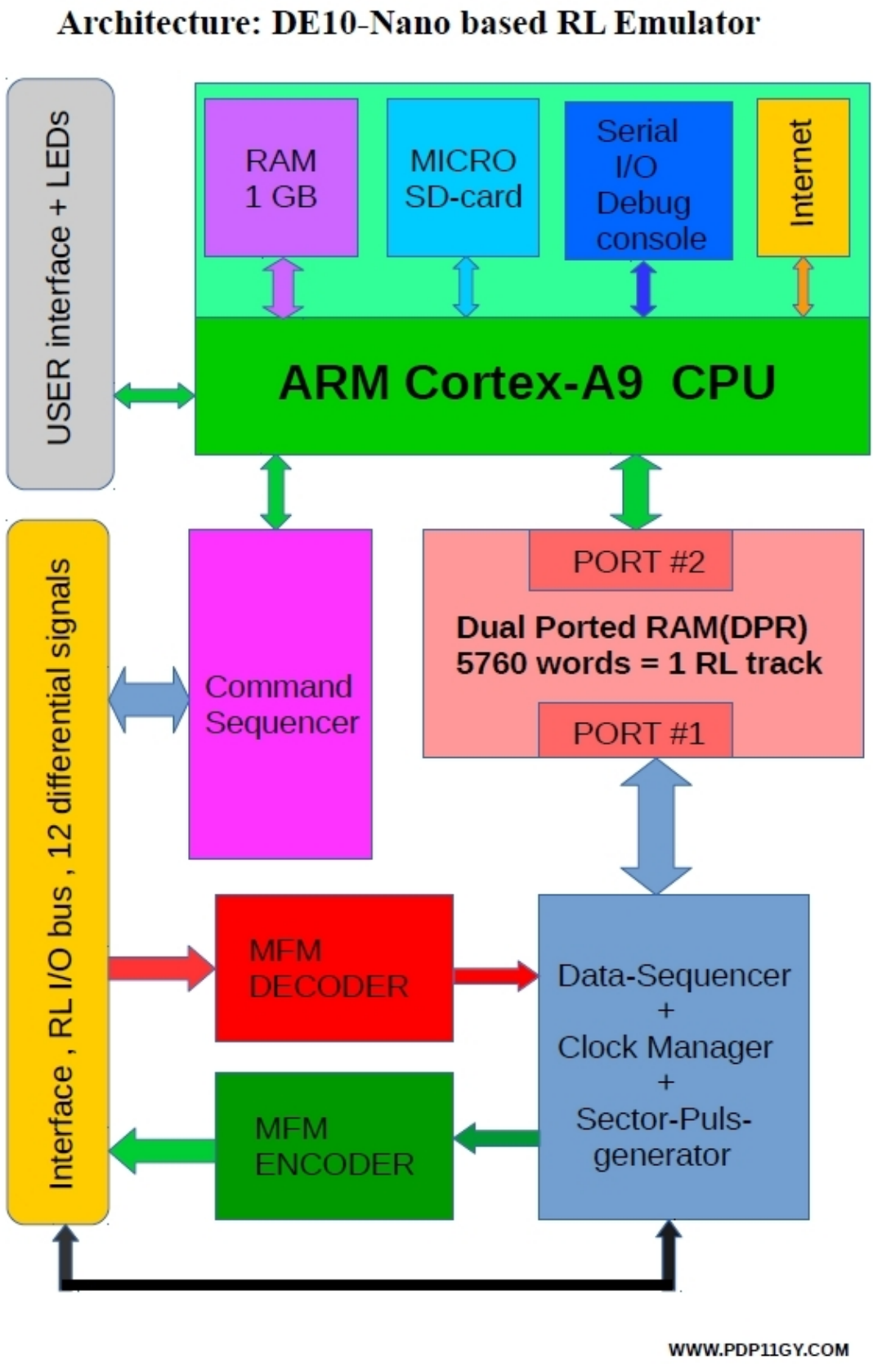
# Overview & Architecture



# Secure the vintage software and preserve it on new technology

## Overview: 2021

Project Start was in 2009, details on my homepage www.pdp11gy.com . The complete application is now ported to an open Linux SoC/HPS environment. In my case, it is the **DE10-Nano** board with Cyclon-V FPGA and 800MHz dual-core ARM Cortex-A9 processor. The performance increase is impressive. For example: Reading 4 RL images only takes about 5 seconds. With this project, much more is possible in addition to the RL-emulator and RL-cloner/reader/writer . It is possible to run the software **and** all SIMH emulators on a single board, in this case the **DE10-Nano** board. A PDP-11, PDP-8 and VAX emulator with all available RL-based software is running on this "one hand" large board. A Raspberry PI connected via network can be used for development purposes with the graphical interface. For example: The compiled programs like SIMH CPU-emulators can be copied it to the DE10-Nano board because it's binary compatible!

**Architecture:**

Basically, the design of my DEC RL02/RL01 disk drive emulator and reader works like a Solid-State-Disk(SSD), interfacing the DEC RL-disk serial bus signals (1980) to the current FPGA technology. The heart of my design is a DPR ( Dual Ported RAM ) which can hold one RL-track. DPR-Port #1 is responsible for the firmware communication like MFM De/En-coding, provides the complete data transfer to/from DPR-Port #1 based on a data sequencer and runs completely automatically. DPR-Port #2 is responsible for the data transfer to/from theARM Cortex-A9 CPU. Sounds easy, but it was very difficult to construct the right data format emulating the cartridge format with CRC and all the servo information. The CPU is also responsible for the data transfer in the memory with up to 4 emulated RL drives and finally also for the transfer to/from the SD card. The operation of the RL02/RL01 emulator is best viewed with a VIDEO via YouTube, however in the first version from **2012**, based on the DE1-Board.
https://www.youtube.com/watch?v=0i3ypBU39as

# Data format

The DEC RL01/RL02 disk drive did have a capacity of 5.2MB/10.4MB, 2 Heads(surfaces), 256/512 cylinder, 40 sectors/track. 1 sector contains 128 16-bit words (256 Byte) of Data + 12 16-Bit words for Servo/Header/CRC Data = 140 words(280 Byte)/sector. The emulater is using the .DEC format which contains all the information plus a serial number and the bad sector file. Another disk format is the disk image structure **.DSK** which is used for CPU emulators.

**This format is full supported and implemented inline. At write operation, the .DEC file and the .DSK file will be written. At read operation, first try is to read the .DEC file. If it does not exist, the .DSK file will be read.**

**RL02: .DSK file = 10485760 byte .DEC file = 11796992 byte**
**RL01: .DSK file = 5242880 byte .DEC file = 5898752 byte**

The .DEC files are **compatible** to all my other RL-emulators.

# Operating Modes

**Emulator Mode** This mode supports a combination of real and emulated RL disk drives. Thus, it is possible to copy the data from a real disk drive into the emulated environment. However, there is still a computer system, e.g. a PDP-11 required. The interface is working in **Slave Mode** with the program **rlemulator**

**Clone Mode** With this additional implementation, the need of a computer like a PDP-11 is no longer necessary. It is possible to read (and write) directly a RL disk and save it as a .DSK file. In addition, read errors will be corrected as good as possible before saving the data. The interface is working in **Master Mode** with the program **clonerl**

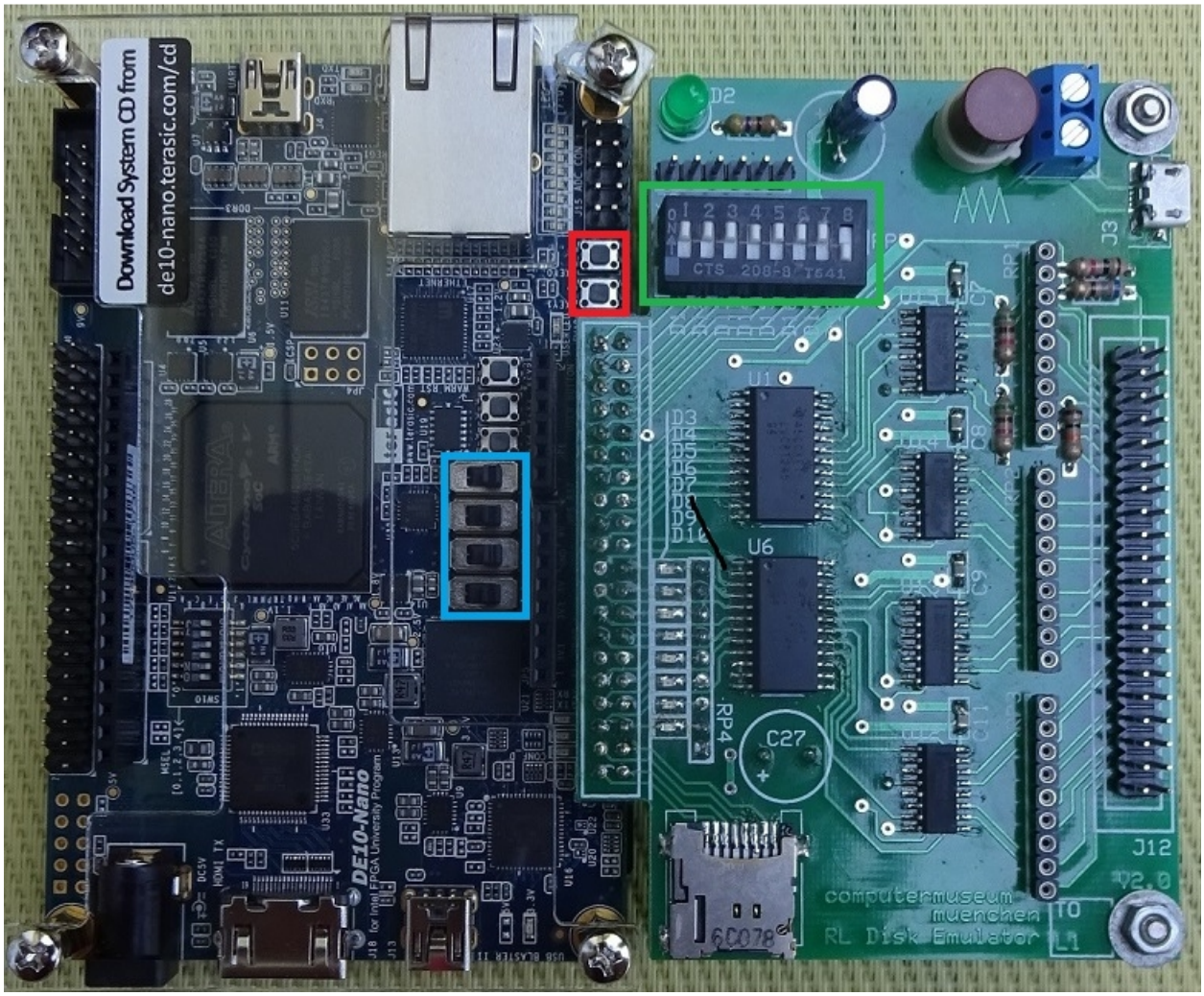
Note: The clone/write mode is available, but I have never tested this mode on a real RL drive. In the end, it doesn't make any sense at all. It was just a personal challenge.

**For the hardware, this means that only the 40pin flat-cable has to be plugged into the RL interface board by 180. degrees as shown in the following overview:**

| FPGA+PINs | | | Emulator-Mode | | Clone-Mode | |
|---|---|---|---|---|---|---|
| AG25=13 | B/A= | 01 | Power_OK | -\|+ | 39 | ---------- |
| AH26=14 | D/C= | 03 | Drive-sel_0 | -\|+ | 37 | Drive-Error +\|- |
| AH24=15 | F/E= | 05 | Drive-sel_1 | -\|+ | 35 | Drive-ready +\|- |
| AF25=16 | J/H= | 07 | Write-gate | -\|+ | 33 | Sector +\|- |
| ------- | L/K= | 09 | ---------- | | 31 | ---------- |
| AG23=17 | N/M= | 11 | System-Clk | -\|+ | 29 | Status-Clk +\|- |
| ------- | R/P= | 13 | ---------- | | 27 | ---------- |
| AF23=18 | T/S= | 15 | Write-data | -\|+ | 25 | Status-IN +\|- |
| ------- | V/U= | 17 | ---------- | | 23 | ---------- |
| AG24=19 | X/W= | 19 | Command | -\|+ | 21 | Read-data +\|- |
| AH22=20 | Z/Y= | 21 | Read-data | -\|+ | 19 | Command +\|- |
| ------- | BB/AA= | 23 | ---------- | | 17 | ---------- |
| AH21=21 | DD/CC= | 25 | Status-IN | -\|+ | 15 | Write-data +\|- |
| ------- | FF/EE= | 27 | ---------- | | 13 | ---------- |
| AF22=25 | JJ/HH= | 29 | Status-Clk | -\|+ | 11 | System-Clk +\|- |
| ------- | LL/KK= | 31 | ---------- | | 09 | ---------- |
| AG20=27 | NN/MM= | 33 | Sector | -\|+ | 07 | Write-gate +\|- |
| AH19=32 | RR/PP= | 35 | Drive-ready | -\|+ | 05 | Drive-sel_1 +\|- |
| AH18=34 | TT/SS= | 37 | Drive-Error | -\|+ | 03 | Drive-sel_0 +\|- |
| ------- | VV/UU= | 39 | ---------- | | 01 | Power_OK +\|- |

**However, there is one exception, the Power_OK signal. Details and how to modify the interface board on Page 7**

# Hardware: DE10-Nano + Interface board




**slide switches** **0-3 : select one of 16 disk set: 0 to F**

**Button 1** Reset / Restart after Reset

**Button 2** Reconfigure / Exit after Reset

**SW-0 (Nr.8) - SW-7(Nr.1) :**

**SW-0**(Nr.8) **Initialize** a new disk subset , selected by the **slide switches**

**SW-1**(Nr.7) **Force power OK**

**SW-2**(Nr.6) **Debug mode ON/OFF**

**SW-3**(Nr.5) RL drive type, **RL01 or RL02** ( ON)

**SW-7 – SW-4 :** 4 disk units, **DL3: - DL0:** will be selected and configured.
All 4 switches OFF = OFFLINE mode.

**Interface LED's** (from right to left):

| | |
|---|---|
| **LED 0** | heartbeat (blinking) |
| **LED 1** | Power OK |
| **LED 2** | Read/Seek in progress |
| **LED 3** | Write in progress |
| **LED 4** | Configured Unit dl3 active |
| **LED 5** | Configured Unit dl2 active |
| **LED 6** | Configured Unit dl1 active |
| **LED 7** | Configured Unit dl0 active |

**Pluggable resistor networks:**
Necessary if the interface board is connected directly to the RL controller.

**Serial Interface:**
The serial interface is configured for **19200** baud based on a 6 pin connector with + 3.3 Volt.
A “RoHS TTL-232R-3V3” USB converter will provide PC-connection.

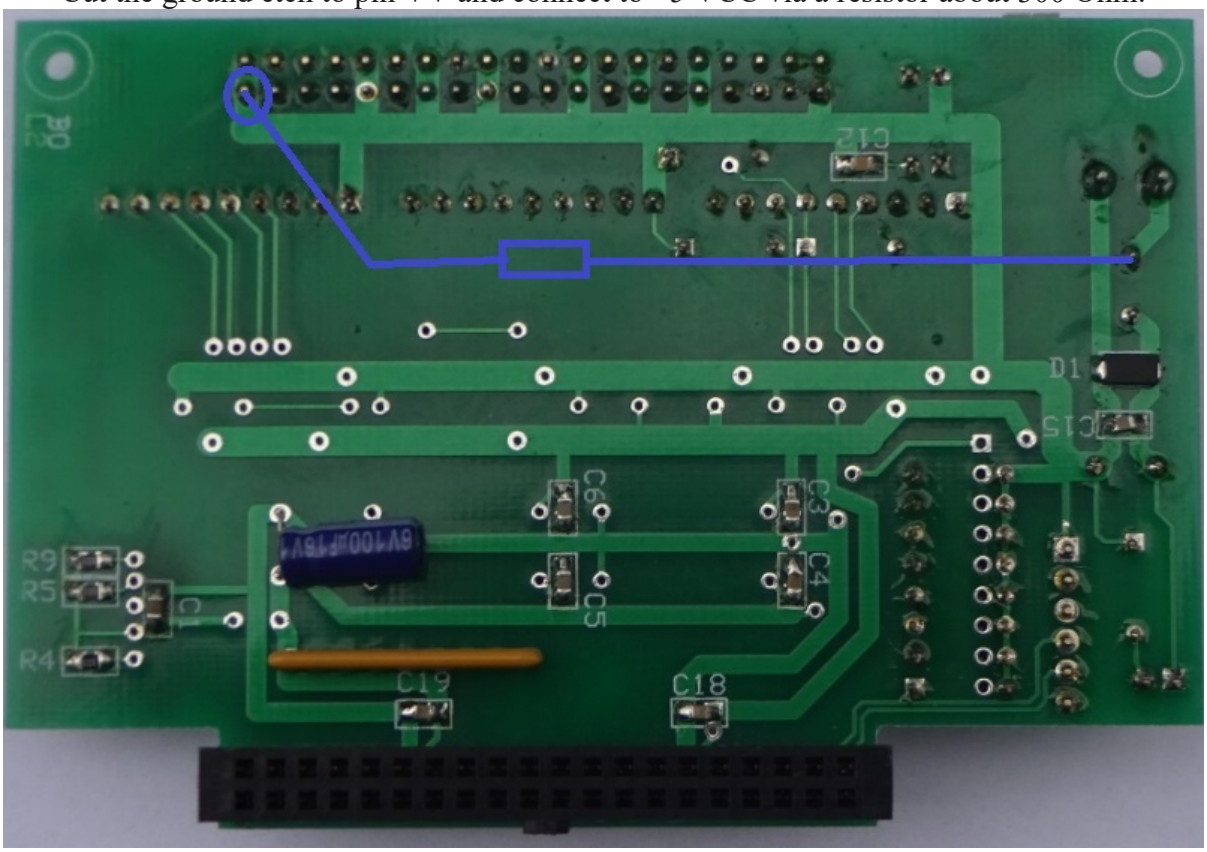
**Battery Backup:**
The additional micro-USB connector is available for connecting a standard Handy Power Bank.
This is a very simple and cost-effective Battery Backup implementation.

**Micro-SD**
Is not used and is replaced by the onboard Micro-SD from the DE10-Nano board.

## Clone-Mode: Power_OK Signal:

This signal is present at PIN B as input in slave mode and as output at pin VV in master mode. However, the pin VV is connected to ground on the interface board.

**Todo:**
Cut the ground etch to pin VV and connect to +5 VCC via a resistor about 300 Ohm:

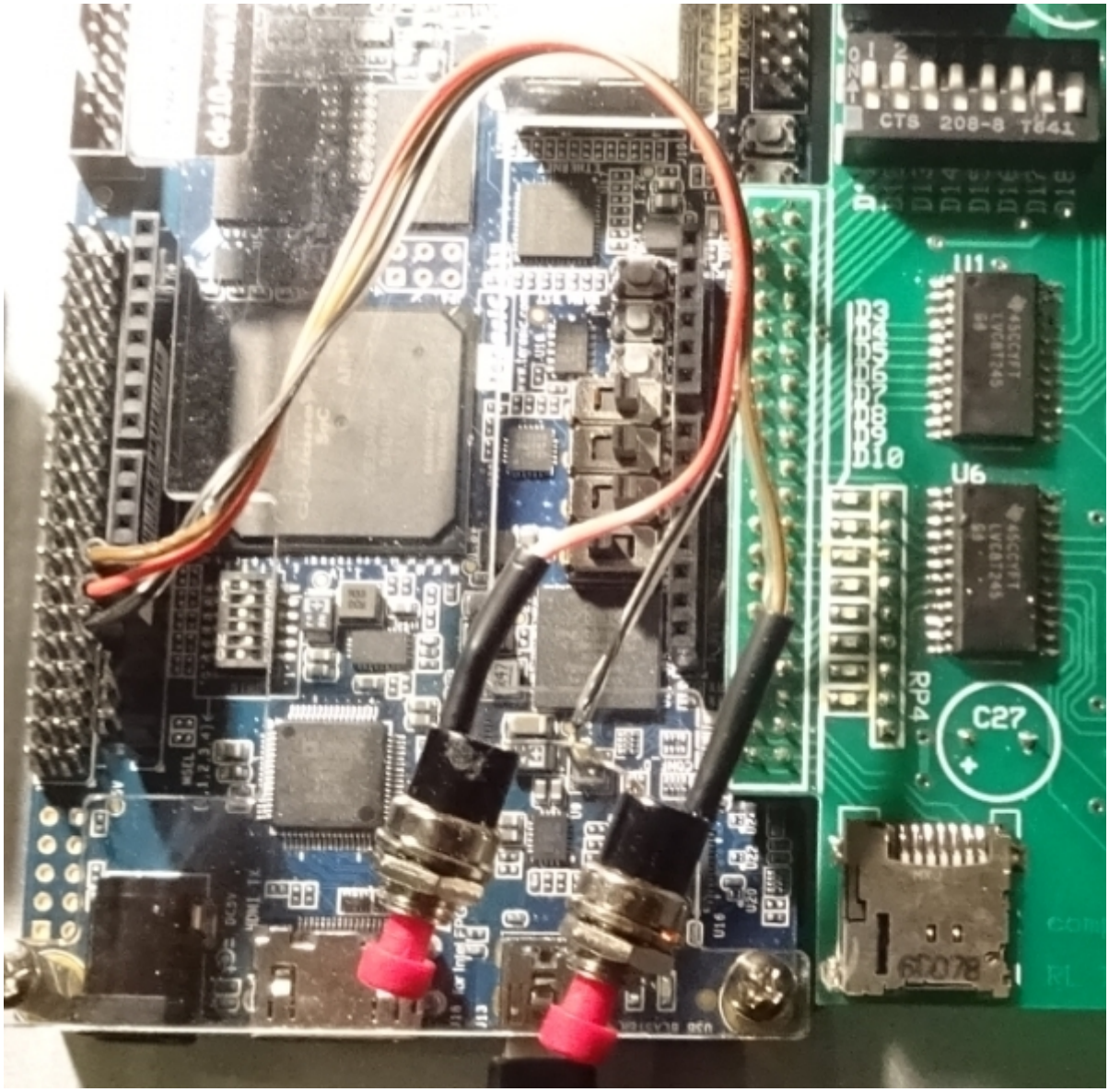


## 2.2 Reset/Reconfig buttons

Unfortunately, the reset and reconfig buttons 1 and 2 on the DE10 Nano board are very small and difficult to reach. Now it is possible to control the reset/reconfig function alternatively via 2 external button. These buttons must be connected to the Arduino connector as follows:

Arduino_IO13 = AH12 (Button 1) = reset/exit
Arduino_IO12 = AH11 (Button 2) = reconfig/restart
See also DE10 User Guide 3.6.3 Arduino Uno R3 Expansion Header , page 30

**Design example:**

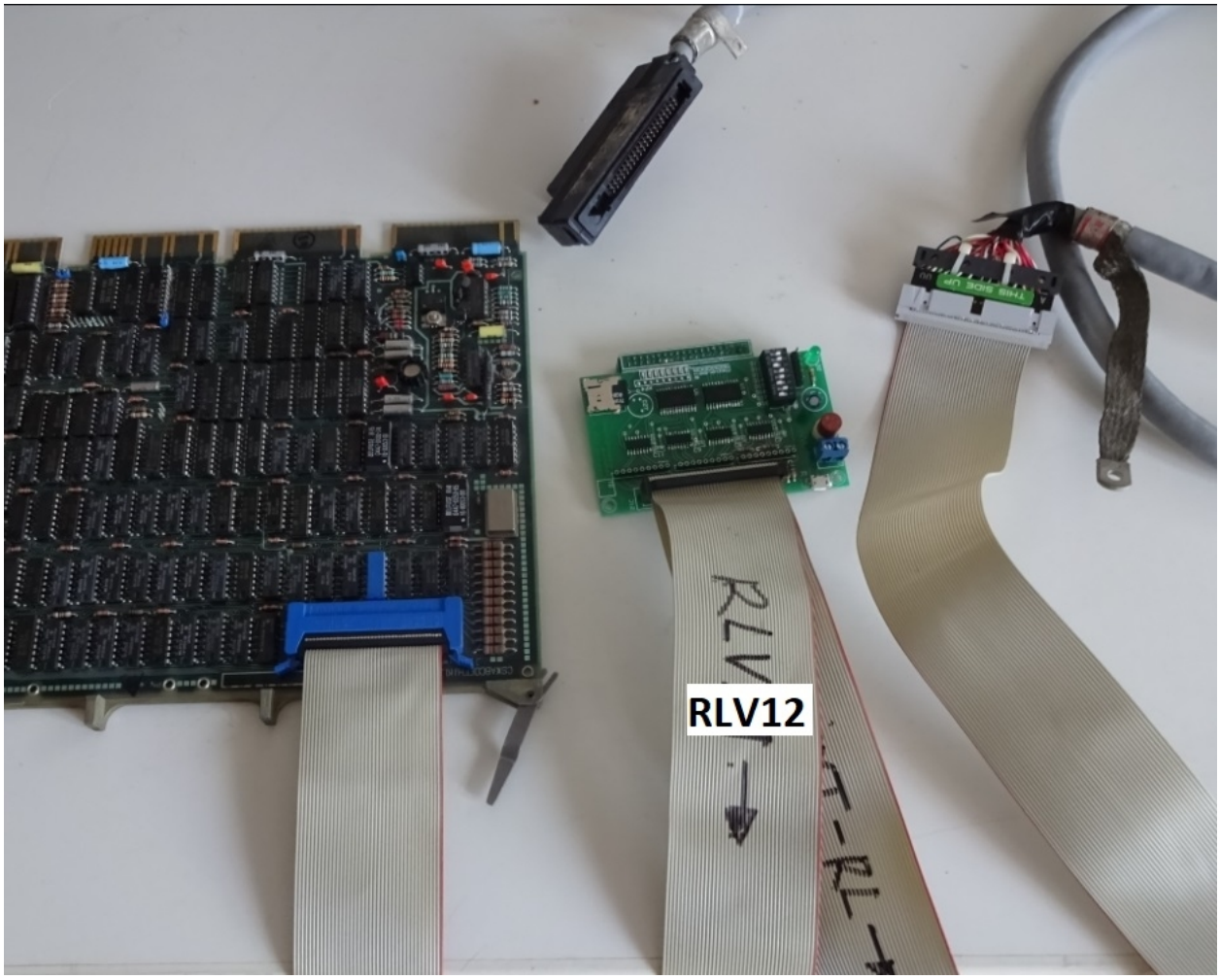


# Environment and Startup

**Overview of the hardware and software setup including step-by-step procedures from installing the necessary software tools to use the DE10-Lite board.**

**This example shows a Q-BUS implementation with RLV12 controller**

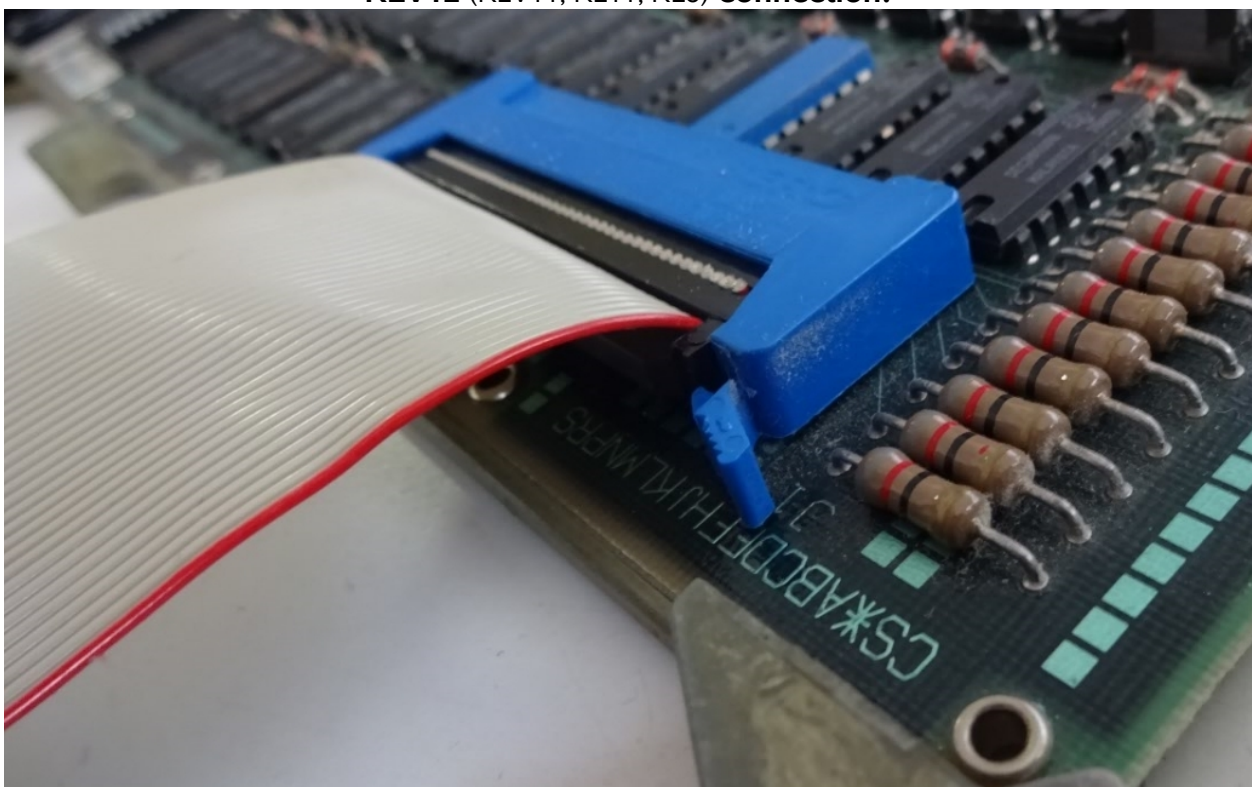
**The following figure shows the connections based on a RLV12 Q-BUS controller-board to the emulator board and to an external RL disk drive.**



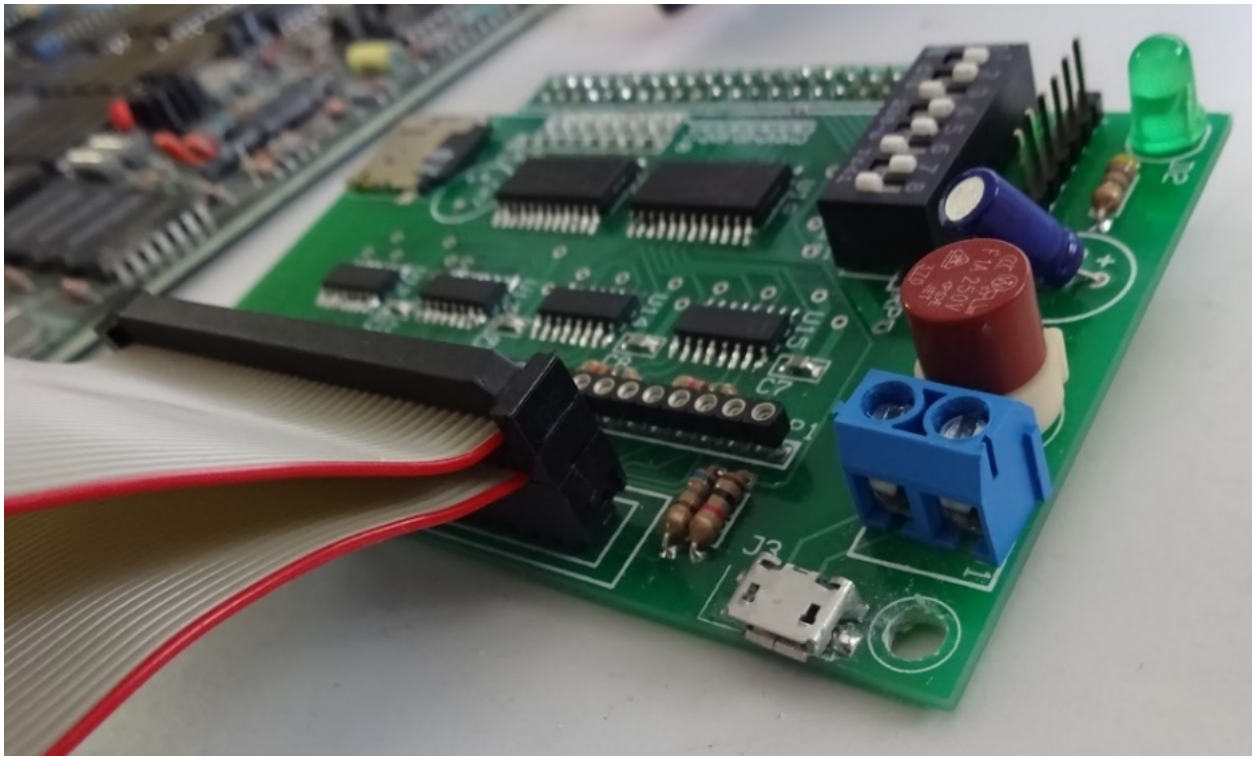

**A 40-pin flat ribbon cable is required for the connections**

**The details of the connections are shown in the next 3 pictures**

**RLV12** (RLV11, RL11, RL8) **connection:**



**Emulator board connection:**

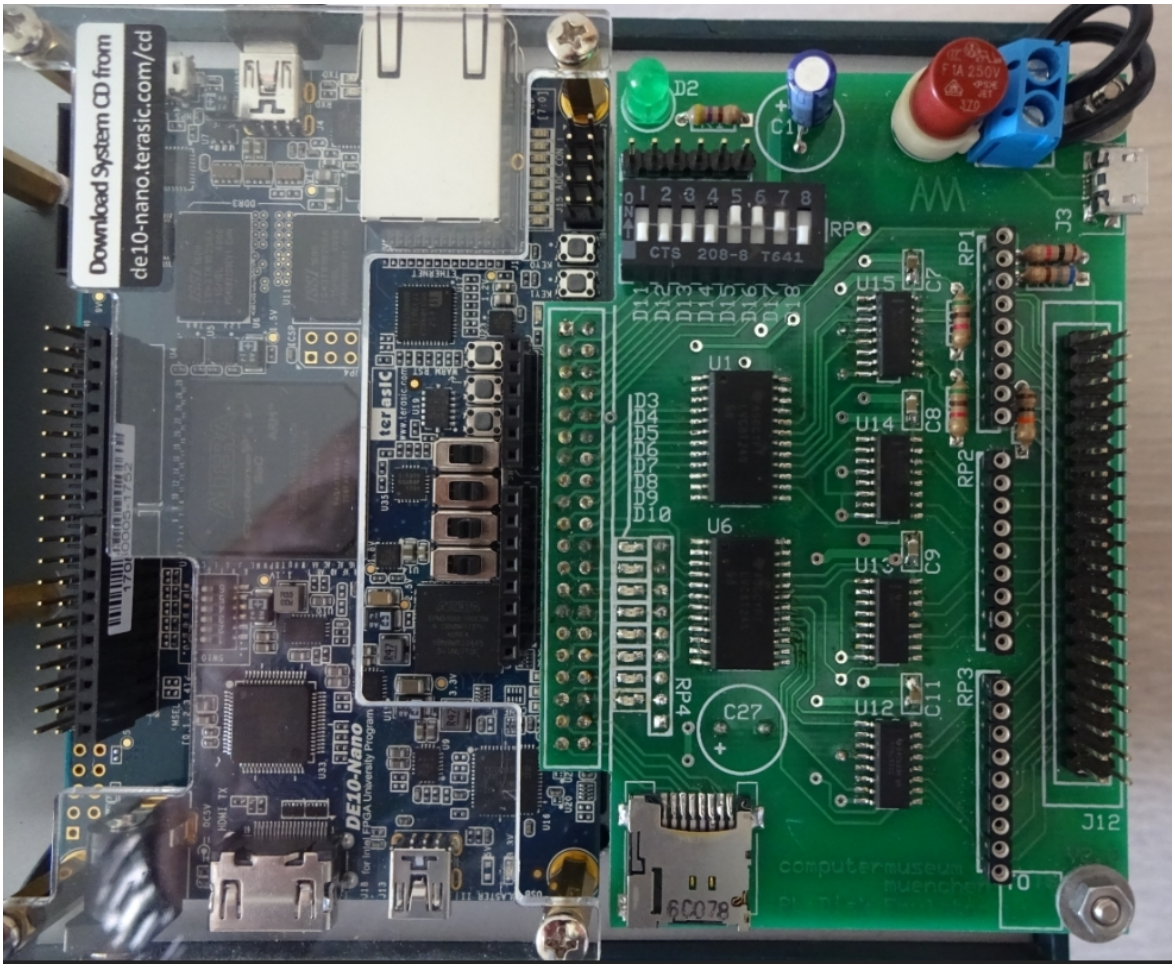


**RL-BUS connection:**


**Disconnect if no external RL-drive is used , but install the 3 terminator resistor-networks on the emulator board.**

**Jumper settings for start-up/test example, NO external connection is required.**

**OFFLINE mode, DEBUG mode, drive-type=RL02, configured device: none, Force POK**



# Firmware and Software

## Both programs, rlemulator and clonerl, need the same firmware

**We recommend to download and install the Unix kernel**
**de10_nano Linux Console (kernel 4.5) V 1.3**
Details in the terasic manual Getting Started Guide, **de10-nano.terasic.com/cd**

## Quick Start:

Download file rlv28e.zip from my homepage, http://www.pdp11gy.com or from GitHub: https://github.com/pdp11gy/DEC-RL02-01-disk-emulator-reader-cloner-writer . Unzip this file and follow the instructions in the README.txt file.

The firmware can be loaded in 3 different ways.

### 1) : Load FPGA from Linux **My recommendation!** see next page

The following 2 additional options require the additional software : Quartus programmer. It is intended for developers rather than pure users.

### 2): Load .sof file (NOT permanent) : Required: Quartus Lite Version 16.1

- De0-Nano-SoC DIP switch (SW10) to default configuration, see page 12 @ User_manual
- unzip the file "rlv28e.zip"
- Start Quartus Lite Version 16.1
- Make sure, your USB connection to the DE10-Nano is working.
- Follow the instruction in the DE10-Nano_User_manual at page 15 and load the **RL_EMULATOR_SoC.sof** file.
- After download , the heartbeat LED schould be blinking.

### 3) Permanent (EPCS): Required: Quartus Lite Version 16.1

- De0-Nano-SoC DIP switch (SW10) to EPCS configuration, see page 12 @ User_manual
- unzip the file "rlv28e.zip"
- Start Quartus Lite Version 16.1
- Make sure, your USB connection to the DE10-Nano is working.
- Follow the instruction in the DE10-Nano_User_manual at page 112 and flash the DE10-Nano board with the fil **RL_EMULATOR_SoC.jic** from folder /flash.
- After re-powering the DE10-Nano board, the heartbeat LED schould be blinking.

# Load FPGA from Linux:

To load the firmware from Linux , another software is used, see
https://github.com/nhasbun/de10nano_fpga_linux_config

This software was taken over unchanged, only the Makefile was modified and the executable file is called loadrbf. As a pure user, I recommend this method because there is no additional software required like Quartus.
Here are the steps to load the firmware and start the RL emulator/cloner:

- First, copy the file "rlv28e.zip" to the DE0-Nano-SoC board, for example, using scp or winscp. Unpack the zip file and navigate to folder clonerl.

**unzip rlv28e**
**cd** rlv28e
**chmod 777 ***
The loadrbf program is using the filename fpga_config_file.rbf but the RL emulator is using the file RL_EMULATOR_SoC.rbf . Use a link to get this issue fixed as follow:

**ln -s ./flash/RL_EMULATOR_SoC.rbf fpga_config_file.rbf**

## That's all !

Directory listing:

```
root@mfmemu:~/rlv28e# ls -l
total 9984
drwxrwxrwx 2 root root    4096 Mar 30 10:48 INFOs
-rwxrwxrwx 1 root root    5514 Mar 30 10:48 README.txt
-rwxrwxrwx 1 root root 9537116 Mar 30 10:48 Subset_0.zip
-rwxrwxrwx 1 root root   40425 Mar 30 10:48 clonerl
drwxrwxrwx 2 root root    4096 Mar 30 10:48 flash
lrwxrwxrwx 1 root root      27 Mar 30 10:49 fpga_config_file.rbf ->
./flash/RL_EMULATOR_SoC.rbf
-rwxrwxrwx 1 root root   13795 Mar 30 10:48 loadrbf
-rwxrwxrwx 1 root root  559820 Mar 30 10:48 pdp11
-rwxrwxrwx 1 root root   45835 Mar 30 10:48 rlemulator
root@mfmemu:~/rlv28e#
```

**One additional folder is available with 4 bootable RL02 images using subset 0:**

```
DL0: XXDP22  CHMDLD0 XXDP+ DL MONITOR
DL1: XXDP25  CHMDLD0 XXDP+ DL MONITOR
DL2: bootable, RT-11 V05.04 C with  Macro-11, BASIC, Fortran, FOCAL + Kermit
DL3: bootable, RT-11 V05.04 C with  Macro-11, BASIC, Fortran, FOCAL + Kermit
```

**Extract the files:**
root@mfmemu:~/rlv28e# **unzip subsets.zip**
root@mfmemu:~/rlv28e# **mv subsets/*.* .**

Now you have to start first the **A**) firmware loader
and then the **B**) rlemulator or **C**) clonerl:

**A)** root@socfpga:~/rlv28e# **./loadrbf**
**B)** root@socfpga:~/rlv28e# **./rlemulator**
**C)** root@socfpga:~/rlv28e# **./clonerl**

## loadrbf program output:

```
******************************************************
MSEL Pin Config..... 0xa
FPGA State.......... Powered Off
cfgwdth Register.... 0x1
cdratio Register.... 0x0
axicfgen Register... 0x0
Nconfig pull reg.... 0x0
CONF DONE........... 0x0
Ctrl.en?............ 0x0
******************************************************
Turning FPGA Off.
Setting cdratio with 0x3.
Turning FPGA On.
Loading rbf file.
EOF reached.
******************************************************
MSEL Pin Config..... 0xa
FPGA State.......... User Phase
cfgwdth Register.... 0x1
cdratio Register.... 0x3
axicfgen Register... 0x0
Nconfig pull reg.... 0x0
CONF DONE........... 0x0
Ctrl.en?............ 0x0
******************************************************
```

## The heartbeat LED is blinking.

It takes about 10 seconds to start the Linux system. After starting the rlemulator, the 8 LED's show a quick back and forth run which means the rlemulator has been started and the communication between FPGA and HPS is working fine.

Depending on Online or **Offline** mode, a different LED pattern is started

# Software: rlemulator

### Emulated cartridge SERIAL NUMBER (SN) handling:

Up to the version 1.5, the handling of the cartridge serial numbers was static, and by default, always the same serial number was used. This can result in errors by some DEC operating systems. In this version, the cartridge serial number can be set with the content of the file **SNx.TXT** and can be changed individually for each subset at any time with a text editor. It contains the serial numbers for each 4 cartridges per disk-subset (DL0: to DL3:) in the form of 2 16-bit integer values (HEX-notation). As long as the file **SNx.TXT** is present, the serial number with the values from the file **SNx.TXT** will be always set after loading the RL images. If this is no longer necessary, then simply delete the file **SNx.TXT.** Now, the serial numbers of disk image are used. The cartridge serial number is located on the last cylinder, RL01=256, RL02=512. You can also check the serial number with a HEX editor by opening a RL02 emulator image file and navigating to the offset (h) B3A610. For example, if serial number is 1234 and 5678

**00B3A610** 00 00 00 80 34 12 78 56 00 00 00 00 FF FF FF FF

**Please do not use a (hex) editor to change the SN. It would not build the new data CRC and would therefore cause problems, like boot/dup error.**

**Offline Mode: ( SW-4 -SW-7 is OFF)**

In this operating mode, no complete RL drives are emulated, access to the SD card is not possible and the emulator can be started without external connections, primary for verify purpose. **BUT,** if you connect the RL-Bus to the emulator board :
Access to an external "real" RL drives is possible ( for test/verify purpose the external cable )
Limited access to cylinder 0-31 only is also possible. ( about 0.3 MB )

Assuming RT-11 runs from another drive, such as RX01, RX02 or RX50, alternatively, my bootable RT-11 image files are available from my homepage, then the following commands can be used without problems ( in this hardware example ) :

**dump/term dl0:** ( or dl2: , dl3: )
**dump/term/only:23730** **// get the cartridge SN**
**init dl0:** ( or dl2: , dl3: )
**copy/sys *.* dl0:** ( or dl2: , dl3: ) **( cancellation after 0.3 MB )**
**dir dl1:** ( external , "real" RL02 )

**Online Mode:**
**At leased one of the 4 SWITCHES SW-4 -SW-7 is ON**: **Online mode is selected**

## SELECT + INIT mode

With the implementation of the Select mode, 16 disk sets, each consisting of a maximum of 4 RL-images are supported. This results in a total of 16 sets and means that a maximum of 64 RL-images are available and accessable in sets of 4 RL-images. Of course you can extend this as you like because it is a Linux environment.
**The SELECT + INIT mode is activated with SW-0 on the interface board. Please note: 4 files are always created for DL0: to DL3:**
Assuming the slide switches are set to ON-OFF-OFF-OFF , disk set **8** will be used as in the following picture:


## Example_1:

Assuming, we have a real RL02 disk drive, unit **1** and we want to copy the data from the real RL02 to the emulated RL02 disk drives. First, we have to remove the terminator from the emulator board and cabling the real RL02 to be at the end of the RL-bus with connected RL-bus terminator. The real RL02 disk drive is configured as unit **dl1** and the emulator interface board is configured for RL02 units dl0, dl2 and dl3 : SWITCH 7, 6, 4 = ON , **SWITCH 5 = OFF**.

Note: The file RL02_3-8.DSK will be used instead of the .DEC file.

Starting the RL-emulator , the following messages appears on the screen :

```
     **********>  DEC RL01/RL02 EMULATOR  <**********
       SoC/HPS DE10-Nano board based Version V.2.8E
                  (c) WWW.PDP11GY.COM

             >>>>> Device Type = RL02 <<<<
             >>>>>> DEBUG-MODE = ON <<<<<<
             >>>>>> Disk-subset: 8  <<<<<<
    Configurated RL01/RL02 Unit(s): DL0: DL2: DL3:

             ******** ONLINE MODE ********

 ************************************************************************
               SOC/HPC based V2.8E RL01/RL02 disk emulator
                  developed with Quartus Version 16.1
                (C) www.pdp11gy.com  info@pdp11gy.com
                           info-file RL8.TXT
          <Edit the file RL8.TXT to change the info-message>
 ************************************************************************

+-------------------------------------------------------------------------+
|   Unit number: 0 > file RL02_0-8.DEC  used                              |
+-------------------------------------------------------------------------+

   Unit number: 1  = Not configured

+-------------------------------------------------------------------------+
|   Unit number: 2 > file RL02_2-8.DEC  used                              |
+-------------------------------------------------------------------------+

+-------------------------------------------------------------------------+
|   Unit number: 3 > file RL02_3-8.DEC  not found, using file RL02_3-8.DSK  |
+-------------------------------------------------------------------------+


 RL cartridges Serial-Numbers(HEX), located in file SN8.TXT
     DL0: 0AF3,07A2
     DL1: not in use
     DL2: 08A2,077D
     DL3: 07D4,07A4

                  selected unit: 3
 Started with operating mode:  0100 0000 1010 0001
```

Now, we can copy the data from the real RL02 disk drive unit 1 to the emulated RL02 disk drives, for example (RT-11): copy/device dl1: dl0: (dl2: / dl3:)

**Here comes a special feature:**

- Switch down the real RL02 disk drive
- Set SWITCH 2 = ON (DL2)
- Press button 2 on DE10-Lite board and following message will appear:

```
Reconfigurated RL01/RL02 Unit(s): DL0: DL1: DL2: DL3:
```

From now on, 4 RL02 units will be emulated with full access to the dl2 unit.

**Notes:**

**Customize the disk-set environment:** Feel free to modify the File RL8.TXT according to your own needs.

**Emulated cartridge SERIAL NUMBER (SN) handling:** If file SN8.TXT exist, the content will be used to set the emulated cartridge SERIAL NUMBER. Feel free to modify the File SN8.TXT to change the SERIAL NUMBER.

## Example_2: Convert .DEC file to .DSK file inline with rlemulator and start the PDP-11 emulator using SIMH.

A test RL02 image file is included in the folder socv2_1/ RL/RL02_0-9.DEC **.** It's bootable : RT-11 V05.04 C with Macro-11, BASIC, Fortran, FOCAL + Kermit

**Requirement:** ( see also page 13 )
- set slide switches to disk-set hex 9 **1-0-0-1**
- configure unit DL0: only, set SW to **0-0-0-1 ( Nr. 5 = ON )**
- copy the file `rlv28e.zip` to DE10-Nano board using scp.
- Extract the zip file:
  root@socfpga:~# **unzip rlv28e.zip**

```
// Steps:

root@socfpga:~# cd rlv28e
root@socfpga:~/rlv28e# ls

INFOs  README.txt  clonerl  flash  loadrbf  pdp11  rlemulator
subsets.zip

root@socfpga:~/rlv28e# unzip subsets
root@socfpga:~/rlv28e# chmod 777 *
root@socfpga:~/rlv28e# mv subsets/*.* .
root@socfpga:~/rlv28e# ln -s ./flash/RL_EMULATOR_SoC.rbf  fpga_config_file.rbf
root@socfpga:~/rlv28e# ls -l
total 68304
drwxrwxrwx 3 root root     4096 Mar 30 18:05 INFOs
-rw-r--r-- 1 root root      196 Mar 30 18:10 PDP11GY.INF
-rwxrwxrwx 1 root root     5514 Mar 30 18:05 README.txt
-rw-r--r-- 1 root root      367 Mar 30 18:10 RL0.TXT
-rw-r--r-- 1 root root 11796992 Mar 30 18:10 RL02_0-0.DEC
-rw-r--r-- 1 root root 11796992 Mar 30 18:10 RL02_0-9.DEC
-rw-r--r-- 1 root root 11796992 Mar 30 18:10 RL02_1-0.DEC
-rw-r--r-- 1 root root 11796992 Mar 30 18:10 RL02_2-0.DEC
-rw-r--r-- 1 root root 11796992 Mar 30 18:10 RL02_3-0.DEC
-rw-r--r-- 1 root root      431 Mar 30 18:10 RL9.TXT
```

```
-rw-r--r-- 1 root root       34 Mar 30 18:10 SN0.TXT
-rw-r--r-- 1 root root       36 Mar 30 18:10 SN9.TXT
-rwxrwxrwx 1 root root    40425 Mar 30 18:05 clonerl
drwxrwxrwx 2 root root     4096 Mar 30 18:05 flash
lrwxrwxrwx 1 root root       27 Mar 30 18:19 fpga_config_file.rbf
-> ./flash/RL_EMULATOR_SoC.rbf
-rwxrwxrwx 1 root root    13795 Mar 30 18:05 loadrbf
-rwxrwxrwx 1 root root   559820 Mar 30 18:05 pdp11
-rwxrwxrwx 1 root root    45835 Mar 30 18:05 rlemulator
drwxrwxrwx 2 root root     4096 Mar 30 18:14 subsets
-rwxrwxrwx 1 root root 10228403 Mar 30 18:05 subsets.zip

// Note: the .DEC file always has 11796992 byte

// load fimware
root@socfpga:~/rlv28e# ./loadrbf

// start the rlemulator
root@socfpga:~/rlv28e# ./rlemulator

      *********>  DEC RL01/RL02 EMULATOR  <**********
        SoC/HPS DE10-Nano board based Version V.2.8E
                    (c) WWW.PDP11GY.COM

              >>>>> Device Type = RL02 <<<<
              >>>>>> DEBUG-MODE = ON <<<<<<
              >>>>>> Disk-subset: 9  <<<<<<
    Configurated RL01/RL02 Unit(s): DL0:
              ******** ONLINE MODE ********

 ****************************************************************
              SOC/HPC based V2.2 RL01/RL02 disk emulator
                  developed with Quartus Version 16.1
                PCB design in cooperation with www.GfhR.de
                (C) www.pdp11gy.com  info@pdp11gy.com
                          info-file RL9.TXT
          <Edit the file RL9.TXT to change the info-message>

 DL0:  bootable, RT-11 V05.04 C with  Macro-11, BASIC, Fortran, FOCAL
+ Kermit
 DL1:  not configured
 DL2:  not configured
 DL3:  not configured
 ****************************************************************

+.............................................................+
|   Unit number: 0 > file RL02_0-9.DEC  used                  |
+.............................................................+

    Unit number: 1  = Not configured
```

```
    Unit number: 2  = Not configured

    Unit number: 3  = Not configured

  RL cartridges Serial-Numbers(HEX), located in file SN9.TXT
      DL0: 0AF3,07A2
      DL1: not in use
      DL2: not in use
      DL3: not in use

                   selected unit: 0
 Started with operating mode:  0100000010100001


//********* Press the RESET Button 1  or force a power fail  *********
//*****************************************************************

        ......... Shutting down system .........

+-------------------------------------------------------------------+
|    Unit number: 0  >  Write to file RL02_0-9.DEC and RL02_0-9.DSK |
+-------------------------------------------------------------------+

    Unit number: 1  not configured, will be skipped

    Unit number: 2  not configured, will be skipped

    Unit number: 3  not configured, will be skipped

  Press RESET/Button-1 for exit, Reconfig/Button-2 for restart

// the .DSK file is now available, always 10485760 byte

root@socfpga:~/socv2_1/RL# ls -l RL02_0-9.*
-rw-r--r-- 1 root root 11796992 Mar 30 18:32 RL02_0-9.DEC
-rw-r--r-- 1 root root 10485760 Mar 30 18:32 RL02_0-9.DSK

// Start the PDP-11 simulator
root@socfpga:~/socv2_1/RL# ./pdp11

PDP-11 simulator V3.9-0
sim> set CPU 11/23 512k
Disabling CR
Disabling RK
Disabling HK
Disabling TM
sim> attach RL0 ./RL02_0-9.DSK
sim> boot RL0
```

```
RT-11SJ  V05.04 C

.SET USR NOSWAP

.SET TT SCOPE

.SET EDIT KED

.INIT/NOQUE VM:

.dir

DL0DL0.INF    59                  SWAP   .SYS    27P 02-Sep-87
RT11SJ.SYS    79P 15-Jan-88       DD     .SYS     5P 02-Sep-87
DY     .SYS    4P 02-Sep-87       LS     .SYS     5P 02-Sep-87
SL     .SYS   17P 02-Sep-87       TT     .SYS     2P 02-Sep-87
VM     .SYS    3P 02-Sep-87       DU     .SYS     8P 02-Sep-87
LD     .SYS    8P 02-Sep-87       DL     .SYS     5  17-Oct-84
STARTS.COM     1  28-Mar-99       DIR    .SAV    19  02-Sep-87
PIP    .SAV   30  02-Sep-87       DUP    .SAV    49  02-Sep-87
RESORC.SAV    25  02-Sep-87       KED    .SAV    58  02-Sep-87
UCL    .SAV   16  02-Sep-87       CREF   .SAV     6  02-Sep-87
SRCCOM.SAV    26  02-Sep-87       BASIC  .SAV    53  04-Apr-83
MACRO  .SAV   61  02-Sep-87       DUMP   .SAV     9  02-Sep-87
MKDL0  .BAS    1                  MKDL2  .BAS     1
MKDL3  .BAS    1                  MKDL1  .BAS     1
SYSLIB.OBJ   216  24-Mar-87       FORTRA.SAV   206  24-Mar-87
KERMIT.INI     1  28-Jul-87       KERMIT.SAV   182  02-Apr-86
KERMIT.HLP   148  13-Apr-86       FOCAL  .SAV    36  30-Nov-84
FOCALD.SAV    38  30-Nov-84
 35 Files, 1406 Blocks
 18976 Free blocks


// Let's start BASIC

.r basic
BASIC-11/RT-11 V2.1
OPTIONAL FUNCTIONS (ALL, NONE, OR INDIVIDUAL)? ALL

READY

// If you want, try to run this small program:

10 FOR E=1 TO 30 STEP .1
20 Y=INT((SIN(E)*20)+30)
40 PRINT TAB(Y);"HELLO-1980"
100 NEXT E
```

# Software: clonerl

**Background**: I developed this program for the purpose if it is necessary to save the contents of an RL cartridge without a DEC system such as a PDP-11.

The **clonerl** program runs with the same firmware. How to load this firmware is described in detail on pages 12 to 14. Before you start the **clonerl** program, make sure that the RL-bus cable is plugged in correctly, i.e. reversed compared when using the rlemulator program. See also page 5. In the appendix, the topic of cable length, termination and grounding is addressed and discussed.
Jumper setting, see page 6. **SW-7 – SW-4 :** Select the available real RL01/RL02 disk drives. If more than one disk drive is configured then the disk drive with the lowest unit number is used. Load the fimware with **./loadrbf** and start the program: **./clonerl**

The clonerl-program first checks whether the drive is ready. Then the program tries to read the drive status. If these 2 points are met, the RL drive is positioned on track 0 and the following startup message appears:

```
     *******>  DEC RL01/RL02 Cloner/Reader <********
              SoC/HPS DE10-Nano board V.2.8E
                   (c) WWW.PDP11GY.COM

              >>>>> Device Type = RL02 <<<<
              >>>>>> DEBUG-MODE = ON <<<<<<
              **** Cloning disk-drive: DL0:
              ******** preset memory ******

    Started with operating mode:  1100 0000 1010 0001


               Drive READY signal = TRUE
                   Reset/Init drive
                 Request drive status

           Drive status:  29D  = 0000 0010 1001 1101
               Drive at cylinder position: 0
           Drive positioned to cylinder position : 0

                  ****** Select Mode ******
0=exit, 1=get status, 2=clone disk, 3=read one Cylinder, 4=seek-test, 5=write :
```

If the RL drive does not respond, the program loops and prints a "." every second until the RL drive answers by sending the drive status.

1) **get drive status.** Example:

```
get drive status:  29D  = 0000 0010 1001 1101

Load cartridge state
Spin up
Brush cycle
Load Heads
Seek-Track Counting
                                  > Seek-Linear Mode (Lock ON)
Unload Heads
Spin down
                                  > Brush Home (BH)
                                  > Heads Out (HO)

Cover OPEN (CO)
Head Selected (HS)
                                  > -reserved-
Drive Select Error (DSE)
                                  > Volume Check (VC)
Write Gate Error (WGE)
Spin Error (SPE)
Seek Time Out (SKTO)
Drive Write Locked
Head Current Error (HCE)
Write Data Error (WDE)
```

2) **clone disk.** Example

```
0=exit, 1=get status, 2=clone disk, 3=read one Cylinder, 4=seek-test, 5=write :2

 Data will be saved in file: RL02_0-clone.dsk
 set_track-0: 0000 0000 0000 0101  cylinder: 0  RAM_Address: 0
 set_track-1: 0000 0000 0001 0101
 set_track-0: 0000 0000 1000 0101  cylinder: 1  RAM_Address: 11520
 set_track-1: 0000 0000 0001 0101
 set_track-0: 0000 0000 1000 0101  cylinder: 2  RAM_Address: 23040
 set_track-1: 0000 0000 0001 0101
 set_track-0: 0000 0000 1000 0101  cylinder: 3  RAM_Address: 34560
 set_track-1: 0000 0000 0001 0101
 set_track-0: 0000 0000 1000 0101  cylinder: 4  RAM_Address: 46080
 set_track-1: 0000 0000 0001 0101
 .
 .
 .
 .
 set_track-0: 0000 0000 1000 0101  cylinder: 509  RAM_Address: 5863680
 set_track-1: 0000 0000 0001 0101
 set_track-0: 0000 0000 1000 0101  cylinder: 510  RAM_Address: 5875200
 set_track-1: 0000 0000 0001 0101
 set_track-0: 0000 0000 1000 0101  cylinder: 511  RAM_Address: 5886720
 set_track-1: 0000 0000 0001 0101
 Saved data in file: RL02_0-clone.dsk

                ****** Select Mode ******
 0=exit, 1=get status, 2=clone disk, 3=read one Cylinder, 4=seek-test, 5=write :
```

3) **read one Cylinder.** Example:

```
0=exit, 1=get status, 2=clone disk, 3=read one Cylinder, 4=seek-test, 5=write:3

 Cylinder-Nr.(0 to 255 ) :150

 rl_command-1: 0100 1011 0000 0101  RAM-Address:  1728000
 rl_command-2: 0000 0000 0001 0101  RAM-Address:  1733760
 rl_command-3: 0100 1011 0000 0001  RAM-Address:  0

 Saved data in file: RL02_cylinder-150.dsk


                ****** Select Mode ******

 0=exit, 1=get status, 2=clone disk, 3=read one Cylinder, 4=seek-test, 5=write :
```

Just for information: This is what happens on the RL drive:

```
Drive command received: 0100 1011 0000 0101
  Cylinder difference : 150     Using head 0
  to: Cylinder-Nr. 150 = RAM-address: 1728000
Drive command received: 0000 0000 0001 0101
  Cylinder difference : 0     Using head 1
  to: Cylinder-Nr. 150 = RAM-address: 1733760
Drive command received: 0100 1011 0000 0001
  Cylinder difference : 150     Using head 0
  to: Cylinder-Nr. 0 = RAM-address: 0
```

4) **seek-test.** Example:

```
0=exit, 1=get status, 2=clone disk, 3=read one Cylinder, 4=seek-test, 5=write:4


 Seek to cylinder (max = 511) :  511

 Number of loops: 3

1time: seek to cylinder 511 .....back to  cylinder 0
2time: seek to cylinder 511 .....back to  cylinder 0
3time: seek to cylinder 511 .....back to  cylinder 0
```

## 5) write . Note :

If this write mode is selected, the following menu will be available:
1=write pattern, 2=write bad sector, 3=write .dsk-file

**But !!**

**Implementing this write mode was a purely personal challenge. It does not make any sense to write on a real old RL disk drive. The idea behind it was to get the possibility to control an original RL-drive directly from the SIMH project and/or from a PiDP-11 running SIMH on it. Unfortunately, no cooperation with other people was possible and I no longer want to develop the product further with the write option. I also no longer have the option of accessing an original RL drive to test the software. Note, this part of the software was never tested on a real RL drive !! The program code is available on GitHub. The whole code is written in verilog. Maybe someone else has the time and motivation to expand and verify this option. ( I am now out of motivation and also "too old" to continue here )**

Example: clonerl and **** SIMH interface ****

```
root@socfpga:~/clonerl# ./pdp11
PDP-11 simulator V3.9-0
sim> set CPU 11/23 512k
Disabling CR
Disabling RK
Disabling HK
Disabling TM
sim> attach RL0 ./RL02_0-clone.dsk
sim> boot RL0

RT-11SJ  V05.04 C

.SET USR NOSWAP

.SET TT SCOPE

.SET EDIT KED

.INIT/NOQUE VM:
```

**For comments and questions, please contact me.**
**INFO@pdp11gy.com**

**References:**
**http://www.pdp11gy.com**
**https://github.com/pdp11gy/DEC-RL02-01-disk-emulator-reader-cloner-writer**

**https://github.com/pdp11gy/SoC-HPS-based-RL-disk-emulator**
**https://github.com/pdp11gy/DEC-RL02-RL01-disk-emulator**
**https://github.com/pdp11gy/SoC-HPS-based-MFM-disk-emulator**

## Appendix A

Programming environment:
**********
It was difficult to make everything runable because many things in the documentation and in the examples were not correct. Here is a step by step explamation to rebuild the RL-emulator if necessary or if you want to design some add-on application.

*1 : error You must define soc_cv_av or soc_a10 before compiling with HwLibs
Go to intelFPGA/16.1/embedded/ip/altera/hps/altera_hps/hwlib/include
Copy all .h files in the folder soc_cv_av and soc_a10

*2 : generate_hps_qsys_header.sh : PATH is not set correct: correct as following:

```
#!/bin/sh
PATH=/cygdrive/C/altera_lite/16.1/quartus/sopc_builder/bin:$PATH
sopc-create-header-files \
"$PWD/RL_system.sopcinfo" \
--single hps_0.h \
--module hps_0
```

*3: Modify the Makefiles, here the RL-emulator make file
software/RL_emulator/Makefile

```
#
TARGET = rlemulator
ALT_DEVICE_FAMILY ?= soc_cv_av
ALT_DEVICE_FAMILY ?= soc_a10
#
CROSS_COMPILE = arm-linux-gnueabihf-
#CFLAGS = -static -g -Wall  -I$
{SOCEDS_DEST_ROOT}/ip/altera/hps/altera_hps/hwlib/include
CFLAGS = -g -Wall  -I${SOCEDS_DEST_ROOT}/ip/altera/hps/altera_hps/hwlib/include/$
{ALT_DEVICE_FAMILY} -Dsoc_cv_av -Dsoc_a10
LDFLAGS =  -g -Wall
CC = $(CROSS_COMPILE)gcc
ARCH= arm


build: $(TARGET)
$(TARGET): main.o
        $(CC) $(LDFLAGS)   $^ -o $@
%.o : %.c
        $(CC) $(CFLAGS) -c $< -o $@

.PHONY: clean
clean:
        rm -f $(TARGET) *.a *.o *~
```

## Appendix B

**Notes concerning hardware, cable length and RL-Bus termination**

**RL-Bus chips:**
The RL disk drive and the controller used the Line Receiver chips SN75107A and Line Drivers SN75113. These chips are out of date (from 1980) and no longer available. In addition, the receiver chip SN75107A requires a negative voltage of -5 volts and is therefore difficult to handle. I replaced these chips as follows:
Line Receiver SN75107A → AM26LS32ACDR
Line Drivers SN75113 → AM26LS31CDR
It's also necessary to implement a level converter and I decided to use the chip SN74LVC8T245DWR. At least, these new chips are available in SMD technology.
**cable length:**
The RL-bus works with a frequency of 4.1 Mhz. For proper operation, the cable length should be calculated according to the **lambda**/wavelength rule. This results in a cable length of lambda 1/256 = 29.25cm. Put simply, the cable should be a multiple of about ~29cm. However, I am not a high frequency specialist and would be grateful for any advice.
**Termination :**
In general, the new chips are less critical in terms of termination, but an RL disk drive or RL disk controller has still the old driver and receiver chips. The termination is not critical in emulator mode. As described on page 9, the termination on the RL drive is completely sufficient with a 2m long ribbon cable. Termination is more critical in clone/ read mode. In addition, the receiver chips get relatively hot when cloning a complete RL disk. I had the best results with an approx.1m flat cable directly connected to the RLV12 controller with 330 OHM termination on the interface board.

# Grounding

**Very, very important**. Please make sure that ground with the same potential is available on all involved components. Line filters are built into an RL drive or in a computer like PDP-11. If the grounding is bad, there are reflections which result in data transfer problems.

Finally: The LOM data for the interface are available on my homepage.

Also: I had the idea to merge both interfaces together, i.e. the RL01/RL02-disk emulator and the MFM-disk emulator. Everything is already prepared, but I'm not a CAD specialist. In addition, there is hardly any demand. A cost estimate from an external company was too expensive for me. If anyone is interested in continuing, please contact me.

Info, MFM disk emulator: **https://github.com/pdp11gy/SoC-HPS-based-MFM-disk-emulator**

## All firmware & software is open source