

VGA 编程输出测试实验

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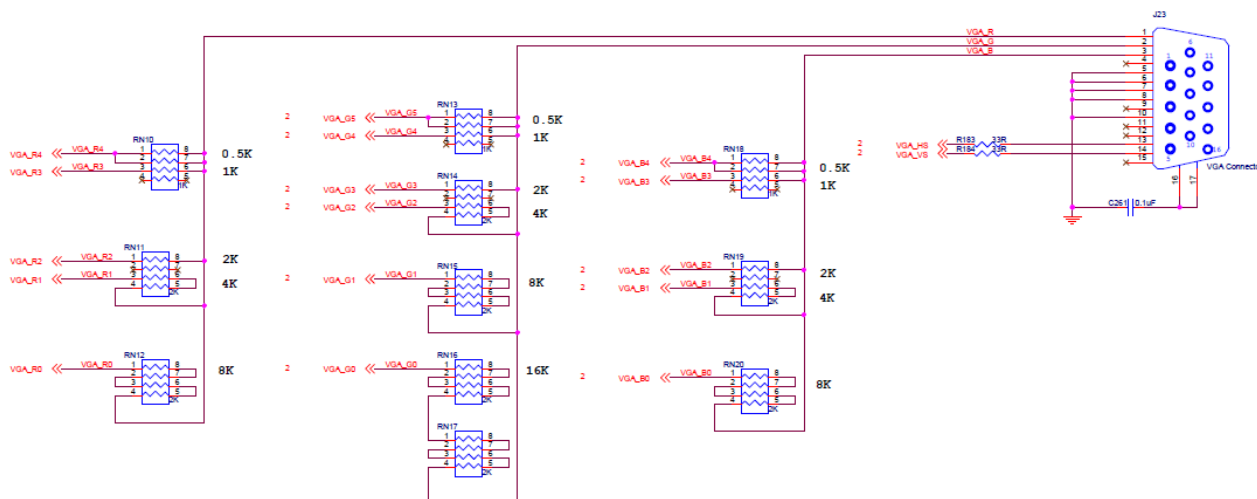
1 实验简介

VGA 接口即电脑采用 VGA 标准输出数据的专用接口。VGA 接口共有 15 针，分成 3 排，每排 5 个孔，显卡上应用最为广泛的接口类型，绝大多数显卡都带有此种接口。它传输红、绿、蓝模拟信号以及同步信号(水平和垂直信号)。本实验将介绍在 AX701 和 AX7102 开发板上如何实现 VGA 图像的显示。

2 实验原理

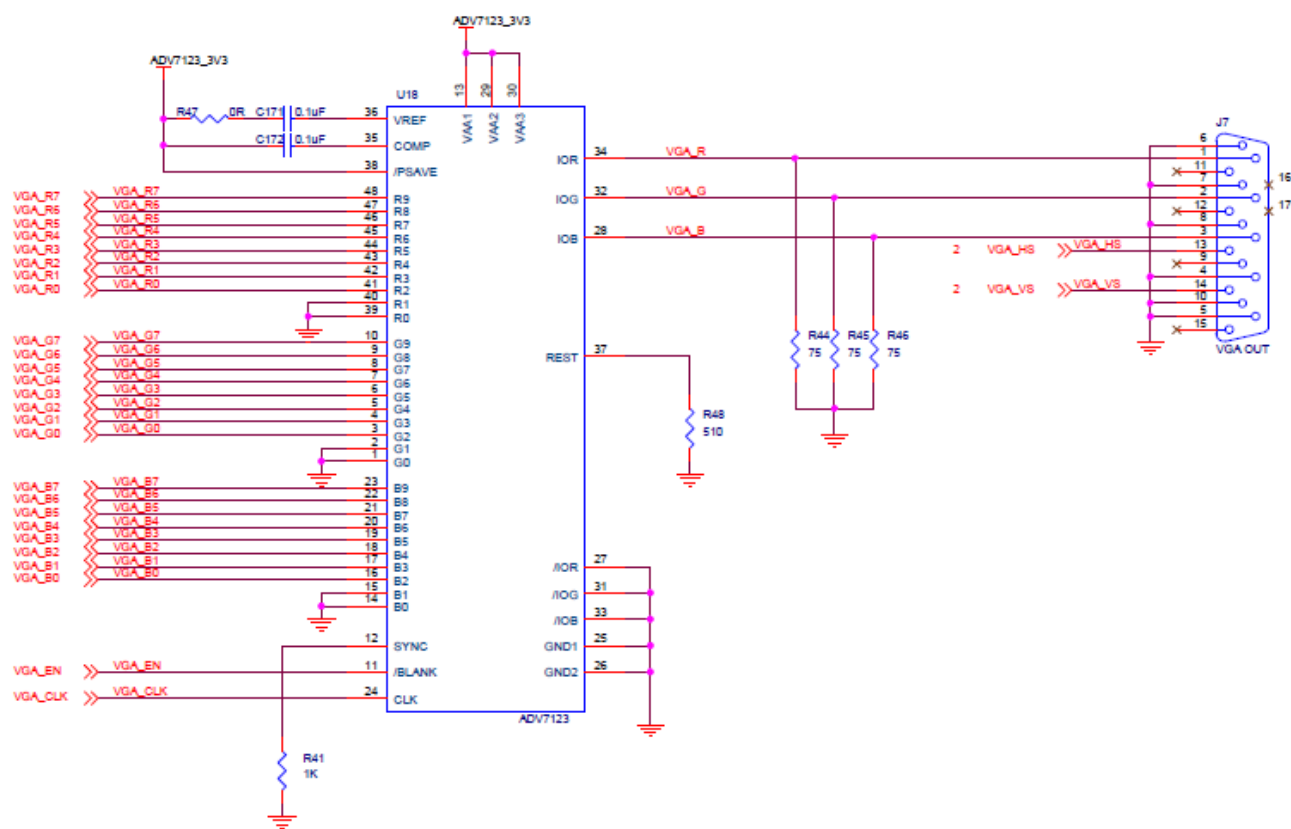
2.1 硬件设计

AX7101 开发板使用常用的 RGB565 数据输出,也就是 16 位的高彩色 VGA 显示,其中红色信号占 5 位,绿色信号占 6 位,蓝色信号占 5 位。电路设计上通过电阻匹配网络实现 RGB 数字信号到模拟信号的转换。



AX7101 VGA 输出部分电路

AX7102 开发板使用了 ADI 公司的 ADV7123 芯片实现 VGA 输出，ADV7123 内含三路 10 位 D/A 转换器，对输入的 RGB 数字信号进行模拟转换输出 VGA 视频信号，最高支持 1080p@60Hz 输出。FPGA 输出的 RGB 数字信号为 24 位色，其中红绿蓝三种颜色各 8 位，FPGA 输出的红绿蓝各 8 位数据连接到 ADV7123 的 3 路 D/A 转换的数据输入高 8 位，数据输入的低 2 位置 0。下图为 ADV7123 的原理图设计：



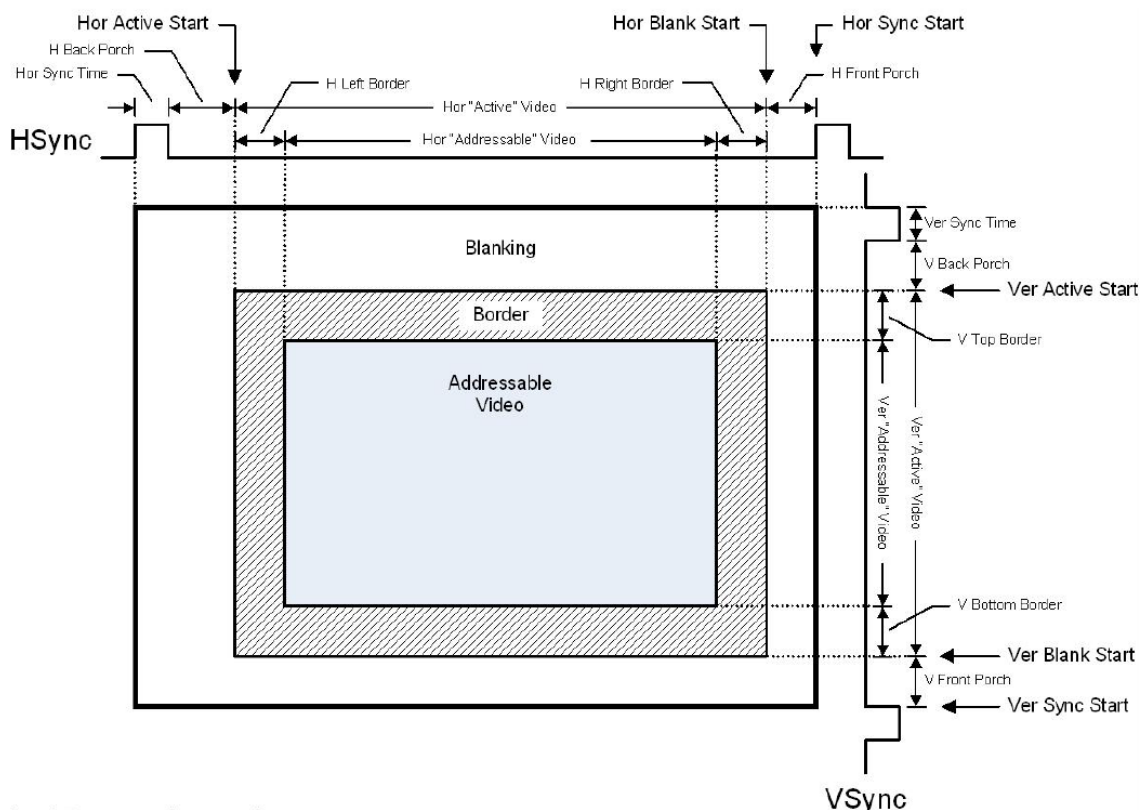
AX7102 VGA 输出部分电路

2.2 视频时序标准

VGA 显示器扫描方式从屏幕左上角一点开始，从左向右逐点扫描，每扫描完一行，电子束回到屏幕的左边下一行的起始位置，在这期间，CRT 对电子束进行消隐，每行结束时，用行同步信号进行同步；当扫描完所有的行，形成一帧，用场同步信号进行场同步，并使扫描回到屏幕左上方，同时进行场消隐，开始下一帧。

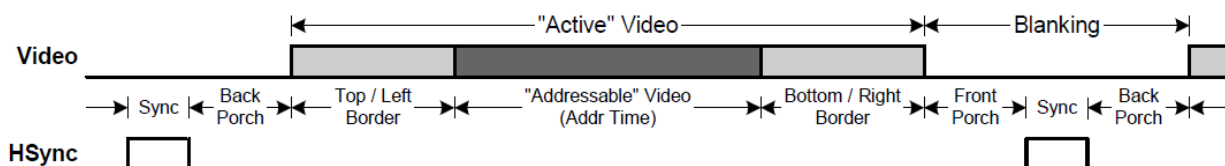
完成一行扫描的时间称为水平扫描时间，其倒数称为行频率；完成一帧（整屏）扫描的时间称为垂直扫描时间，其倒数称为场频率，即刷新一屏的频率，常见的有 60Hz，75Hz 等等。标准的显示的场频 60Hz。

时钟频率：以 1024x768@59.94Hz(60Hz)为例，每场对应 806 个行周期,其中 768 为显示行。每显示行包括 1344 点时钟,其中 1024 点为有效显示区。由此可知：需要点时钟频率：806*1344*60 约 65MHz。



视频时序

VGA 扫描，基本元素是行扫描，多行组成一帧，下图显示一行的时序，其中“Active” Video 是一行视频的有效像素，大部分分辨率时钟中 Top/Left Border 和 Bottom / Right Border 都是 0。“Blanking”是一行的同步时间，“Blanking”时间加上 Active” Video 时间就是一行的时间。“Blanking”又分为“Front Porch”、“Sync”、“Back Porch”三段。



行同步时序

2.3 常见分辨率时序

Timing Name	= 640 x 480 @ 60Hz;			
Hor Pixels	= 640;	// Pixels		
Ver Pixels	= 480;	// Lines		
Hor Frequency	= 31.469;	// kHz	= 31.8 usec	/ line
Ver Frequency	= 59.940;	// Hz	= 16.7 msec	/ frame
Pixel Clock	= 25.175;	// MHz	= 39.7 nsec	± 0.5%
Character Width	= 8;	// Pixels	= 317.8 nsec	
Scan Type	= NONINTERLACED;	// H Phase	= 2.0 %	
Hor Sync Polarity	= NEGATIVE;	// HBlank	= 18.0% of HTotal	
Ver Sync Polarity	= NEGATIVE;	// VBlank	= 5.5% of VTotal	
Hor Total Time	= 31.778;	// (usec)	= 100 chars	= 800 Pixels
Hor Addr Time	= 25.422;	// (usec)	= 80 chars	= 640 Pixels
Hor Blank Start	= 25.740;	// (usec)	= 81 chars	= 648 Pixels
Hor Blank Time	= 5.720;	// (usec)	= 18 chars	= 144 Pixels
Hor Sync Start	= 26.058;	// (usec)	= 82 chars	= 656 Pixels
// H Right Border	= 0.318;	// (usec)	= 1 chars	= 8 Pixels
// H Front Porch	= 0.318;	// (usec)	= 1 chars	= 8 Pixels
Hor Sync Time	= 3.813;	// (usec)	= 12 chars	= 96 Pixels
// H Back Porch	= 1.589;	// (usec)	= 5 chars	= 40 Pixels
// H Left Border	= 0.318;	// (usec)	= 1 chars	= 8 Pixels
Ver Total Time	= 16.683;	// (msec)	= 525 lines	HT – (1.06xHA)
Ver Addr Time	= 15.253;	// (msec)	= 480 lines	= 4.83
Ver Blank Start	= 15.507;	// (msec)	= 488 lines	
Ver Blank Time	= 0.922;	// (msec)	= 29 lines	
Ver Sync Start	= 15.571;	// (msec)	= 490 lines	
// V Bottom Border	= 0.254;	// (msec)	= 8 lines	
// V Front Porch	= 0.064;	// (msec)	= 2 lines	
Ver Sync Time	= 0.064;	// (msec)	= 2 lines	
// V Back Porch	= 0.794;	// (msec)	= 25 lines	
// V Top Border	= 0.254;	// (msec)	= 8 lines	

640x480@60Hz 时序参数

Timing Name	= 800 x 600 @ 60Hz;			
Hor Pixels	= 800;	// Pixels		
Ver Pixels	= 600;	// Lines		
Hor Frequency	= 37.879;	// kHz	= 26.4 usec	/ line
Ver Frequency	= 60.317;	// Hz	= 16.6 msec	/ frame
Pixel Clock	= 40.000;	// MHz	= 25.0 nsec	± 0.5%
Character Width	= 8;	// Pixels	= 200.0 nsec	
Scan Type	= NONINTERLACED;	// H Phase	= 2.3 %	
Hor Sync Polarity	= POSITIVE;	// HBlank	= 24.2% of HTotal	
Ver Sync Polarity	= POSITIVE;	// VBlank	= 4.5% of VTotal	
Hor Total Time	= 26.400;	// (usec)	= 132 chars	= 1056 Pixels
Hor Addr Time	= 20.000;	// (usec)	= 100 chars	= 800 Pixels
Hor Blank Start	= 20.000;	// (usec)	= 100 chars	= 800 Pixels
Hor Blank Time	= 6.400;	// (usec)	= 32 chars	= 256 Pixels
Hor Sync Start	= 21.000;	// (usec)	= 105 chars	= 840 Pixels
// H Right Border	= 0.000;	// (usec)	= 0 chars	= 0 Pixels
// H Front Porch	= 1.000;	// (usec)	= 5 chars	= 40 Pixels
Hor Sync Time	= 3.200;	// (usec)	= 16 chars	= 128 Pixels
// H Back Porch	= 2.200;	// (usec)	= 11 chars	= 88 Pixels
// H Left Border	= 0.000;	// (usec)	= 0 chars	= 0 Pixels
Ver Total Time	= 16.579;	// (msec)	= 628 lines	HT – (1.06xHA)
Ver Addr Time	= 15.840;	// (msec)	= 600 lines	= 5.2
Ver Blank Start	= 15.840;	// (msec)	= 600 lines	
Ver Blank Time	= 0.739;	// (msec)	= 28 lines	
Ver Sync Start	= 15.866;	// (msec)	= 601 lines	
// V Bottom Border	= 0.000;	// (msec)	= 0 lines	
// V Front Porch	= 0.026;	// (msec)	= 1 lines	
Ver Sync Time	= 0.106;	// (msec)	= 4 lines	
// V Back Porch	= 0.607;	// (msec)	= 23 lines	
// V Top Border	= 0.000;	// (msec)	= 0 lines	

800x600@60Hz 时序参数

Timing Name	=	1024 x 768 @ 60Hz;		
Hor Pixels	=	1024;	// Pixels	
Ver Pixels	=	768;	// Lines	
Hor Frequency	=	48.363;	// kHz	= 20.7 usec / line
Ver Frequency	=	60.004;	// Hz	= 16.7 msec / frame
Pixel Clock	=	65.000;	// MHz	= 15.4 nsec ± 0.5%
Character Width	=	8;	// Pixels	= 123.1 nsec
Scan Type	=	NONINTERLACED;	// H Phase	= 5.1 %
Hor Sync Polarity	=	NEGATIVE;	// HBlank	= 23.8% of HTotal
Ver Sync Polarity	=	NEGATIVE;	// VBlank	= 4.7% of VTotal
Hor Total Time	=	20.677;	// (usec)	= 168 chars = 1344 Pixels
Hor Addr Time	=	15.754;	// (usec)	= 128 chars = 1024 Pixels
Hor Blank Start	=	15.754;	// (usec)	= 128 chars = 1024 Pixels
Hor Blank Time	=	4.923;	// (usec)	= 40 chars = 320 Pixels
Hor Sync Start	=	16.123;	// (usec)	= 131 chars = 1048 Pixels
// H Right Border	=	0.000;	// (usec)	= 0 chars = 0 Pixels
// H Front Porch	=	0.369;	// (usec)	= 3 chars = 24 Pixels
Hor Sync Time	=	2.092;	// (usec)	= 17 chars = 136 Pixels
// H Back Porch	=	2.462;	// (usec)	= 20 chars = 160 Pixels
// H Left Border	=	0.000;	// (usec)	= 0 chars = 0 Pixels
Ver Total Time	=	16.666;	// (msec)	= 806 lines HT – (1.06xHA)
Ver Addr Time	=	15.880;	// (msec)	= 768 lines = 3.98
Ver Blank Start	=	15.880;	// (msec)	= 768 lines
Ver Blank Time	=	0.786;	// (msec)	= 38 lines
Ver Sync Start	=	15.942;	// (msec)	= 771 lines
// V Bottom Border	=	0.000;	// (msec)	= 0 lines
// V Front Porch	=	0.062;	// (msec)	= 3 lines
Ver Sync Time	=	0.124;	// (msec)	= 6 lines
// V Back Porch	=	0.600;	// (msec)	= 29 lines
// V Top Border	=	0.000;	// (msec)	= 0 lines

1024x768@60Hz 时序参数

Timing Name	=	1280 x 720 @ 60Hz;			
Hor Pixels	=	1280;	// Pixels		
Ver Pixels	=	720;	// Lines		
Hor Frequency	=	45.000;	// KHz	=	22.2 usec / line
Ver Frequency	=	60.000;	// Hz	=	16.7 msec / frame
Pixel Clock	=	74.250;	// MHz	=	13.5 nsec ± 0.5%
Character Width	=	1;	// Pixels	=	13.5 nsec
Scan Type	=	NONINTERLACED;	// H Phase	=	3.3 %
Hor Sync Polarity	=	POSITIVE;	// HBlank	=	22.4% of HTotal
Ver Sync Polarity	=	POSITIVE;	// VBlank	=	4.0% of VTotal
Hor Total Time	=	22.222;	// (usec)	=	1650 chars = 1650 Pixels
Hor Addr Time	=	17.239;	// (usec)	=	1280 chars = 1280 Pixels
Hor Blank Start	=	17.239;	// (usec)	=	1280 chars = 1280 Pixels
Hor Blank Time	=	4.983;	// (usec)	=	370 chars = 370 Pixels
Hor Sync Start	=	18.721;	// (usec)	=	1390 chars = 1390 Pixels
// H Right Border	=	0.000;	// (usec)	=	0 chars = 0 Pixels
// H Front Porch	=	1.481;	// (usec)	=	110 chars = 110 Pixels
Hor Sync Time	=	0.539;	// (usec)	=	40 chars = 40 Pixels
// H Back Porch	=	2.963;	// (usec)	=	220 chars = 220 Pixels
// H Left Border	=	0.000;	// (usec)	=	0 chars = 0 Pixels
Ver Total Time	=	16.667;	// (msec)	=	750 lines HT – (1.06xHA)
Ver Addr Time	=	16.000;	// (msec)	=	720 lines = 3.95
Ver Blank Start	=	16.000;	// (msec)	=	720 lines
Ver Blank Time	=	0.667;	// (msec)	=	30 lines
Ver Sync Start	=	16.111;	// (msec)	=	725 lines
// V Bottom Border	=	0.000;	// (msec)	=	0 lines
// V Front Porch	=	0.111;	// (msec)	=	5 lines
Ver Sync Time	=	0.111;	// (msec)	=	5 lines
// V Back Porch	=	0.444;	// (msec)	=	20 lines
// V Top Border	=	0.000;	// (msec)	=	0 lines

1280x720@60Hz 时序参数

Timing Name	=	1280 x 800 @ 60Hz;		
Hor Pixels	=	1280;	// Pixels	
Ver Pixels	=	800;	// Lines	
Hor Frequency	=	49.702;	// kHz	= 20.1 usec / line
Ver Frequency	=	59.810;	// Hz	= 16.7 msec / frame
Pixel Clock	=	83.500;	// MHz	= 12.0 nsec ± 0.5%
Character Width	=	8;	// Pixels	= 95.8 nsec
Scan Type	=	NONINTERLACED;	// H Phase	= 3.8 %
Hor Sync Polarity	=	NEGATIVE;	// HBlank	= 23.8% of HTotal
Ver Sync Polarity	=	POSITIVE;	// VBlank	= 3.7% of VTotal
Hor Total Time	=	20.120;	// (usec)	= 210 chars = 1680 Pixels
Hor Addr Time	=	15.329;	// (usec)	= 160 chars = 1280 Pixels
Hor Blank Start	=	15.329;	// (usec)	= 160 chars = 1280 Pixels
Hor Blank Time	=	4.790;	// (usec)	= 50 chars = 400 Pixels
Hor Sync Start	=	16.192;	// (usec)	= 169 chars = 1352 Pixels
// H Right Border	=	0.000;	// (usec)	= 0 chars = 0 Pixels
// H Front Porch	=	0.862;	// (usec)	= 9 chars = 72 Pixels
Hor Sync Time	=	1.533;	// (usec)	= 16 chars = 128 Pixels
// H Back Porch	=	2.395;	// (usec)	= 25 chars = 200 Pixels
// H Left Border	=	0.000;	// (usec)	= 0 chars = 0 Pixels
Ver Total Time	=	16.720;	// (msec)	= 831 lines HT – (1.06xHA)
Ver Addr Time	=	16.096;	// (msec)	= 800 lines = 3.87
Ver Blank Start	=	16.096;	// (msec)	= 800 lines
Ver Blank Time	=	0.624;	// (msec)	= 31 lines
Ver Sync Start	=	16.156;	// (msec)	= 803 lines
// V Bottom Border	=	0.000;	// (msec)	= 0 lines
// V Front Porch	=	0.060;	// (msec)	= 3 lines
Ver Sync Time	=	0.121;	// (msec)	= 6 lines
// V Back Porch	=	0.443;	// (msec)	= 22 lines
// V Top Border	=	0.000;	// (msec)	= 0 lines

1280x800@60Hz 时序参数

Timing Name	=	1280 x 960 @ 60Hz;		
Hor Pixels	=	1280;	// Pixels	
Ver Pixels	=	960;	// Lines	
Hor Frequency	=	60.000;	// kHz	= 16.7 usec / line
Ver Frequency	=	60.000;	// Hz	= 16.7 msec / frame
Pixel Clock	=	108.000;	// MHz	= 9.3 nsec ± 0.5%
Character Width	=	8;	// Pixels	= 74.1 nsec
Scan Type	=	NONINTERLACED;	// H Phase	= 6.0 %
Hor Sync Polarity	=	POSITIVE;	// HBlank	= 28.9% of HTotal
Ver Sync Polarity	=	POSITIVE;	// VBlank	= 4.0% of VTotal
Hor Total Time	=	16.667;	// (usec)	= 225 chars = 1800 Pixels
Hor Addr Time	=	11.852;	// (usec)	= 160 chars = 1280 Pixels
Hor Blank Start	=	11.852;	// (usec)	= 160 chars = 1280 Pixels
Hor Blank Time	=	4.815;	// (usec)	= 65 chars = 520 Pixels
Hor Sync Start	=	12.741;	// (usec)	= 172 chars = 1376 Pixels
// H Right Border	=	0.000;	// (usec)	= 0 chars = 0 Pixels
// H Front Porch	=	0.889;	// (usec)	= 12 chars = 96 Pixels
Hor Sync Time	=	1.037;	// (usec)	= 14 chars = 112 Pixels
// H Back Porch	=	2.889;	// (usec)	= 39 chars = 312 Pixels
// H Left Border	=	0.000;	// (usec)	= 0 chars = 0 Pixels
Ver Total Time	=	16.667;	// (msec)	= 1000 lines HT – (1.06xHA)
Ver Addr Time	=	16.000;	// (msec)	= 960 lines = 4.1
Ver Blank Start	=	16.000;	// (msec)	= 960 lines
Ver Blank Time	=	0.667;	// (msec)	= 40 lines
Ver Sync Start	=	16.017;	// (msec)	= 961 lines
// V Bottom Border	=	0.000;	// (msec)	= 0 lines
// V Front Porch	=	0.017;	// (msec)	= 1 lines
Ver Sync Time	=	0.050;	// (msec)	= 3 lines
// V Back Porch	=	0.600;	// (msec)	= 36 lines
// V Top Border	=	0.000;	// (msec)	= 0 lines

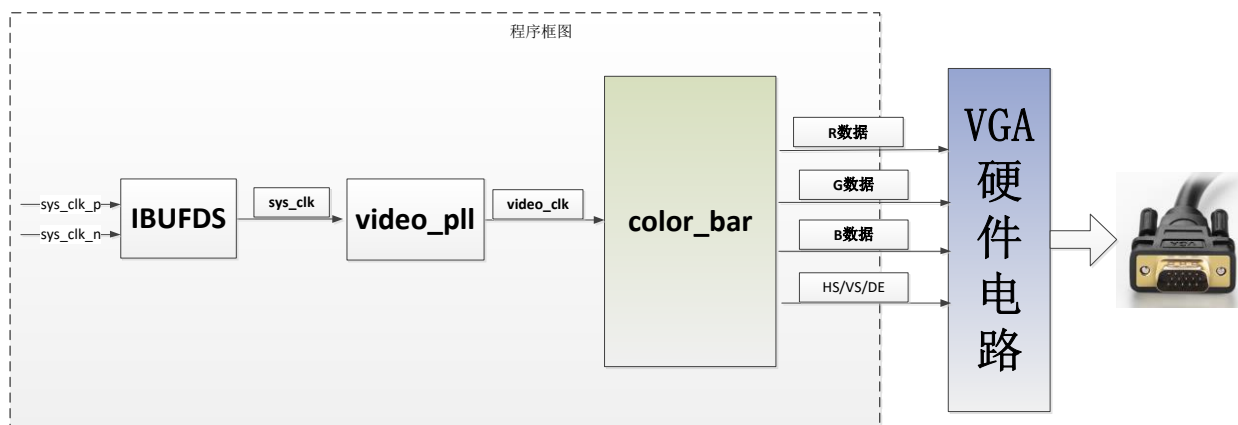
1280x960@60Hz 时序参数

Timing Name	=	1280 x 1024 @ 60Hz;		
Hor Pixels	=	1280;	// Pixels	
Ver Pixels	=	1024;	// Lines	
Hor Frequency	=	63.981;	// kHz	= 15.6 usec / line
Ver Frequency	=	60.020;	// Hz	= 16.7 msec / frame
Pixel Clock	=	108.000;	// MHz	= 9.3 nsec ± 0.5%
Character Width	=	8;	// Pixels	= 74.1 nsec
Scan Type	=	NONINTERLACED;	// H Phase	= 5.9 %
Hor Sync Polarity	=	POSITIVE;	// HBlank	= 24.2% of HTotal
Ver Sync Polarity	=	POSITIVE;	// VBlank	= 3.9% of VTotal
Hor Total Time	=	15.630;	// (usec)	= 211 chars = 1688 Pixels
Hor Addr Time	=	11.852;	// (usec)	= 160 chars = 1280 Pixels
Hor Blank Start	=	11.852;	// (usec)	= 160 chars = 1280 Pixels
Hor Blank Time	=	3.778;	// (usec)	= 51 chars = 408 Pixels
Hor Sync Start	=	12.296;	// (usec)	= 166 chars = 1328 Pixels
// H Right Border	=	0.000;	// (usec)	= 0 chars = 0 Pixels
// H Front Porch	=	0.444;	// (usec)	= 6 chars = 48 Pixels
Hor Sync Time	=	1.037;	// (usec)	= 14 chars = 112 Pixels
// H Back Porch	=	2.296;	// (usec)	= 31 chars = 248 Pixels
// H Left Border	=	0.000;	// (usec)	= 0 chars = 0 Pixels
Ver Total Time	=	16.661;	// (msec)	= 1066 lines HT – (1.06xHA)
Ver Addr Time	=	16.005;	// (msec)	= 1024 lines = 3.07
Ver Blank Start	=	16.005;	// (msec)	= 1024 lines
Ver Blank Time	=	0.656;	// (msec)	= 42 lines
Ver Sync Start	=	16.020;	// (msec)	= 1025 lines
// V Bottom Border	=	0.000;	// (msec)	= 0 lines
// V Front Porch	=	0.016;	// (msec)	= 1 lines
Ver Sync Time	=	0.047;	// (msec)	= 3 lines
// V Back Porch	=	0.594;	// (msec)	= 38 lines
// V Top Border	=	0.000;	// (msec)	= 0 lines

1280x1024@60Hz 时序参数

3 程序设计

本实验实现 VGA 输出显示，在 VGA 显示器里显示测试的彩条图像。程序由 3 个模块实现，分别是差分转单端 IBUFDS 模块，时钟模块 vidio_pll，彩条生成模块 color_bar。实现的逻辑框图如下：



1. IBUFDS 模块

功能是对输入时钟进行差分转单端输出。

2.VGA 时钟模块 video_pll

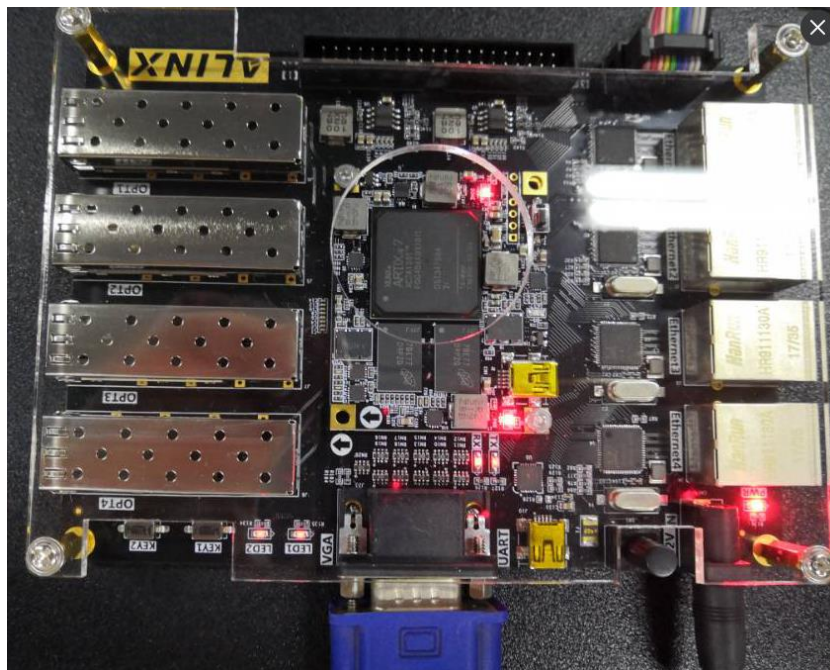
video_pll 模块是倍频产生模块，通过输入的 sys_clk 时钟产生 VGA 显示所需要的时钟信号，模块中设置为 65MHz，用来满足 VGA 分辨率为 1024x768 的要求。

3. 彩条产生模块 color_bar.v

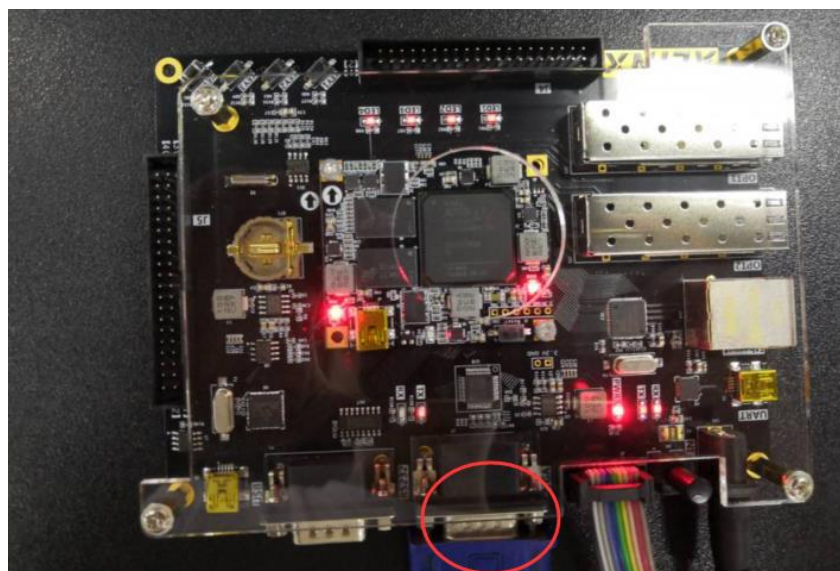
color_bar.v 是产生 8 种颜色的 VGA 格式的彩条，彩条分别为白、黄、青、绿、紫、红、蓝和黑。针对 VGA 的时序，行同步和场同步各使用一个计数器，行同步计数器用于产生行同步，行有效像素，场同步计数器用于产生场同步，场有效像素。同时根据计数器的值可以产生水平 (X) 和垂直 (Y) 坐标，通过坐标信息，可以实时显示一些图形。程序中预设了几种分辨率的时序参数，包括 2 款 LCD 液晶屏的，为后续的 LCD 验证试验做准备。

4 试验现象

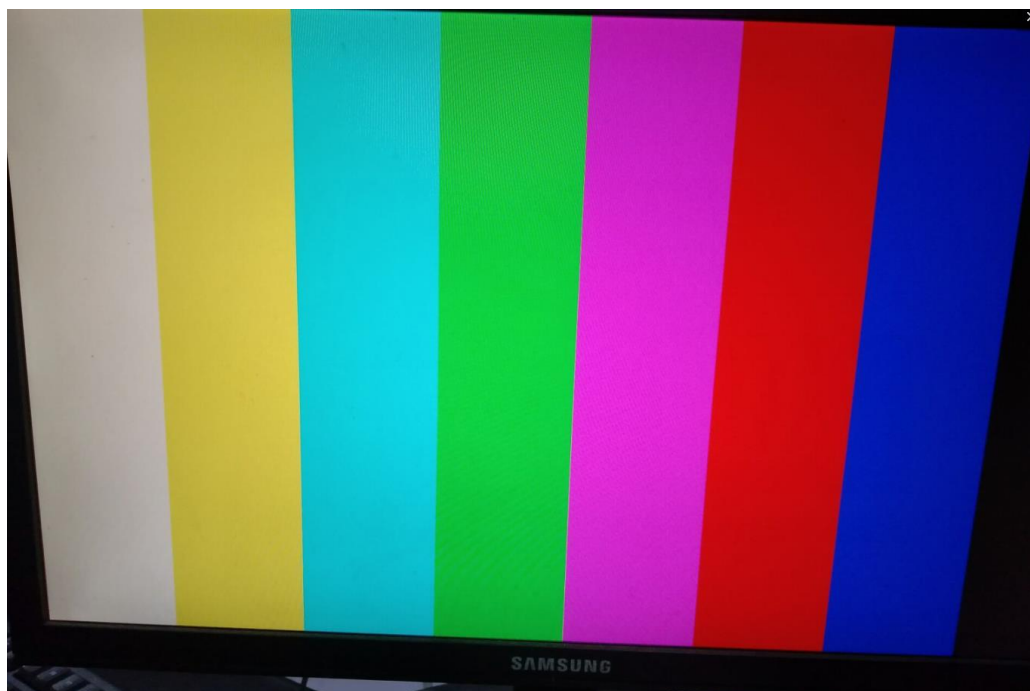
连接好开发板和显示器，需要注意，开发板的各个连接器不要带电热插拔，下载好试验程序，可以看到显示器显示 8 条彩条。开发板做为 VGA 输出设备，只能通过 VGA 显示设备来显示，注意不要试图通过笔记本电脑的 VGA 接口来显示，因为笔记本也是输出设备。



AX7101 VGA 显示器连接



AX7102 VGA 显示器连接



彩条显示

在用 AX7101 开发板做 4.3 寸 LCD、7 寸 LCD 屏显示实验时，LCD 模块接 J11 扩展口；在用 AX7102 开发板做 4.3 寸 LCD 、7 寸 LCD 屏显示实验时，LCD 模块接 J5 扩展口，注意管脚不要接错。