《 数 字 电 路 实 验 》 实 验 报 告

实验名称： 静态和动态数码管显示实验 指导教师： 高兴宇，李扬波

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小组成员分工

- 尹超：负责基础实验内容，实验报告撰写、实验结果分析。
- 张硕：负责基础实验及拓展实验内容、实验代码编写。
- 李雨恒：负责基础实验及拓展实验协助、实验结果分析。

实验 GitHub 仓库地址

https://github.com/CarterYin/Digital_electronics_experiments

目录

§1 实验仪器与用具

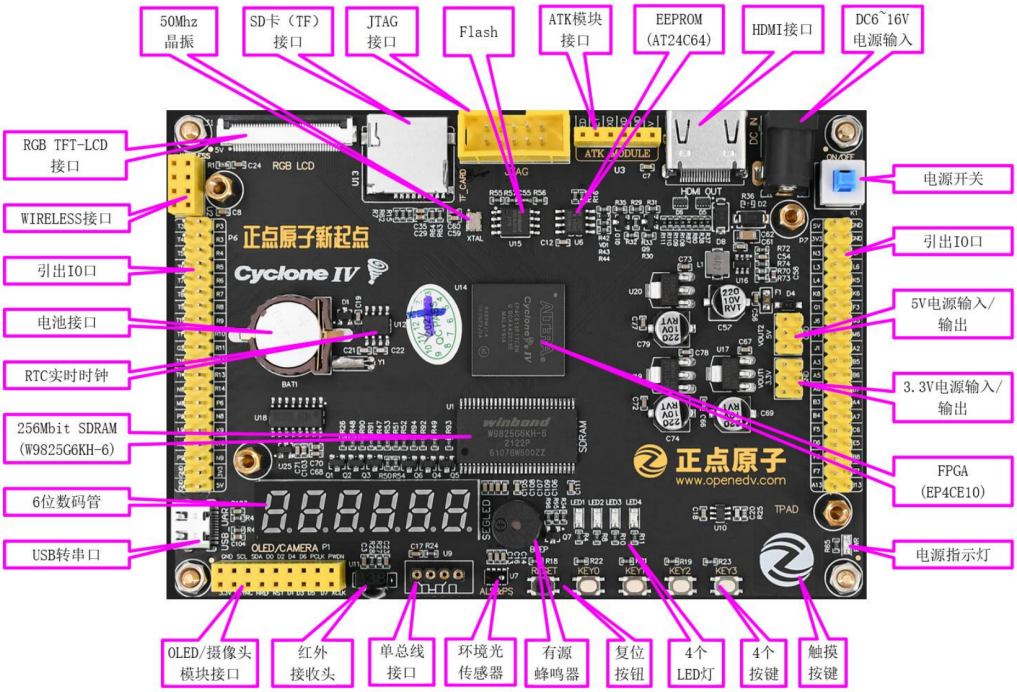

图 1: 实验仪器与用具

新起点 FPGA 开发板板载资源如下：

- 主控芯片：EP4CE10F17C8N，封装：BGA256
- 晶振：50 MHz
- FLASH：W25Q16，容量：16 Mbit（2 M 字节）
- SDRAM：W9825G6KH-6，容量：256 Mbit（32 M 字节）
- EEPROM：AT24C64，容量：64 Kbit（8 K 字节）
- 1 个电源指示灯（蓝色）
- 4 个状态指示灯（DS0 DS3：红色）
- 1 个红外接收头，并配备一款小巧的红外遥控器
- 1 个无线模块接口，支持 NRF24L01 无线模块
- 1 路单总线接口，支持 DS18B20/DHT11 等单总线传感器
- 1 个 ATK 模块接口，支持正点原子蓝牙/GPS/MPU6050/RGB 灯模块
- 1 个环境光传感器，采用 AP3216C 芯片
- 1 个标准的 RGB TFT-LCD 接口
- 1 个 OLED/摄像头模块接口
- 1 个 USB 串口
- 1 个有源蜂鸣器
- 1 个 SD 卡接口（在板子背面）
- 1 个 HDMI 接口
- 1 个标准的 JTAG 调试下载口
- 1 组 5V 电源供应/接入口
- 1 组 3.3V 电源供应/接入口
- 1 个直流电源输入接口（输入电压范围：DC6 16V）

- 1 个 RTC 后备电池座，并带电池（在板子背面）
- 1 个 RTC 实时时钟，采用 PCF8563 芯片
- 1 个复位按钮，可作为 FPGA 程序执行的复位信号
- 4 个功能按钮
- 1 个电容触摸按键
- 1 个电源开关，控制整个开发板的电源
- 两个 20×2 扩展口，共 72 个扩展 IO 口（除去电源和地）

图 2: RGB-LCD 屏

LCD 的全称是 Liquid Crystal Display, 即液晶显示屏, 它显示的每个像素点都是由集成在液晶后面的薄膜晶体管独立驱动, 因此 LCD 具有较高的响应速度以及较好的图像质量。正点原子推出的 RGB-LCD 液晶屏较多,7 寸 RGB-LCD 屏的实物图如上图所示。

LCD 的构造是在两片平行的玻璃基板当中放置液晶盒, 下基板玻璃上设置 TFT(薄膜晶体管), 上基板玻璃上设置彩色滤光片, 通过 TFT 上的信号与电压改变来控制液晶分子的转动方向, 从而达到控制每个像素点偏振光出射与否而达到显示目的。

§2 实验内容与步骤

2.1 概述

RGB-LCD 彩条显示实验

A. 按照指南开发指南第二十二章（P391）复现 RGB-LCD 彩条显示实验，熟悉引脚分配及 LCD 屏幕显示实现

RGB-LCD 字符和图片显示实验

(1) 参考指南开发指南第二十三章（P414）RGB-LCD 字符和图片显示实验，修改实验代码与逻辑，使其分别实现下述功能：

A. 显示的内容为 UCAS 文字与 UCAS-LOGO 图像，字宽和字高都设置为 64

B. 显示小组成员 3(2) 人的名字 (并排与换行均可)，并修改显示区域的大小，字宽和字高都设置为 64

C.（拓展内容）添加控制功能，与按键绑定，按下按键 1，2，3，4 分别显示小组成员姓名，小组成员学号，“中国科学院大学数字电路”，自定义图像 (非 UCAS-LOGO，注意图像大小)

2.2 本次实验的快速实验步骤

LCD 连接开发板

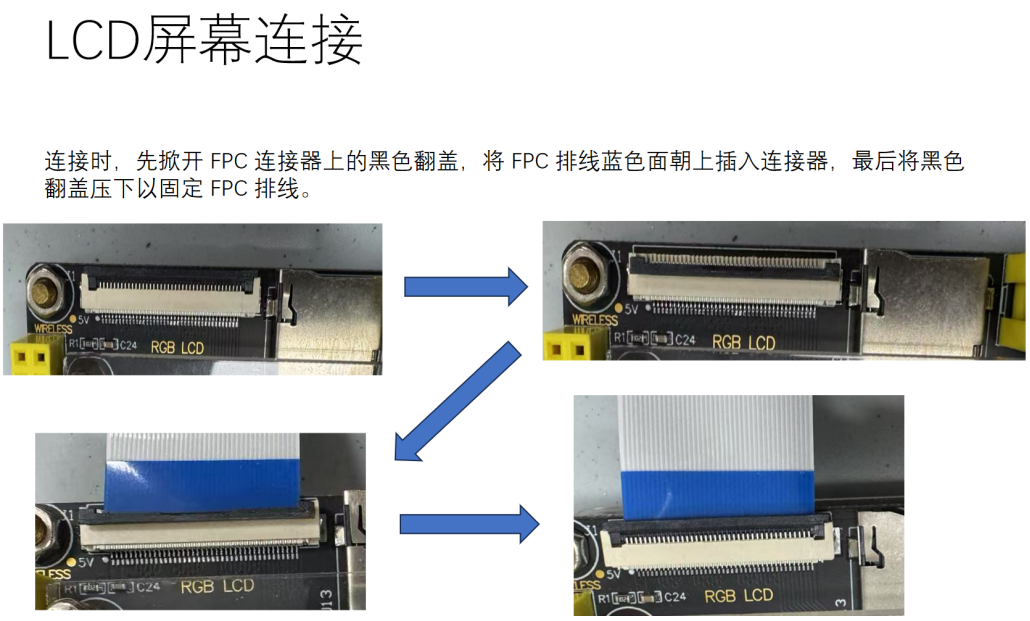

图 3: LCD 连接开发板

字符到点阵—使用 PCLtoLCD 工具

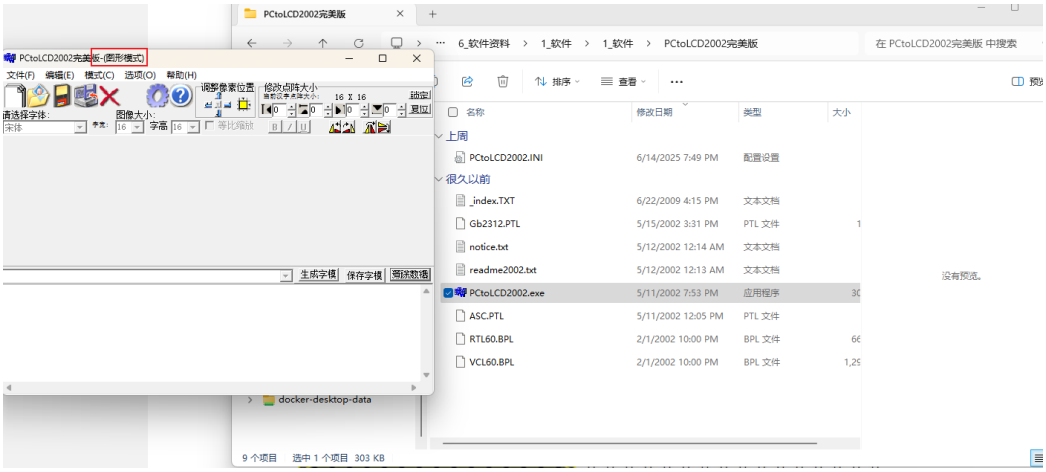

图 4: PCLtoLCD 工具

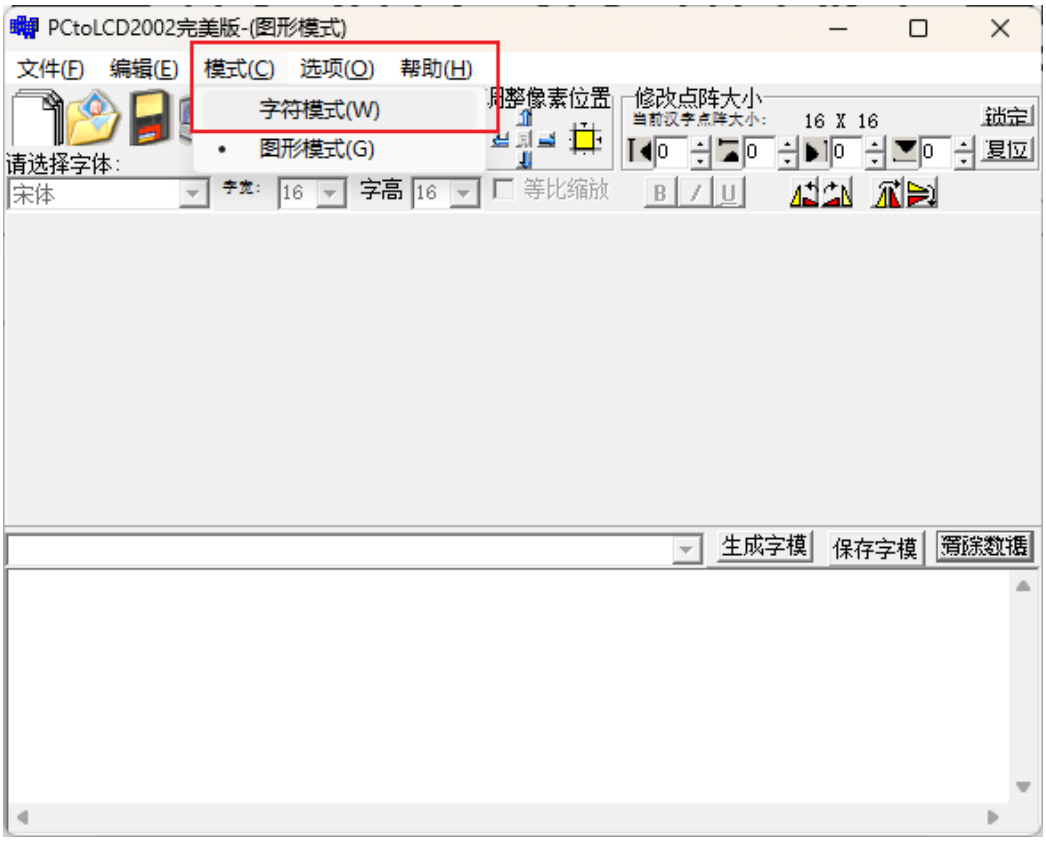

图 5: PCLtoLCD 工具

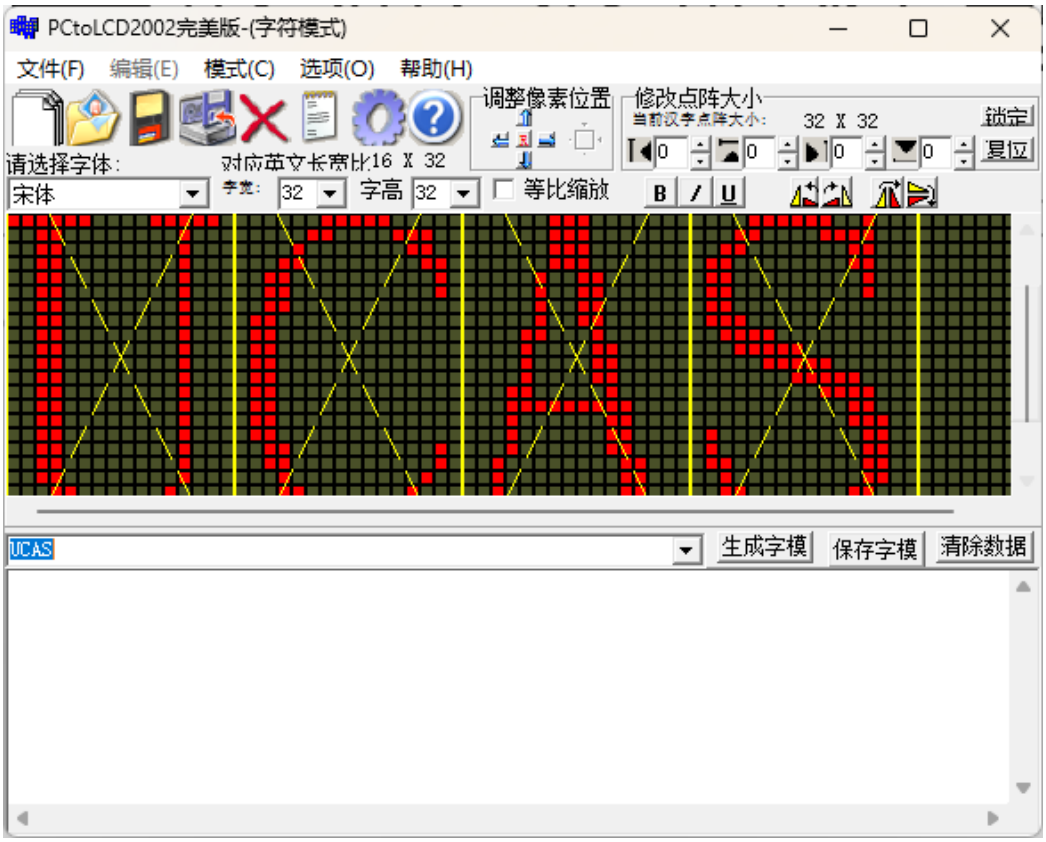

图 6: PCLtoLCD 工具

先另存为 BMP 再转为整体

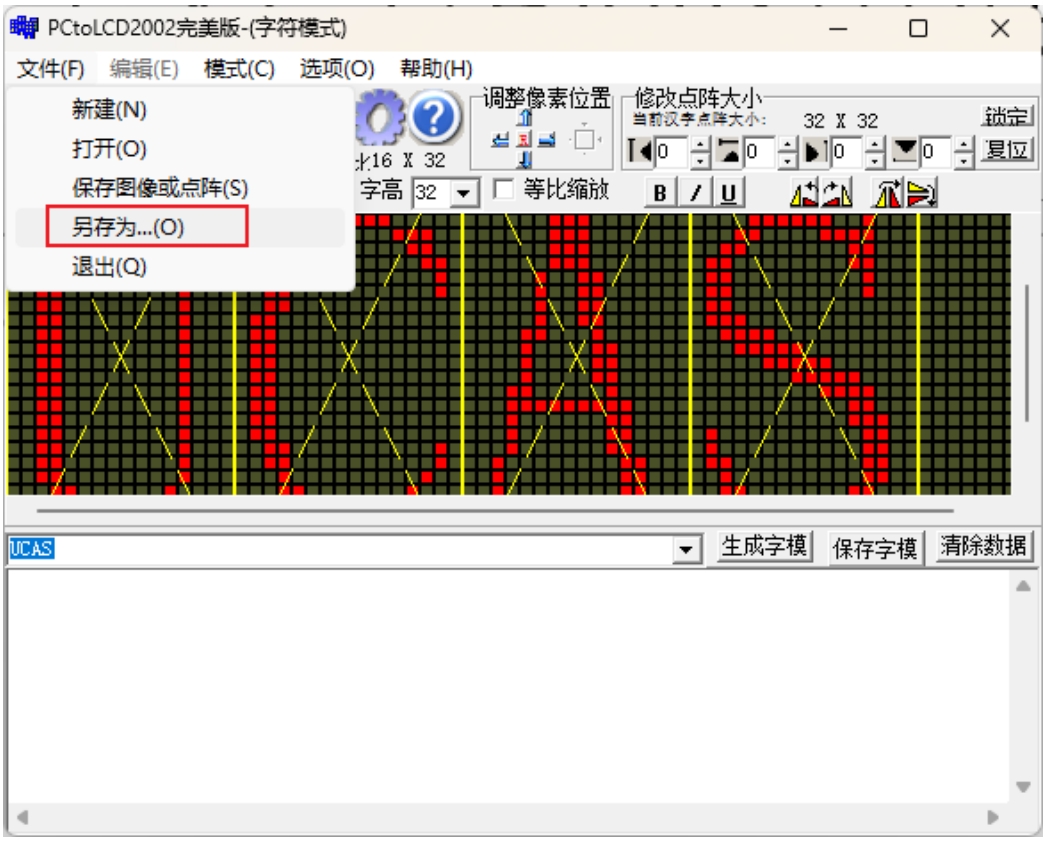

图 7: 转化为 bmp 格式

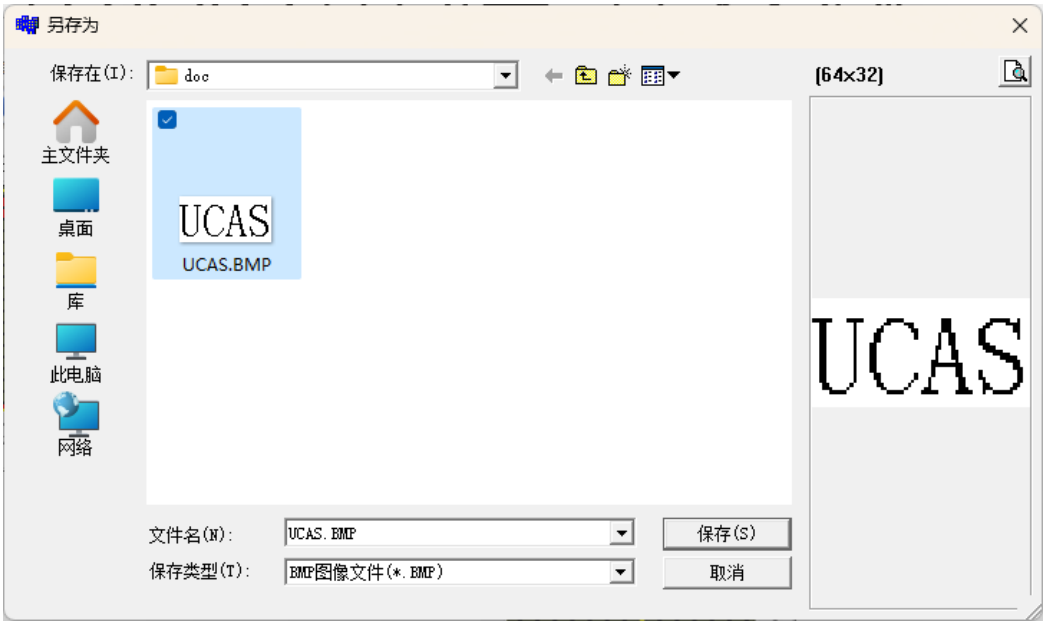

图 8: 转化为整体

切换回图形模式，打开保存的 BMP 文件

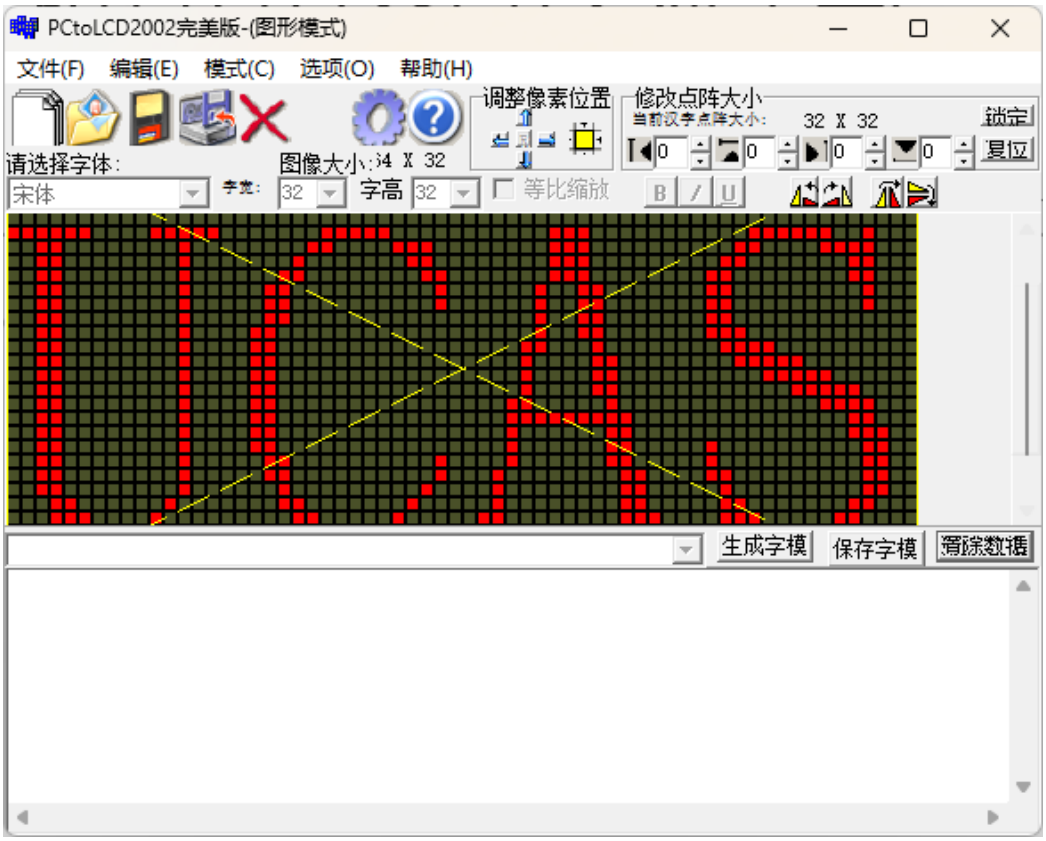

图 9: 切换回图形模式

点击选项修改字模选项如下

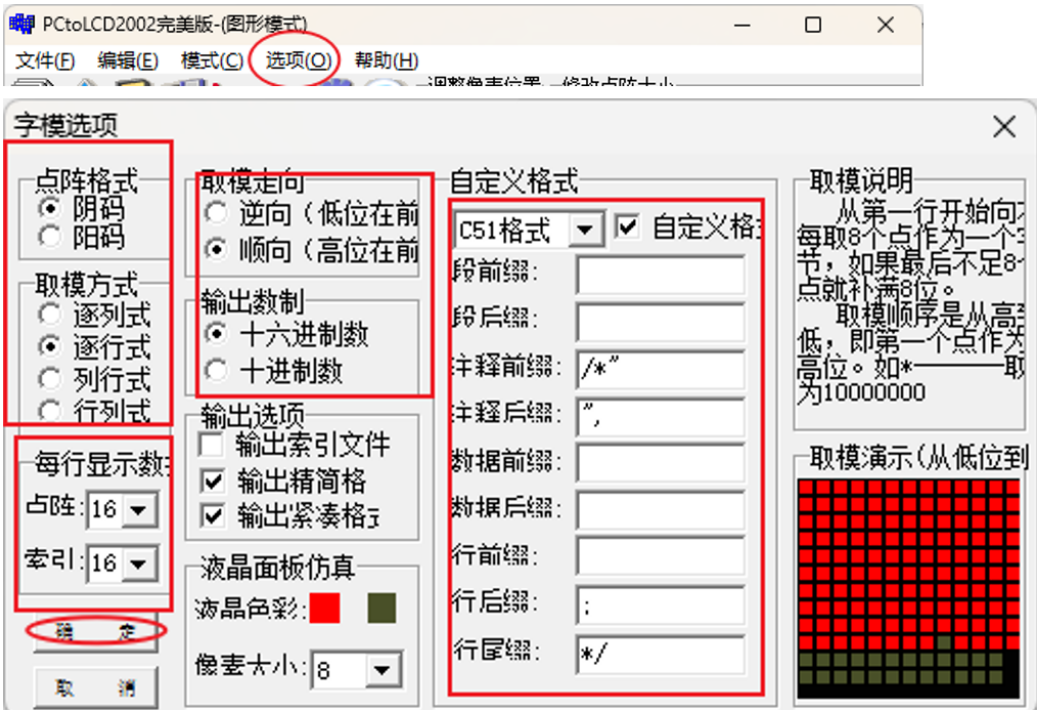

图 10: 修改字模选项

接着生成字模后保存字模即可

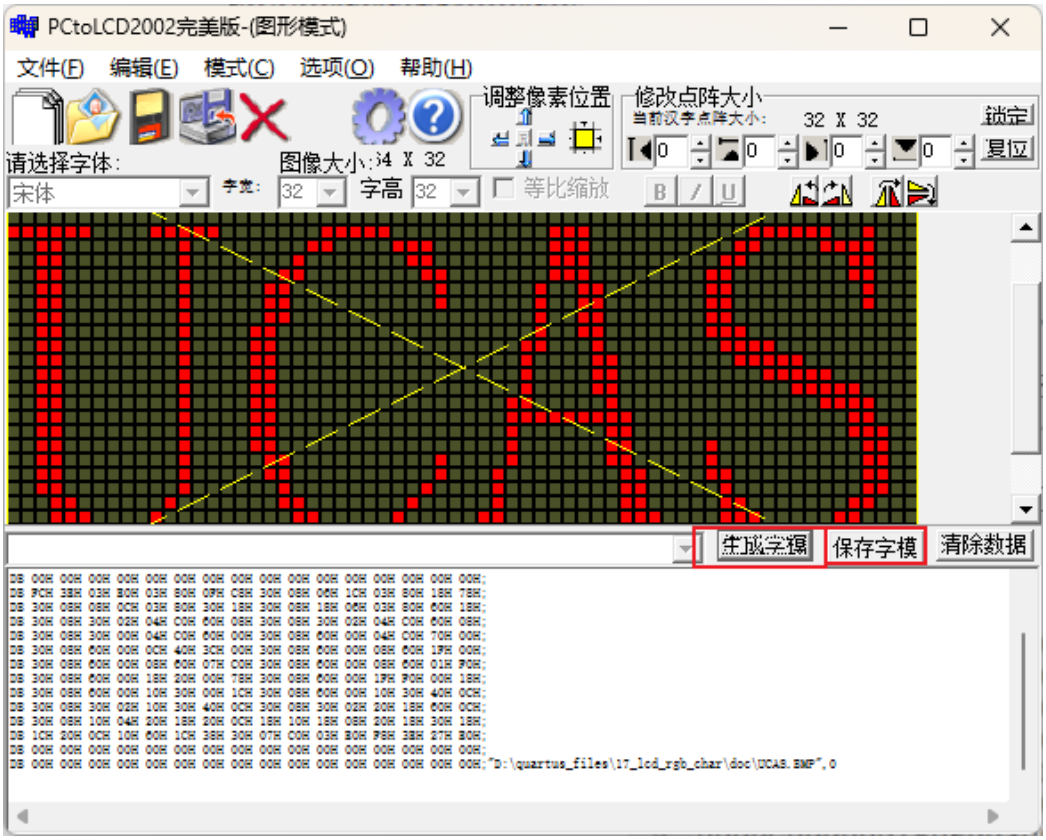

图 11: 生成字模

图像传输—转为 MIF 格式通过 ROM 传入使用 PicToMif 进行转换，加载 UCASLOGO 后进行转换

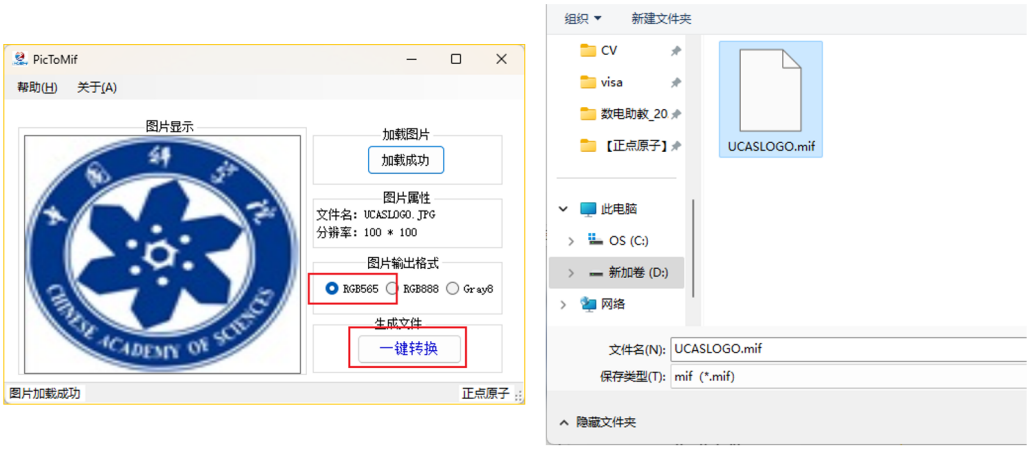

图 12: UCASLOGO 转为 MIF 格式

接着通过 ip-core 访问 mif 格式图像

```
75   // 根据当前扫描点的横纵坐标为 ROM 地址赋值
76   always @(posedge lcd_clk or negedge sys_rst_n) begin
77       if (!sys_rst_n)
78           rom_addr <= 14'd0;
79       else if ((pixel_ypos >= PIC_Y_START) && (pixel_ypos < PIC_Y_START + PIC_HEIGHT) &&
80                (pixel_xpos >= PIC_X_START) && (pixel_xpos < PIC_X_START + PIC_WIDTH))
81           rom_addr <= rom_addr + 1'b1;
82       else if (pixel_ypos >= PIC_Y_START + PIC_HEIGHT)
83           rom_addr <= 14'd0;
84   end
85
86   // ROM 实例化：存储图片
87   rom_10000x16b u_rom_10000x16b(
88       .address (rom_addr),
89       .clock   (lcd_clk),
90       .rden    (rom_rd_en),
91       .q       (rom_rd_data)
92   );
93
94   endmodule
```

图 13: ip-core 访问 mif 格式图像

在 FPGA 开发中，使用 Quartus 提供的 IP Core 中的 ROM 模块，可以高效、安全、资源友好地加载和显示固定图像等静态数据，尤其适用于像 LCD 显示模块这类场景

这里需要借助 Quartus 里的 Ipcore 创建一个 ROM 模块，并指定其读取的固定 mif 文件

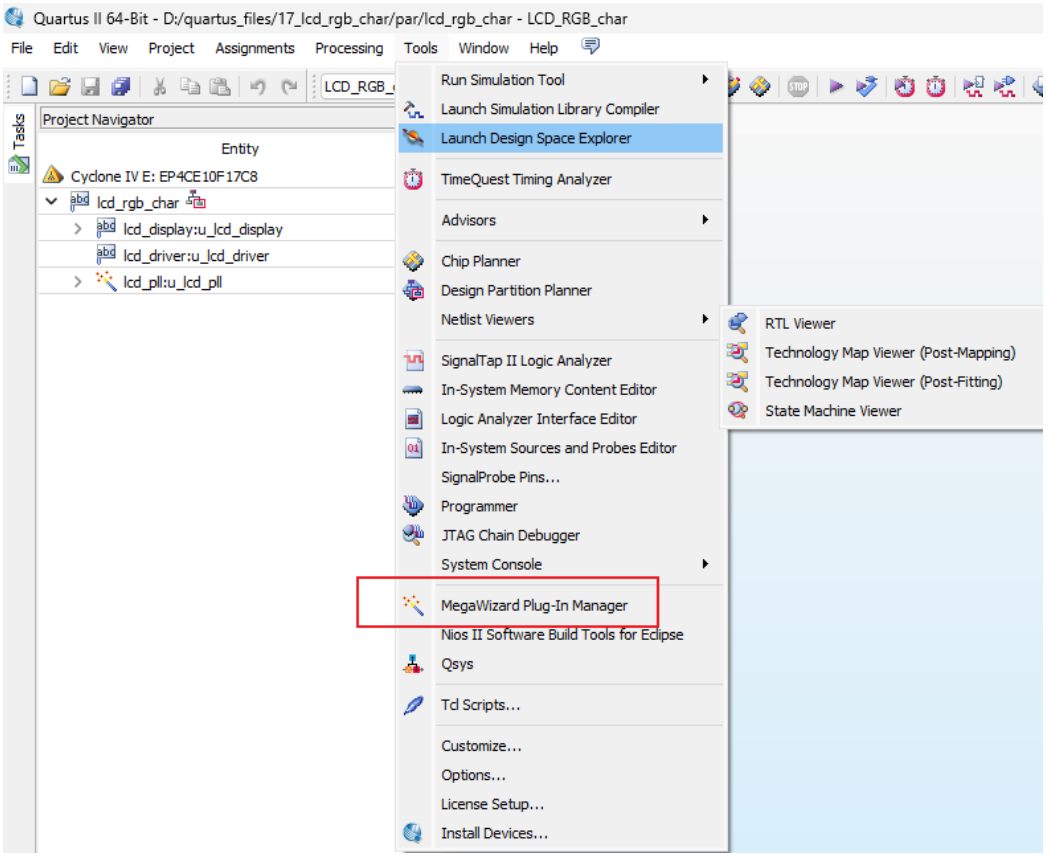

图 14: ip-core 创建 ROM 模块

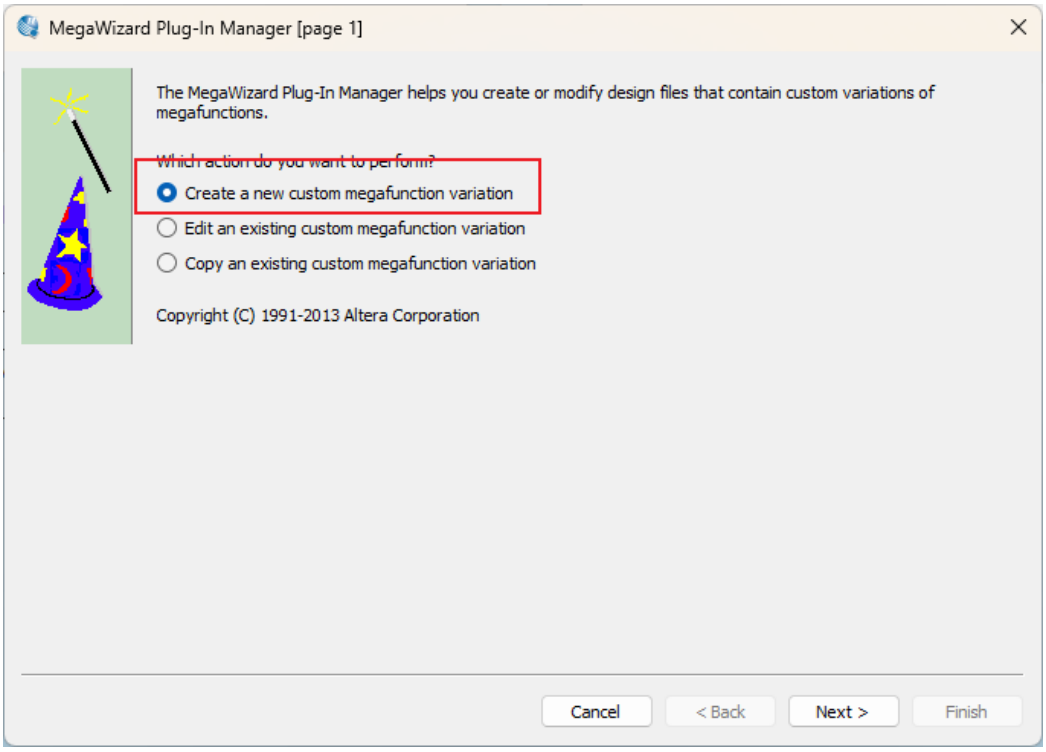

图 15: ip-core 创建 ROM 模块

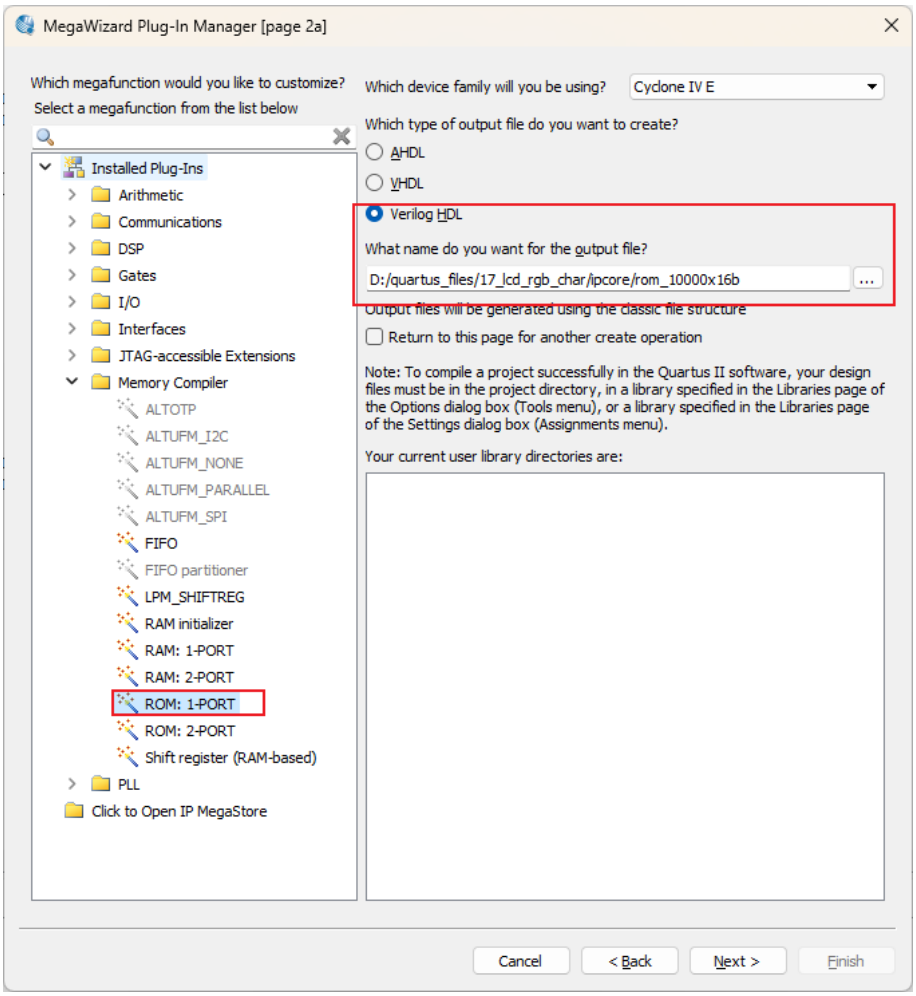

图 16: ip-core 创建 ROM 模块

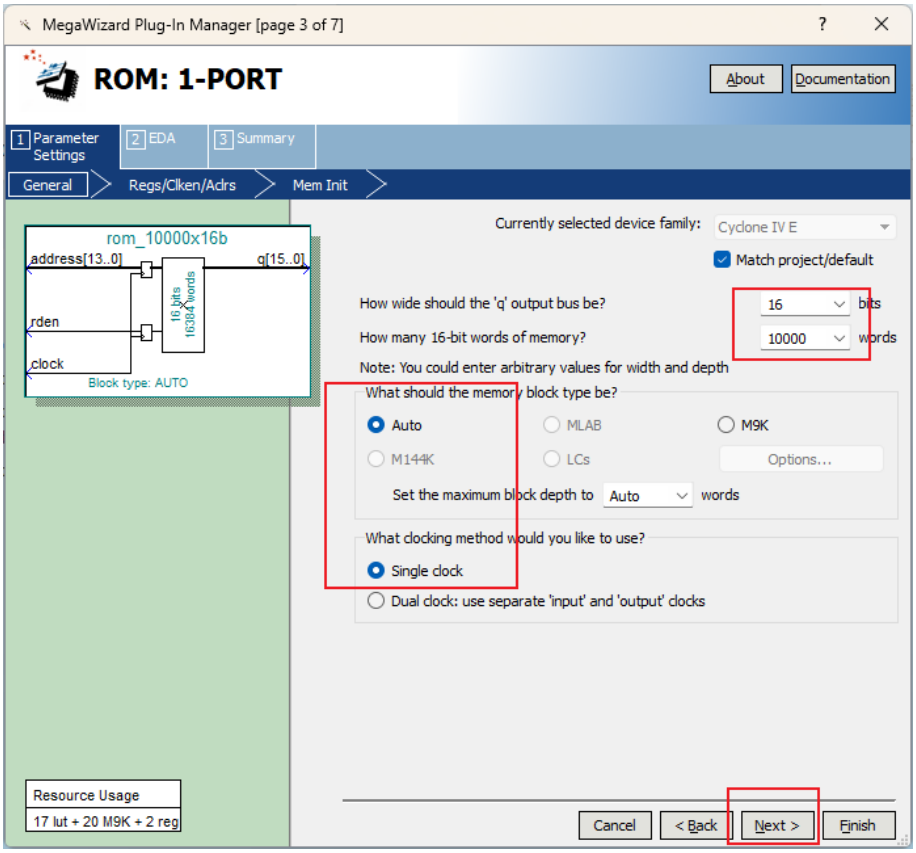

图 17: ip-core 创建 ROM 模块

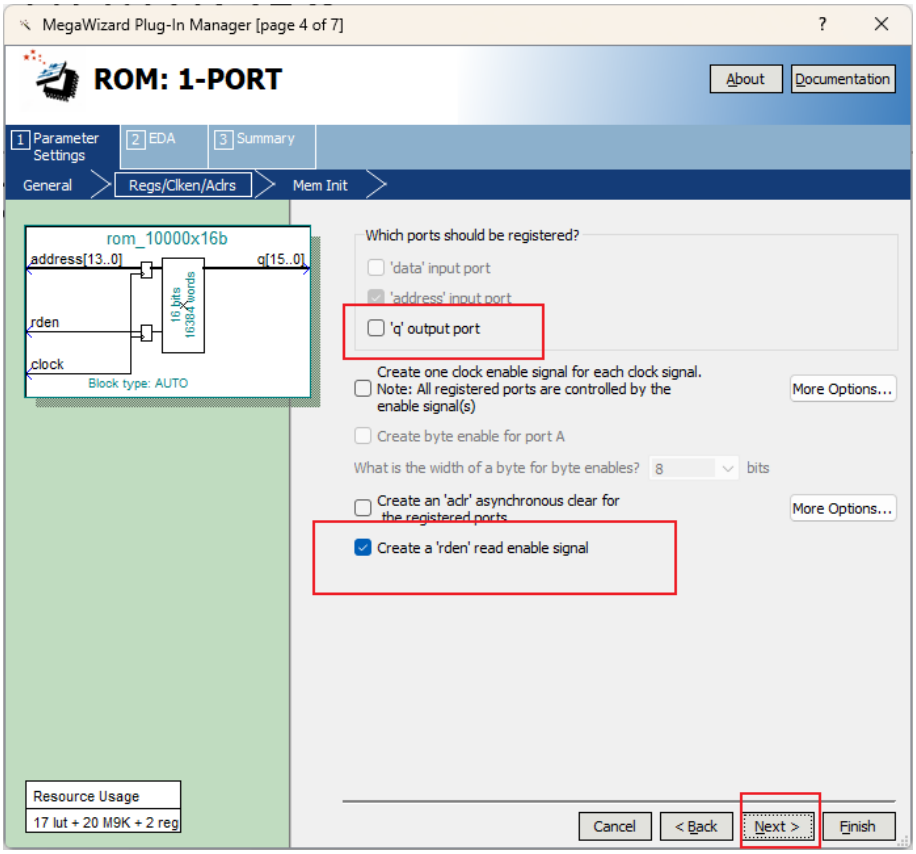

图 18: ip-core 创建 ROM 模块

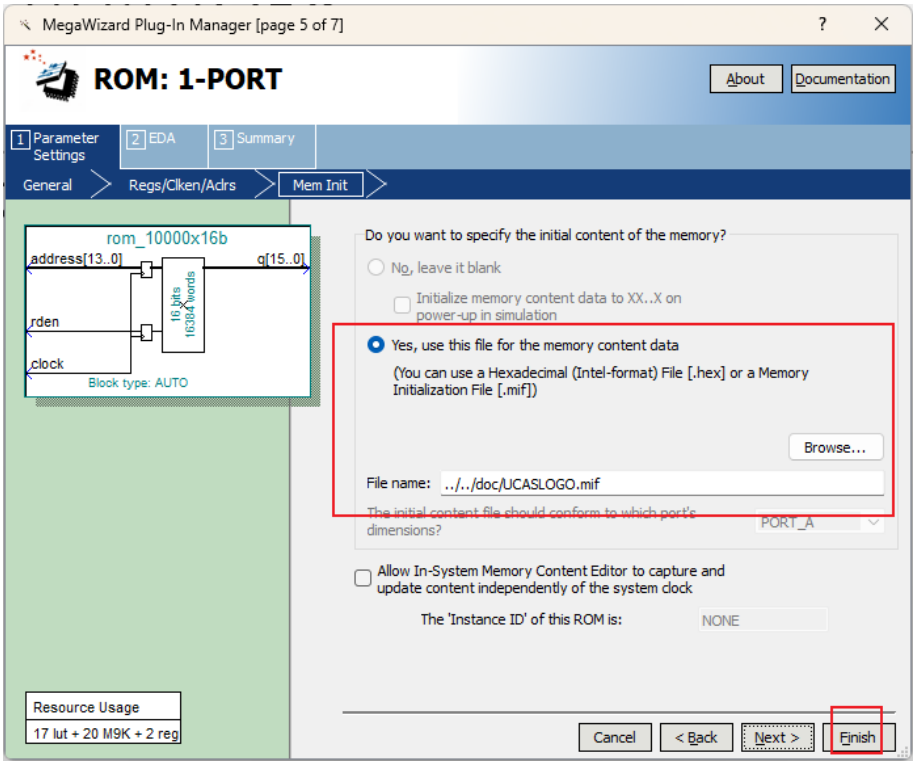

图 19: ip-core 创建 ROM 模块

直接打开老师提供的项目 QPF 文件即可，打开后会自动加载所有的源文件和设置。然后就是编译和下载程序到开发板。（部分实验需要修改 verilog 代码）

步骤 1： 完整编译工程

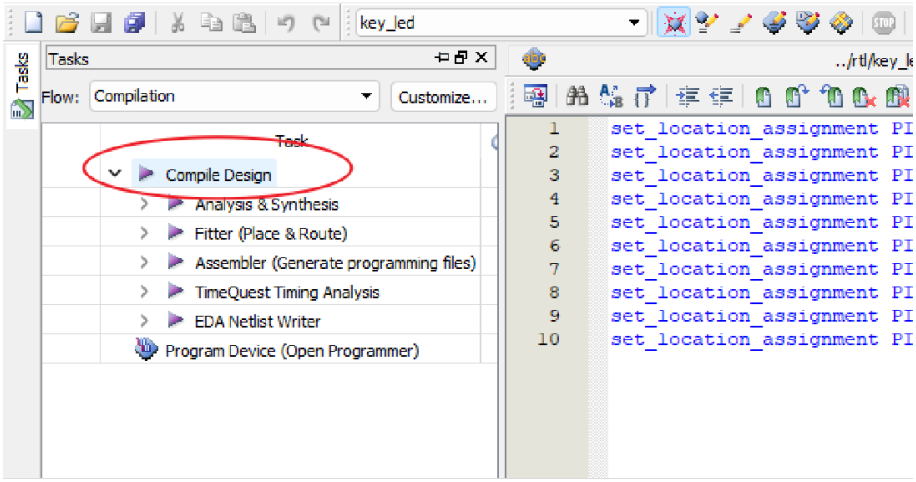

图 20: 完整编译工程界面

说明：完整编译流程包括：首先点击主界面的“Start Compilation”按钮，Quartus 会自动依次执行 Analysis & Synthesis、Fitter、Assembler、TimeQuest Timing Analysis 等步骤。编译过程中如遇到错误（Error）或警告（Warning），可在 Messages 窗口查看详细信息，双击可定位到相关代码或设置。常见注意事项包括：确保所有源文件已正确添加到工程、顶层模块设置无误、引脚分配无冲突、时钟约束合理等。建议每次修改代码或引脚分配后都重新完整编译，确保设计的正确性和可用性。

步骤 2： 下载程序至开发板

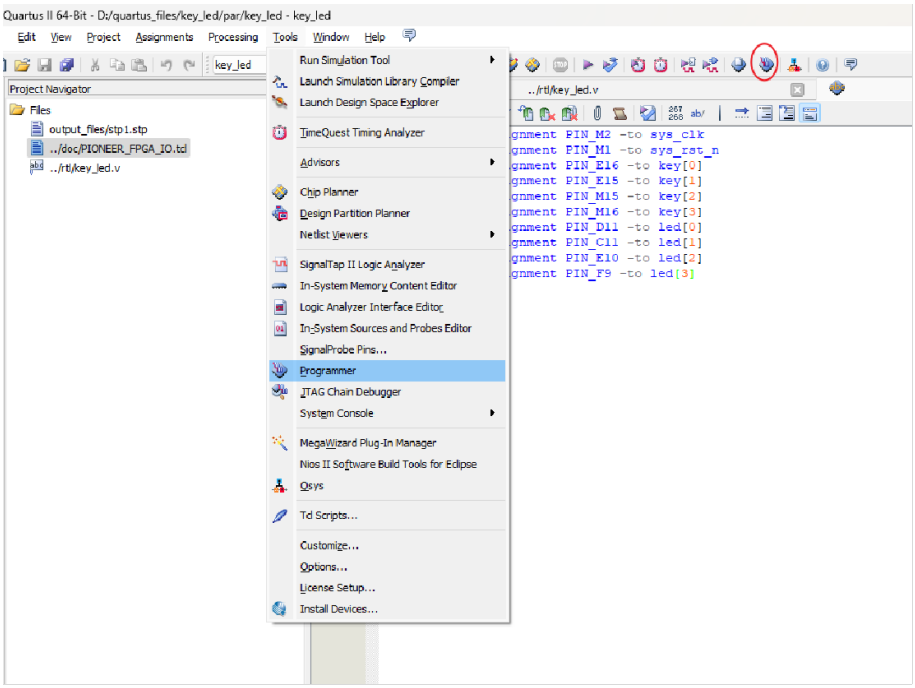

图 21: 下载程序到开发板界面 1

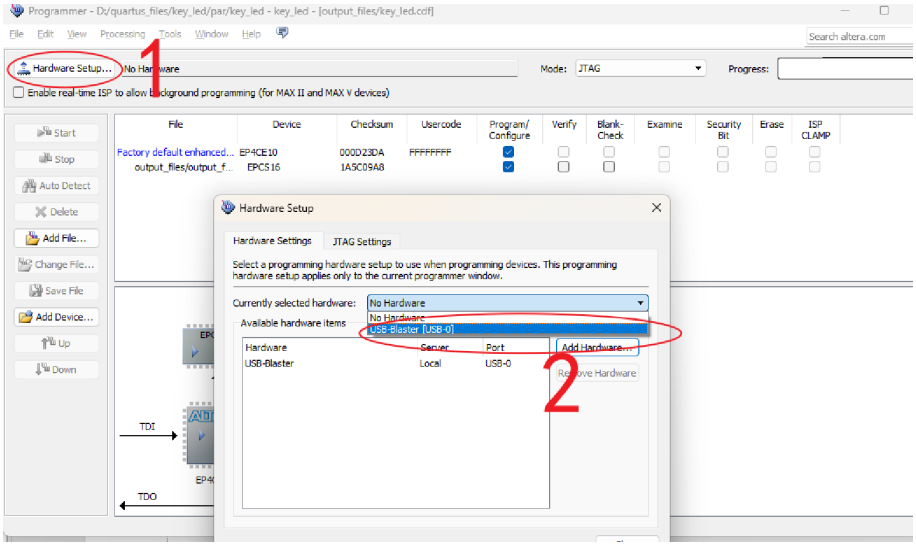

图 22: 下载程序到开发板界面 2

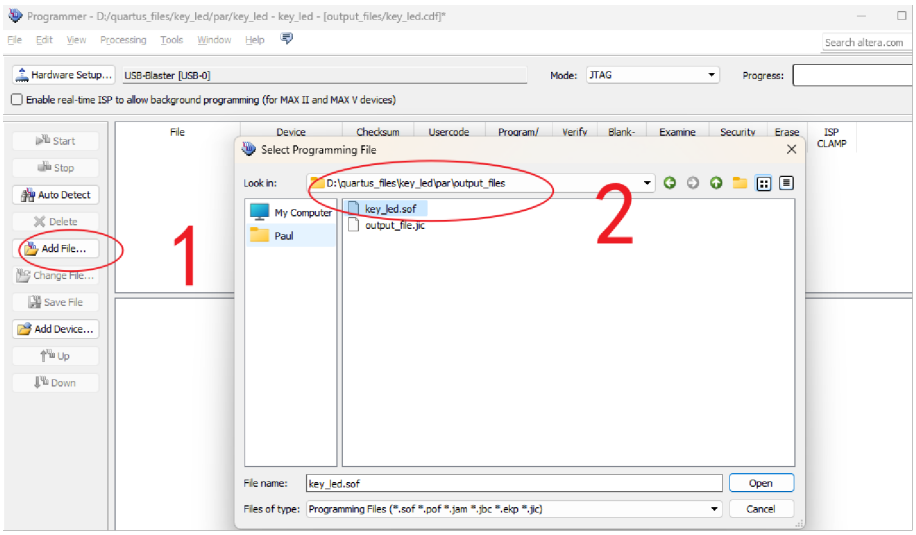

图 23: 下载程序到开发板界面 3

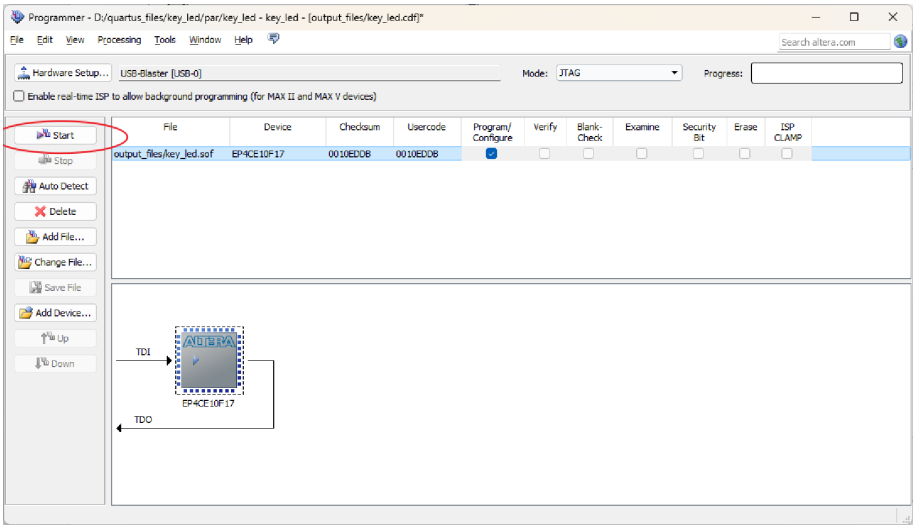

图 24: 下载程序到开发板界面 4

说明：下载程序到开发板的步骤如下：首先确保开发板已正确连接至电脑，并安装好驱动程序。打开 Quartus，点击工具栏的“Programmer”按钮，进入下载界面。点击“Hardware Setup”选择正确的下载器型号（如 USB-Blaster），然后点击“Auto Detect”自动识别芯片。添加编译生成的.sof 文件，勾选“Program/Configure”，最后点击“Start”按钮开始下载。下载完成后，观察开发板上的数码管显示是否正常。常见问题包括：未识别到下载器、芯片型号选择错误、下载过程中断等，遇到问题可尝试重新连接设备、检查驱动或重启软件。

§3 实验结果

3.1 实验结果：RGB-LCD 彩条显示实验

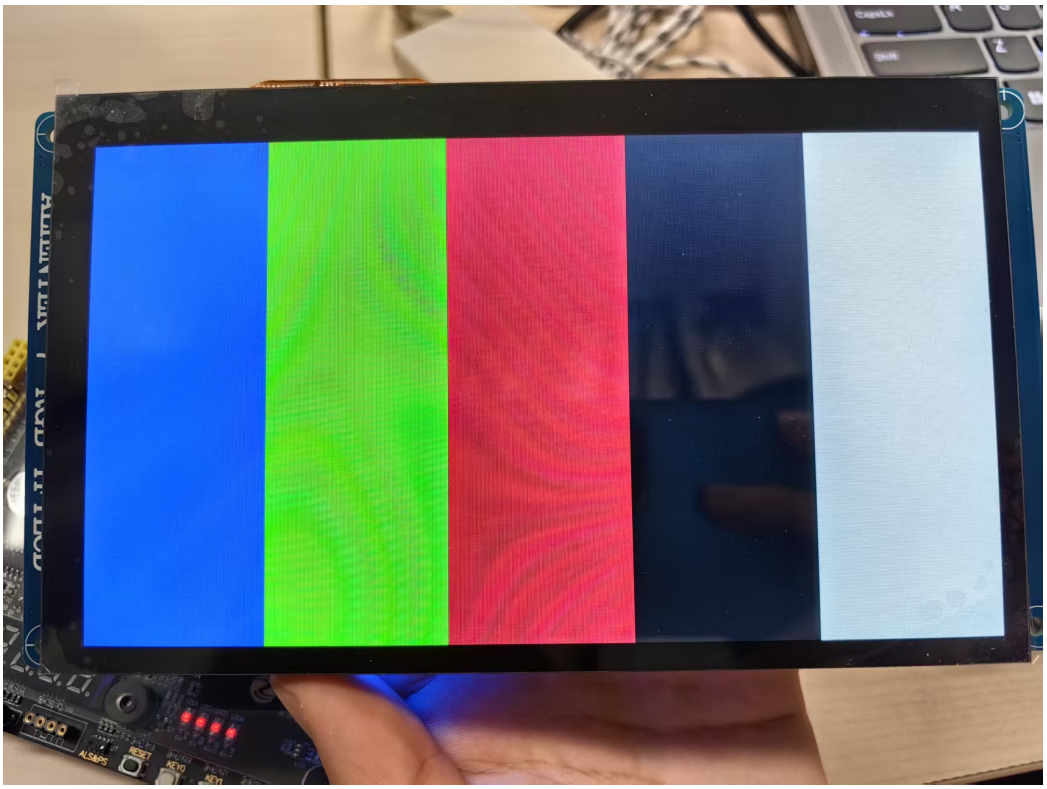

图 25: RGB-LCD 彩条显示实验结果

3.2 实验结果：RGB-LCD 字符和图片显示实验

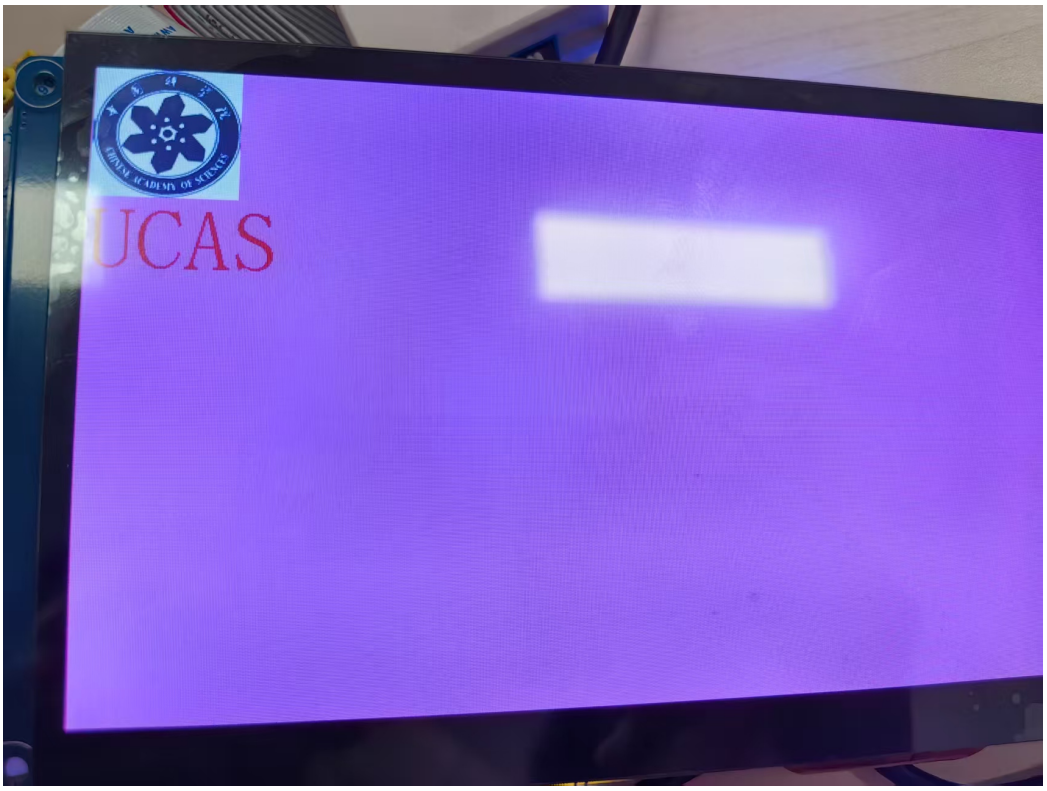

图 26: RGB-LCD 字符和图片显示实验结果

3.3 实验结果：小组成员姓名显示

图 27: 小组成员姓名显示结果

3.4 拓展实验结果：按键绑定实现

网页端（哔哩哔哩）演示视频：点击查看演示视频

§4 实验总结

4.1 实验中的问题

(1) 在这次实验的过程中，除了拓展实验之外的所有代码老师已经提供，直接放置在英文目录下即可打开项目，稍加修改编译后即可运行下载。

(2) 在显示中文字符的时候，要注意中文字符是 2 个字节的，而英文字符是 1 个字节的，所以在显示中文字符的时候要注意字宽和字高的设置，不能设置为 1 个字节的大小，否则会出现乱码。

(3) 对于除拓展实验外不同实验的不同文字，我们要注意修改代码的不同部分，最多的修改需要修改五处。

(4) 拓展实验中字符的宽、高，我们遇到了字符的宽不统一的问题（两个 256 一个 352），最后将较短数组与 96 位 0 拼接，也就是在字符后加空格，统一了字符的宽。

(5) 由于我们在拓展实验中 lcd_display.v 中改变了图片的分辨率（从 100*100 的 UCASLOGO 改成 180*108），这里的 rom 地址会出现越界问题，14 位二进制不够用，最后生成的图片会发生上半部分重复出现下半部分不出现的问题，所以改成 15 位二进制解决问题。

(6) 更多有关拓展实验的内容可以参考实验报告的附录代码部分。

4.2 实验收获

(1) 通过这次实验，我们对 RGB-LCD 屏幕的工作原理有了更深入的了解，掌握了如何使用 Quartus 软件进行 FPGA 开发和编程。

(2) 学会了如何使用 PCLtoLCD 工具将字符转换为点阵数据，并通过 PicToMif 工具将图像转换为 MIF 格式，以便在 FPGA 中使用。

(3) 掌握了如何使用 Quartus 中的 IP Core 创建 ROM 模块，并将静态图像数据加载到 FPGA 中进行显示。

(4) 通过拓展实验，我们学会了如何使用按键控制显示内容，增强了对 FPGA 编程的理解和实践能力。

(5) 在实验过程中我们深知耐心的重要性，尤其是在完成拓展实验时，遇到各种问题需要不断调试和修改代码，最终成功实现了预期功能。

§5 附录：基础实验 Verilog 代码修改部分

RGB-LCD 彩条显示实验没有代码修改；

RGB-LCD 字符和图片显示实验之 UCAS 文字与 UCAS-LOGO 图像显示 Verilog 代码修改部分如下（仅需修改 lcd_display）：

```
localparam CHAR_WIDTH  = 11'd128;
localparam CHAR_HEIGHT = 11'd64;

// reg define
reg [127:0] char [63:0];             // 字符数组

// 字符数组赋值，显示“UCAS-LOGO与UCAS文字”
always @(posedge lcd_clk) begin
char[ 0] <= 128'h00000000000000000000000000000000;
char[ 1] <= 128'h00000000000000000000000000000000;
char[ 2] <= 128'h00000000000000000000000000000000;
char[ 3] <= 128'h00000000000000000000000000000000;
char[ 4] <= 128'h00000000000000000000000000000000;
char[ 5] <= 128'h00000000000000000000000000000000;
char[ 6] <= 128'h00000000000000000000000000000000;
char[ 7] <= 128'h00000000000000000000000000000000;
char[ 8] <= 128'h00000000000000000000000000000000;
char[ 9] <= 128'h00000000000000000000000000000000;
char[10] <= 128'h00000000000000000000000000000000;
char[11] <= 128'h7FF807FE0003FC100003C000001FE000;
char[12] <= 128'h7FF807FE000FFFF00003C000007FF880;
char[13] <= 128'h0FC000F0003C07F00003C00000F03F80;
char[14] <= 128'h07800060007801F00007E00001C00F80;
char[15] <= 128'h0780006000E000F80007E00003C00780;
char[16] <= 128'h0780006001C000780006E000078003C0;
char[17] <= 128'h0780006003C000380006E000078001C0;
char[18] <= 128'h07800060038000180 00CF000070001C0;
char[19] <= 128'h07800060078000180 00CF0000F0000C0;
char[20] <= 128'h07800060070000C000C70000F0000C0;
char[21] <= 128'h078000600F00000C000C70000F000000;
char[22] <= 128'h078000600E000008001878000F000000;
char[23] <= 128'h078000601E000000001878000F000000;
char[24] <= 128'h078000601E000000001878000F800000;
char[25] <= 128'h078000601E000000018380007C00000;
char[26] <= 128'h078000601E00000000303C0007E00000;
char[27] <= 128'h078000603C00000000303C0007F00000;
char[28] <= 128'h078000603C00000000303C0003FC0000;
char[29] <= 128'h078000603C00000000301C0001FF0000;
char[30] <= 128'h078000603C00000000601E00007FC000;
char[31] <= 128'h078000603C00000000601E00003FF000;
char[32] <= 128'h078000603C00000000601E00000FFC00;
char[33] <= 128'h078000603C00000000600E000003FE00;
char[34] <= 128'h078000603C00000000E00E000000FF00;
char[35] <= 128'h078000603C00000000C00F0000003F80;
char[36] <= 128'h078000603C00000000C00F0000000FC0;
char[37] <= 128'h078000603C00000000FFFF00000007E0;
```

```
char[38] <= 128'h078000603C00000001FFFF00000003E0;
char[39] <= 128'h078000603C000000180078000001E0;
char[40] <= 128'h078000601E000000180078000001F0;
char[41] <= 128'h078000601E000000180078000000F0;
char[42] <= 128'h078000601E000008038078008000F0;
char[43] <= 128'h078000601E00000C030003C0180000F0;
char[44] <= 128'h078000601E00000C030003C0180000F0;
char[45] <= 128'h078000600F000008030003C01C0000F0;
char[46] <= 128'h078000600F000018070003C00C0000F0;
char[47] <= 128'h078000E00780001006000 1E00E0000E0;
char[48] <= 128'h038000C00780003006000 1E00E0001E0;
char[49] <= 128'h03C001C003C00060060001E00F0001C0;
char[50] <= 128'h01C0038001E000C00E0001E00F8003C0;
char[51] <= 128'h01E0070000F001C00E0001F00FC00780;
char[52] <= 128'h00F81E00007C07001F0001F807F81F00;
char[53] <= 128'h003FFC00001FFE007FC00FFE061FFC00;
char[54] <= 128'h000FE0000007F8007FC00FFE0407F000;
char[55] <= 128'h00000000000000000000000000000000;
char[56] <= 128'h00000000000000000000000000000000;
char[57] <= 128'h00000000000000000000000000000000;
char[58] <= 128'h00000000000000000000000000000000;
char[59] <= 128'h00000000000000000000000000000000;
char[60] <= 128'h00000000000000000000000000000000;
char[61] <= 128'h00000000000000000000000000000000;
char[62] <= 128'h00000000000000000000000000000000;
char[63] <= 128'h00000000000000000000000000000000;
end
```

Listing 1: UCAS 文字与 UCAS-LOGO 图像显示 Verilog 代码修改部分

RGB-LCD 字符和图片显示实验之小组成员姓名显示 Verilog 代码修改部分如下:

```
localparam CHAR_WIDTH  = 11'd192;
localparam CHAR_HEIGHT = 11'd256;

// reg define
reg [191:0] char [255:0];             // 字符数组

// 字符数组赋值, 显示“UCAS-LOGO和小组成员名字: 尹超 张硕 李雨恒”, 形式是换行;
always @(posedge lcd_clk) begin
char[ 0] <= 192'h000000000000000000000000000000000000000000000000;
char[ 1] <= 192'h000000000000000000000000000000000000000000000000;
char[ 2] <= 192'h000000000000000000000000000000000000000000000000;
char[ 3] <= 192'h000000000000000000000000000000000000000000000000;
char[ 4] <= 192'h000000000000000000000000000000000000000000000000;
char[ 5] <= 192'h000000000000000000000000000000000000000000000000;
char[ 6] <= 192'h000000000000000000000000000000000000000000000000;
char[ 7] <= 192'h000000000000000000000000000000000000000000000000;
char[ 8] <= 192'h000000000000000000000000000000000000000000000000;
char[ 9] <= 192'h000000000000000000000000000000000000000000000000;
char[10] <= 192'h000000000000000000000000000000000000000000000000;
char[11] <= 192'hFFF807FE0003FC100003C000001FE000000000000000000;
char[12] <= 192'hFFF807FE000FFFF00003C000007FF880000000000000000;
```

```
char[13] <= 192'h0FC000F0003C07F00003C00000F03F80000000000000000;
char[14] <= 192'h0F8000F0007801F00007E00001C00F80000000000000000;
char[15] <= 192'h0F8000F000E000F80007E00003C007800000000000000000;
char[16] <= 192'h0F8000F001C000780006E000078003C0000000000000000;
char[17] <= 192'h0F8000F003C000380006E000078001C0000000000000000;
char[18] <= 192'h0F8000F003800018000CF000070001C0000000000000000;
char[19] <= 192'h0F8000F007800018000CF0000F0000C0000000000000000;
char[20] <= 192'h0F8000F00700000C000C70000F0000C0000000000000000;
char[21] <= 192'h0F8000F00F00000C000C70000F000000000000000000000;
char[22] <= 192'h0F8000F00E000008001878000F000000000000000000000;
char[23] <= 192'h0F8000F01E000000001878000F000000000000000000000;
char[24] <= 192'h0F8000F01E000000001878000F800000000000000000000;
char[25] <= 192'h0F8000F01E000000018380007C000000000000000000000;
char[26] <= 192'h0F8000F01E00000000303C0007E000000000000000000000;
char[27] <= 192'h0F8000F03C00000000303C0007F000000000000000000000;
char[28] <= 192'h0F8000F03C00000000303C0003FC000000000000000000000;
char[29] <= 192'h0F8000F03C00000000301C0001FF000000000000000000000;
char[30] <= 192'h0F8000F03C00000000601E00007FC000000000000000000000;
char[31] <= 192'h0F8000F03C00000000601E00003FF000000000000000000000;
char[32] <= 192'h0F8000F03C00000000601E00000FFC000000000000000000000;
char[33] <= 192'h0F8000F03C00000000600E000003FE000000000000000000000;
char[34] <= 192'h0F8000F03C00000000E00E000000FF000000000000000000000;
char[35] <= 192'h0F8000F03C00000000C00F0000003F800000000000000000000;
char[36] <= 192'h0F8000F03C00000000C00F0000000FC000000000000000000000;
char[37] <= 192'h0F8000F03C00000000FFFF00000007E000000000000000000000;
char[38] <= 192'h0F8000F03C00000001FFFF00000003E000000000000000000000;
char[39] <= 192'h0F8000F03C000000018007800000001E000000000000000000000;
char[40] <= 192'h0F8000F01E000000018007800000001F000000000000000000000;
char[41] <= 192'h0F8000F01E000000018007800000000F000000000000000000000;
char[42] <= 192'h0F8000F01E000008038007800800000F000000000000000000000;
char[43] <= 192'h0F8000E01E00000C030003C0180000F000000000000000000000;
char[44] <= 192'h0F8000E01E00000C030003C0180000F000000000000000000000;
char[45] <= 192'h0F8000E00F00000803003C01C0000F000000000000000000000;
char[46] <= 192'h0F8000E00F00001807003C00C0000F000000000000000000000;
char[47] <= 192'h0FC000E007800010060001E00E0000E000000000000000000000;
char[48] <= 192'h07C001C007800030060001E00E0001E000000000000000000000;
char[49] <= 192'h07C003C003C00060060001E00F0001C000000000000000000000;
char[50] <= 192'h03E0078001E000C00E0001E00F8003C000000000000000000000;
char[51] <= 192'h01F81F0000F001C00E0001F00FC007800000000000000000000;
char[52] <= 192'h00FFFE00007C07001F0001F807F81F000000000000000000000;
char[53] <= 192'h001FF000001FFE007FC00FFE061FFC000000000000000000000;
char[54] <= 192'h000000000007F8007FC00FFE0407F000000000000000000000;
char[55] <= 192'h000000000000000000000000000000000000000000000000000;
char[56] <= 192'h000000000000000000000000000000000000000000000000000;
char[57] <= 192'h000000000000000000000000000000000000000000000000000;
char[58] <= 192'h000000000000000000000000000000000000000000000000000;
char[59] <= 192'h000000000000000000000000000000000000000000000000000;
char[60] <= 192'h000000000000000000000000000000000000000000000000000;
char[61] <= 192'h000000000000000000000000000000000000000000000000000;
char[62] <= 192'h000000000000000000000000000000000000000000000000000;
char[63] <= 192'h000000000000000000000000000000000000000000000000000;
char[64] <= 192'h000000000000000000000000000000000000000000000000000;
```

```
char[65] <= 192'h000000000000000000000000000000000000000000000000;
char[66] <= 192'h000000000000000000000000000000000000000000000000;
char[67] <= 192'h000000000000000000080000000000000000000000000000;
char[68] <= 192'h00000000000000000000E0000000000000000000000000;
char[69] <= 192'h00000000000000000000F8000000000000000000000000;
char[70] <= 192'h000000000000E0000000F8000000080000000000000000;
char[71] <= 192'h000000000001F0000000F000000001C0000000000000000;
char[72] <= 192'h007FFFFFFFFF8000000F001FFFFFFE0000000000000000;
char[73] <= 192'h007FFFFFFFFFC000000F000FFFFFFE0000000000000000;
char[74] <= 192'h003E007C0003F0000000F00061E003C0000000000000000;
char[75] <= 192'h0000007C0003F0000000F00001E003800000000000000000;
char[76] <= 192'h0000007C0003F0000000F02001E003800000000000000000;
char[77] <= 192'h0000007C0003F0000000F07001E003800000000000000000;
char[78] <= 192'h0000007C0003F00007FFFFF801E003800000000000000000;
char[79] <= 192'h0000007C0003F00003FFFFFC01E003800000000000000000;
char[80] <= 192'h0000007C0003F0000100F00001E003800000000000000000;
char[81] <= 192'h0000007C0003F1000000F00003C007800000000000000000;
char[82] <= 192'h0000007C0003F3800000F00003C007800000000000000000;
char[83] <= 192'h0000007C0003F7C00000F00003C007800000000000000000;
char[84] <= 192'h0000007C0003FFE00000F000078007800000000000000000;
char[85] <= 192'h0FFFFFFFFFFFFFF00000F000078007800000000000000000;
char[86] <= 192'h07FFFFFFFFFFFF80000F0000F000700000000000000000;
char[87] <= 192'h03E0007C0003F0000000F0000E060F00000000000000000;
char[88] <= 192'h0000007C0003F0000000F0301E03FF00000000000000000;
char[89] <= 192'h0000007C0003F0000000F0783C00FE00000000000000000;
char[90] <= 192'h0000007C0003F0001FFFFFFC38003E00000000000000000;
char[91] <= 192'h0000007C0003F0000FFFFFFE7000180000000000000000;
char[92] <= 192'h0000007C0003F00004007001E000100000000000000000;
char[93] <= 192'h0000007C0003F0000000700380000000000000000000000;
char[94] <= 192'h0000007C0003F0000000700700000000000000000000000;
char[95] <= 192'h0000007C0003F0000000700420000200000000000000000;
char[96] <= 192'h000000FC0003F0000000700038000700000000000000000;
char[97] <= 192'h000000FC0003F00000E070003FFFFF800000000000000000;
char[98] <= 192'h00FFFFFFFFFFF00000F870003FFFFFC00000000000000000;
char[99] <= 192'h007FFFFFFFFF00000F870003C000F800000000000000000;
char[100] <= 192'h003E00F80003F00000F070183C000F000000000000000000;
char[101] <= 192'h000000F80003F00000F0703C3C000F000000000000000000;
char[102] <= 192'h000001F80003F00000E07FFE3C000F000000000000000000;
char[103] <= 192'h000001F00003800000E07FFF3C000F000000000000000000;
char[104] <= 192'h000001F00000000000E070003C000F000000000000000000;
char[105] <= 192'h000003F00000000000E070003C000F000000000000000000;
char[106] <= 192'h000003F00000000000E070003C000F000000000000000000;
char[107] <= 192'h000003E00000000000E070003C000F000000000000000000;
char[108] <= 192'h000007E00000000001E070003C000F000000000000000000;
char[109] <= 192'h000007C00000000001E070003C000F000000000000000000;
char[110] <= 192'h00000FC00000000001F070003C000F000000000000000000;
char[111] <= 192'h00001F800000000001D870003FFFFF000000000000000000;
char[112] <= 192'h00001F000000000001DC70003FFFFF000000000000000000;
char[113] <= 192'h00003E000000000001CE70003C000F000000000000000000;
char[114] <= 192'h00007E0000000000038770003C000F000000000000000000;
char[115] <= 192'h0000FC0000000000383F0003C000E000000000000000000;
char[116] <= 192'h0001F800000000000301F0003C0008000000000000000000;
```

```
char[117] <= 192'h0003F000000000000700F8003000000000000000000000000;
char[118] <= 192'h0007C000000000006003F0000000000000000000000000000;
char[119] <= 192'h000F8000000000006001FF0000000000000000000000000000;
char[120] <= 192'h003F000000000000C0007FFF0000000000000000000000000;
char[121] <= 192'h007C000000000000C0000FFFFFFFFF8000000000000000000;
char[122] <= 192'h01F0000000000001800001FFFFFFFE0000000000000000000;
char[123] <= 192'h07C0000000000001000000007FFFFF80000000000000000000;
char[124] <= 192'h0700000000000002000000000FFF80000000000000000000;
char[125] <= 192'h000000000000000000000000000000000000000000000000000;
char[126] <= 192'h000000000000000000000000000000000000000000000000000;
char[127] <= 192'h000000000000000000000000000000000000000000000000000;
char[128] <= 192'h000000000000000000000000000000000000000000000000000;
char[129] <= 192'h000000000000000000000000000000000000000000000000000;
char[130] <= 192'h000000000000000000000000000000000000000000000000000;
char[131] <= 192'h00000001C000000000000000000000000000000000000000000;
char[132] <= 192'h00000001F000000000000C0000000800000000000000000000;
char[133] <= 192'h00000001FC000000000001E0000003C0000000000000000000;
char[134] <= 192'h00000E01FC0000001FFFFFF7FFFFFE0000000000000000000;
char[135] <= 192'h00001F81F00000000FFFFFFBFFFFFFF0000000000000000000;
char[136] <= 192'h1FFFFFC1F00018000603C00100780000000000000000000000;
char[137] <= 192'h0FFFFF81F000380000078000007800000000000000000000000;
char[138] <= 192'h07C01F01F0003C000007800000700000000000000000000000;
char[139] <= 192'h00001F01F0007E000007800000700000000000000000000000;
char[140] <= 192'h00001F01F0007F000007800000E00000000000000000000000;
char[141] <= 192'h00001F01F000FF000007000000E00000000000000000000000;
char[142] <= 192'h00001F01F001FC00000F000000C00000000000000000000000;
char[143] <= 192'h00001F01F003F800000F000000C00000000000000000000000;
char[144] <= 192'h00001F01F007E000000E000008002000000000000000000000;
char[145] <= 192'h00001F01F00FC000000E000181800700000000000000000000;
char[146] <= 192'h00001F01F00F8000001E0001FFFFFFC0000000000000000000;
char[147] <= 192'h01801F01F01F0000001C0001FFFFFF80000000000000000000;
char[148] <= 192'h01C01F01F03E0000001C0001E000070000000000000000000;
char[149] <= 192'h01FFFF01F0F80000003C0001E000070000000000000000000;
char[150] <= 192'h01FFFF01F1F0000000380001E000070000000000000000000;
char[151] <= 192'h01E01F01F3E0000000380381E040070000000000000000000;
char[152] <= 192'h01E01F01F7C00000007FFFC1E020070000000000000000000;
char[153] <= 192'h03E01C01FF000000007FFFC1E038070000000000000000000;
char[154] <= 192'h03E00001FE00000000F80781E03E070000000000000000000;
char[155] <= 192'h03E00001F800038000F80781E03C070000000000000000000;
char[156] <= 192'h03E00001F00007C000F80781E038070000000000000000000;
char[157] <= 192'h03E00001F0000FE001F80781E078070000000000000000000;
char[158] <= 192'h03E003FFFFFFFFE001B80781E078070000000000000000000;
char[159] <= 192'h03C019FFFFFFFFF003B80781E078070000000000000000000;
char[160] <= 192'h07C03EF9F1C0000003380781E078070000000000000000000;
char[161] <= 192'h07FFFF01F1C0000006380781E078070000000000000000000;
char[162] <= 192'h0FFFFF01F1C0000004380781E078070000000000000000000;
char[163] <= 192'h07C07E01F0E000000C380781E078070000000000000000000;
char[164] <= 192'h03807C01F0E0000018380781E078070000000000000000000;
char[165] <= 192'h00007C01F0F0000010380781E078070000000000000000000;
char[166] <= 192'h00007C01F0700000000380781E070070000000000000000000;
char[167] <= 192'h00007C01F0780000000380781E070070000000000000000000;
char[168] <= 192'h00007C01F078000000380781E0F007000000000000000000;
```

```
char[169] <= 192'h00007C01F03C000000380781E0F007000000000000000000;
char[170] <= 192'h00007C01F03E000000380781E0F007000000000000000000;
char[171] <= 192'h00007C01F01E000000380781E0E007000000000000000000;
char[172] <= 192'h00007C01F01F0000003FFF81E1E006000000000000000000;
char[173] <= 192'h00007801F00F8000003FFF8181E004000000000000000000;
char[174] <= 192'h00007801F00FC0000038078003C600000000000000000000;
char[175] <= 192'h0000F801F007E0000038078003C380000000000000000000;
char[176] <= 192'h0000F801F003F000003807000781E000000000000000000;
char[177] <= 192'h0000F801F01FF800003804000F00F800000000000000000;
char[178] <= 192'h0000F801F07DFC00003800000F003E000000000000000000;
char[179] <= 192'h0000F801F1F0FF00003800001E001F000000000000000000;
char[180] <= 192'h0001F801F7E07FC0003800007C000FC000000000000000000;
char[181] <= 192'h0301F001FFC03FF800200000F8000FC000000000000000000;
char[182] <= 192'h07FFF001FF801FFC00000001E00007E000000000000000000;
char[183] <= 192'h01FFF001FF000FF800000007C00003E000000000000000000;
char[184] <= 192'h007FE003FC0007C00000000F000001E000000000000000000;
char[185] <= 192'h003FC001F80003800000003C000001E000000000000000000;
char[186] <= 192'h001F8001F8000000000000F0000000E000000000000000000;
char[187] <= 192'h001F0000F000000000000380000000400000000000000000;
char[188] <= 192'h00180000600000000000C000000000000000000000000000;
char[189] <= 192'h000000000000000000000000000000000000000000000000;
char[190] <= 192'h000000000000000000000000000000000000000000000000;
char[191] <= 192'h000000000000000000000000000000000000000000000000;
char[192] <= 192'h000000000000000000000000000000000000000000000000;
char[193] <= 192'h000000000000000000000000000000000000000000000000;
char[194] <= 192'h000000000000000000000000000000000000000000000000;
char[195] <= 192'h000000000000000000000000000000000000000000000000;
char[196] <= 192'h00000007000000000000000000000000800000000000;
char[197] <= 192'h00000007C000000000000000000000000E000000000000;
char[198] <= 192'h00000007F000000000000000000000000F800000000000;
char[199] <= 192'h00000007F000000000000000000200000F800000000000;
char[200] <= 192'h00000007C000000000000000000700000F000000000200;
char[201] <= 192'h00000007C0000000000000000F80000E000000000700;
char[202] <= 192'h00000007C000070007FFFFFFFFFFFC0000E000000000F80;
char[203] <= 192'h00000007C0000F8003FFFFFFFFFFFE0000E01FFFFFFFFC0;
char[204] <= 192'h00000007C0001FC00100000380000000000E00FFFFFFFFE0;
char[205] <= 192'h0FFFFFFFFFFFFFE000000003800000000000E004000000000;
char[206] <= 192'h0FFFFFFFFFFFFFF000000003800000000000E000000000000;
char[207] <= 192'h07C000FFF800000000000003800000000000E000000000000;
char[208] <= 192'h000000FFDC000000000000038000000000F000000000000;
char[209] <= 192'h000001FFDC000000000000038000000000FC00000000000;
char[210] <= 192'h000003F7CE000000000000038000000000EF00000000000;
char[211] <= 192'h000003E7CF000000040000380001000000E781000002000;
char[212] <= 192'h000007C7C78000000020000380003C00010E3C1800007000;
char[213] <= 192'h00000F87C7C00000003FFFFFFFFFE00010E3E1FFFFFFC00;
char[214] <= 192'h00001F07C3F00000003FFFFFFFFFE00010E1E1FFFFFFE00;
char[215] <= 192'h00003E07C1F8000003800038000 3C00010E1E1E00007800;
char[216] <= 192'h00007C07C0FE000003800038000 3C00030E0E1E00007800;
char[217] <= 192'h0000F807C07F800003800038000 3C00030E0E1E00007800;
char[218] <= 192'h0001F007C03FE000003800038000 3C00030E041E00007800;
char[219] <= 192'h0003E007C01FF800003870038E003C00070E001E00007800;
char[220] <= 192'h000FC007C00FFF8000383C0387803C00070E001E00007800;
```

```
char[221] <= 192'h001F00070033FFF800381E0383E03C000F0E001E00007800;
char[222] <= 192'h003E00000079FFF800380F8381F03C001F0E001E00007800;
char[223] <= 192'h00F9FFFFFFC7FC000380F8380F83C003F0E001E00007800;
char[224] <= 192'h01F0FFFFFFE1F00003807C380783C003E0E001FFFFFF800;
char[225] <= 192'h07C0700001FF0700003803C380383C00000E001FFFFFF800;
char[226] <= 192'h1F00000003FC000000380383803C00000E001E00007800;
char[227] <= 192'h3C00000007E000000038018380183C00000E001E00007800;
char[228] <= 192'h000000000F8000000038000380003C00000E001E00007800;
char[229] <= 192'h00000003BE000000038000380003C00000E001E00007800;
char[230] <= 192'h00000003FC000000038000380003C00000E001E00007800;
char[231] <= 192'h00000003F000000000380003800003C00000E001E00007800;
char[232] <= 192'h00000003FC000000038000380003C00000E001E00007800;
char[233] <= 192'h00000003F80003800038E00380003C00000E001E00007800;
char[234] <= 192'h00000003F00007C00038780386003C00000E001E00007800;
char[235] <= 192'h00000003F0000FE000383E0383C03C00000E001E00007800;
char[236] <= 192'h1FFFFFFFFFFFFFF000381F0381F03C00000E001E00007800;
char[237] <= 192'h0FFFFFFFFFFFFFF800380F8380F83C00000E001FFFFFF800;
char[238] <= 192'h07C00003F000000000380783807 83C00000E001FFFFFF800;
char[239] <= 192'h00000003F000000000380783807C3C00000E001E00007800;
char[240] <= 192'h00000003F000000000380383803C3C00000E001E00007800;
char[241] <= 192'h00000003F000000000380303801 83C00000E001E00007000;
char[242] <= 192'h00000003F000000000380003801 83C00000E001C00004000;
char[243] <= 192'h00000003F000000000380003800 03C00000E001000000000;
char[244] <= 192'h00000003F000000000380003800 03C00000E000000000000;
char[245] <= 192'h00000003F000000000380003800 03C00000E000000000180;
char[246] <= 192'h00000003F000000000380003800 03C00000E0000000003C0;
char[247] <= 192'h00000003F000000000380003800 0380007800000E0000000007E0;
char[248] <= 192'h000007E3F000000000380003800 0380FFF800000E1FFFFFFFFF0;
char[249] <= 192'h000007FFE000000000380003800 03800FF800000E0FFFFFFFFF8;
char[250] <= 192'h000001FFE000000000380003800 38003F800000E040000000000;
char[251] <= 192'h0000003FE000000000380003000 30001F000000E000000000000;
char[252] <= 192'h0000001FC000000000300004000 0E000000E000000000000;
char[253] <= 192'h0000000F800000000040000000008000000F000000000000;
char[254] <= 192'h0000000F000000000000000000000000000800000000000000;
char[255] <= 192'h0000000000000000000000000000000000000000000000000000;
end
```

Listing 2: 小组成员姓名显示 Verilog 代码修改部分

§6 拓展实验 Verilog 代码

lcd_driver.v 文件不用修改

lcd_rgb_char_key.v 文件需要修改，增加了四个按键。lcd_rgb_char_key.v

```
module lcd_rgb_char_key(
  input sys_clk,
  input sys_rst_n,
  input[3:0]key,
  output lcd_hs,
  output lcd_vs,
  output lcd_de,
  output[15:0]lcd_rgb,
```

```
    output lcd_bl,
    output lcd_rst,
    output lcd_pclk
    );
wire lcd_clk_w;
wire locked_w;
wire rst_n_w;
wire[15:0]pixel_data_w;
wire[9:0]pixel_xpos_w;
wire[9:0]pixel_ypos_w;
assign rst_n_w=sys_rst_n&&locked_w;

lcd_pll u_lcd_pll(
    .inclk0(sys_clk),
    .areset(~sys_rst_n),
    .c0(lcd_clk_w),
    .locked(locked_w)
    );
lcd_driver u_lcd_driver(
    .lcd_clk(lcd_clk_w),
    .sys_rst_n(rst_n_w),
    .lcd_hs(lcd_hs),
    .lcd_vs(lcd_vs),
    .lcd_de(lcd_de),
    .lcd_rgb(lcd_rgb),
    .lcd_bl(lcd_bl),
    .lcd_rst(lcd_rst),
    .lcd_pclk(lcd_pclk),
    .pixel_data(pixel_data_w),
    .pixel_xpos(pixel_xpos_w),
    .pixel_ypos(pixel_ypos_w)
    );
lcd_display u_lcd_display(
    .lcd_clk(lcd_clk_w),
    .sys_rst_n(rst_n_w),
    .key(key),
    .pixel_xpos(pixel_xpos_w),
    .pixel_ypos(pixel_ypos_w),
    .pixel_data(pixel_data_w)
    );
endmodule
```

Listing 3: lcd_rgb_char_key.v 代码修改片段

由于 lcd_display 代码过长，无法在此处展示，完整代码请查看附件，附件代码包含注释。lcd_display.v 文件需要修改。lcd_display.v