VGATonic Serial Graphics Card
Hardware System Design Document

Version 1.0
PK

1. Introduction

VGATonic is an open source serial graphics card designed to enable graphical output for microcontrollers, single board computers, and other devices with SPI or Asynchronous TTL Serial output.

VGATonic provides up to 640x480 resolution in 8 bit color using standard VGA timings. The framebuffer memory can be accessed over both SPI and TTL UART.

VGATonic allows hardware accelerated resolutions of 320x240, 160x120, and 80x60. Additionally, it enables accelerated color bit depths of 4, 2, and 1 – and any combination of color depth and resolution. VGATonic also enables hardware accelerated positioning allowing partial frame updates.

In UART mode, VGATonic also exposes a VT52 compatible terminal emulator with 40x15 columns of text along with a built-in font.

1.1 Purpose

VGATonic was created as a graphics card with easy to use VGA output when provided input in serial format. It enables easily usable VGA output for low to medium serial speeds by allowing a designer to pick a combination of accelerated bit depths and resolutions acceptable for his or her design.

For applications where only text output is needed or framebuffer modes which fit the available serial speed are too slow, there is a VT52 compatible terminal emulator with a built-in font onboard.

1.2 Scope

This version of VGATonic is intended to provide graphical output over VGA in standard 640x480 at 60Hz timings. It requires a driver which can output SPI and/or asynchronous TTL serial, and requires a monitor, television, adapter, capture card, or other device providing VGA input as a consumer of its VGA output.

1.3 Overview

This document provides a brief description of some of the specific functions, design decisions, and technical specifications of VGATonic. It is hoped that the reader can create a design utilizing VGATonic's graphical output using this document, *The User's Guide* and supporting collateral such as schematics, example code, and drivers.

2. VGATonic Overview

2.1 Product Functions

2.1.1.   Framebuffer Mode

VGATonic's main mode is a framebuffer mode. Utilizing an onboard 4 Mbit SRAM, VGATonic can accept pixel by pixel data in 8, 4, 2, or 1 bit color depths. VGATonic writes left to right and top to bottom, while the number of writes is determined by the resolution of the screen (and the bit depth). Other than 640x480, VGATonic also does power of two resolution reductions internally, accepting 320x240, 160x120, and 80x60.

VGATonic allows three forms of hardware acceleration in order to improve performance over serial connections. Please see the *User's Guide* for an in depth description of these modes and a description of the control characters that allow resolution and bit depth changes as well as write positioning.

- *Chip Select*
  - Toggling chip select at any point during a serial transfer (chip select *high* then *low*) will reset the framebuffer write pointer to the upper left pixel at location 1 in row 1.
- *Hardware Positioning*
  - Control characters can be used to change the location of the framebuffer write pointer. Positioning changes the row where a serial write will begin.
- *Bit Depth and Resolution*
  - Changing bit depth and resolution from 640x480 in 8 bits primes VGATonic to accept fewer bytes in a given serial transaction.

2.1.2.   Terminal Emulator Mode

VGATonic includes a terminal emulator onboard with one built in font. It is accessible over asynchronous TTL serial. It provides 40 columns by 15 lines of text and allows a subset (roughly 90%) of VT52 escape codes. Please see the *User's Guide* for a listing.

2.1.3.   Administration Mode

Using special escape codes not available on the VT52, VGATonic exposes certain functionality useful for a serial graphics card. Connecting over asynchronous TTL serial, *Administration Mode* allows toggling UART speed between 9600 baud and 38400 baud. In the case that a device will not sync to VGATonic's VGA output, *Administration Mode* also allows calibration of the onboard LTC6903 programmable oscillator.

2.2 Product Constrains

- 5V Power (most commonly using USB-B input)
- SPI: 5v, 3.3v or 2.5v logic (1 byte transactions)
  - (and/or)
- Serial: 3.3v 9600 or 38400 baud 8-N-1 logic

2.3 Product Assumptions

VGATonic assumes the availability of a VGA input device, such as a monitor, television, capture card, converter box, or other form of input. It also assumes compatibility with IBM's 1987 VGA standard timings for 640x480 resolution at 60 Hz. It also assumes the availability of a suitable 5 volt power source.

VGA's original 640x480 standard called for 16 colors (4 bit color), and VGATonic goes beyond that specification with 256 color (8 bit) mode available in all resolutions.

Although we assume all existing VGA monitors can handle (or ignore) the added color modes, if you have a classic monitor you will be connecting to VGAtonic please check the monitor's user manual first.

3. System Requirements and Specifications

3.1 Functionality

VGATonic outputs a constant 640x480 at 60 Hz signal and all processing for lower resolutions and color depths is done internally. VGATonic can multiplex writing and reading with a single buffering schema, and can accept SPI writes faster than the VGA pixel clock.

In UART mode, VGATonic starts up in 9600 baud 8-N-1, but can be toggled to 38400 baud.

3.2 Performance

3.2.1   Serial Maximum Speeds

- 59.7 MHz Maximum SPI Speed Recommended
  - 62.5 MHz tested working on 100% of prototype boards, but technically violates CPLD setup times.
- 9600 or 38400 baud 8-N-1 Asynchronous Serial

3.2.2   Serial Voltages

- 5v, 3.3v, or 2.5v SPI
- 3.3v Asynchronous Serial (UART)

3.2.3   Resolutions, Bit Depths, and Bits Written

- *640x480 @ 256 Colors*
  - 2,457,600 bits per frame (307,200 bytes)
- *640x480 @ 16 Colors*
  - 1,228,800 bits per frame (153,600 bytes)
- *640x480 @ 4 Colors*
  - 614,400 bits per frame (76,800 bytes)
- *640x480 @ 2 Colors*
  - 307,200 bits per frame (38,400 bytes)
- *320x240 @ 256 Colors*
  - 614,400 bits per frame (76,800 bytes)
- *320x240 @ 16 Colors*
  - 307,200 bits per frame (38,400 bytes)
- *320x240 @ 4 Colors*
  - 153,600 bits per frame (19,200 bytes)
- *320x240 @ 2 Colors*
  - 76,800 bits per frame (9,600 bytes)
- *160x120 @ 256 Colors*
  - 153,600 bits per frame (19,200 bytes)
- *160x120 @ 16 Colors*
  - 76,800 bits per frame (9,600 bytes)

- *160x120 @ 4 Colors*
  - 38,400 bits per frame (4,800 bytes)
- *160x120 @ 2 Colors*
  - 19,200 bits per frame (2,400 bytes)
- *80x60 @ 256 Colors*
  - 38,400 bits per frame (4,800 bytes)
- *80x60 @ 16 Colors*
  - 19,200 bits per frame (2,400 bytes)
- *80x60 @ 4 Colors*
  - 9,600 bits per frame (1,200 bytes)
- *80x60 @ 2 Colors*
  - 4,800 bits per frame (600 bytes)

3.2.4   Theoretical Top Framerate for Full Screen Writes (SPI Only, 59.7 MHz)

- *640x480 @ 8 Bits Per Color:* 24.29 Frames Per Second
- *640x480 @ 8 Bits Per Color:* 48.58 Frames Per Second
- *All other color and resolution combinations:* 60 Frames Per Second

3.2.5   Power Usage

Typical*: 140 – 170 mA at 5V, 0.7 – 0.85 Watts

If there is a fault condition on the 5V power supply, the 750 mA PTC fuse aboard VGATonic should trip. Once you fix the fault, please wait for the fuse to cool down before providing VGATonic with power again. PTC fuses can take up to 24 hours (even more) to reset.

*VGATonic power usage varies based on mode (UART, SPI). As the VGA standard calls for VGATonic to source current, the average color of the pixels on screen and the rate VGATonic updates internal framebuffer memory also can cause a measurable change in the amount of power used.

3.3 Design Constraints

VGATonic was designed with a few requirements in mind:

- Low cost per board
- Ease of use
- Easy to use interfaces
- Very low to medium serial interface speed (No USB 2.0+, PCI, etc.)
- Highly constrained: challenge of CPLD and Tiny Microcontroller vs. FPGA and 32 bit microcontroller.
- Hackability: programmable oscillator and programmable logic and microcontroller
- Power consumption able to run off a USB port

3.4 **Applicable Licenses**

- [MIT:](#)
  - All hardware - the PCBs and Kicad collateral.
  - CPLD Firmware
  - Microcontroller Firmware
  - Arduino Framebuffer Driver
  - UART Examples
- [GPL version 2:](#) (Kernel code and SPIDEV)
  - All of the Linux Framebuffer Code
  - The Linux User Space Driver code
- Third Party Licenses:
  - LGPL:
    - arduino-tiny core
      - https://code.google.com/p/arduino-tiny/

3.5 Applicable Standards

- 8-N-1 3.3V TTL Serial at 9600 or 38400 baud
- SPI at 5v, 3.3v, or 2.5v
  - (Commonly Mode 0 or 3, but there is no official SPI standard)
- 640x480 @ 60Hz Industry Standard (IBM) VGA timing
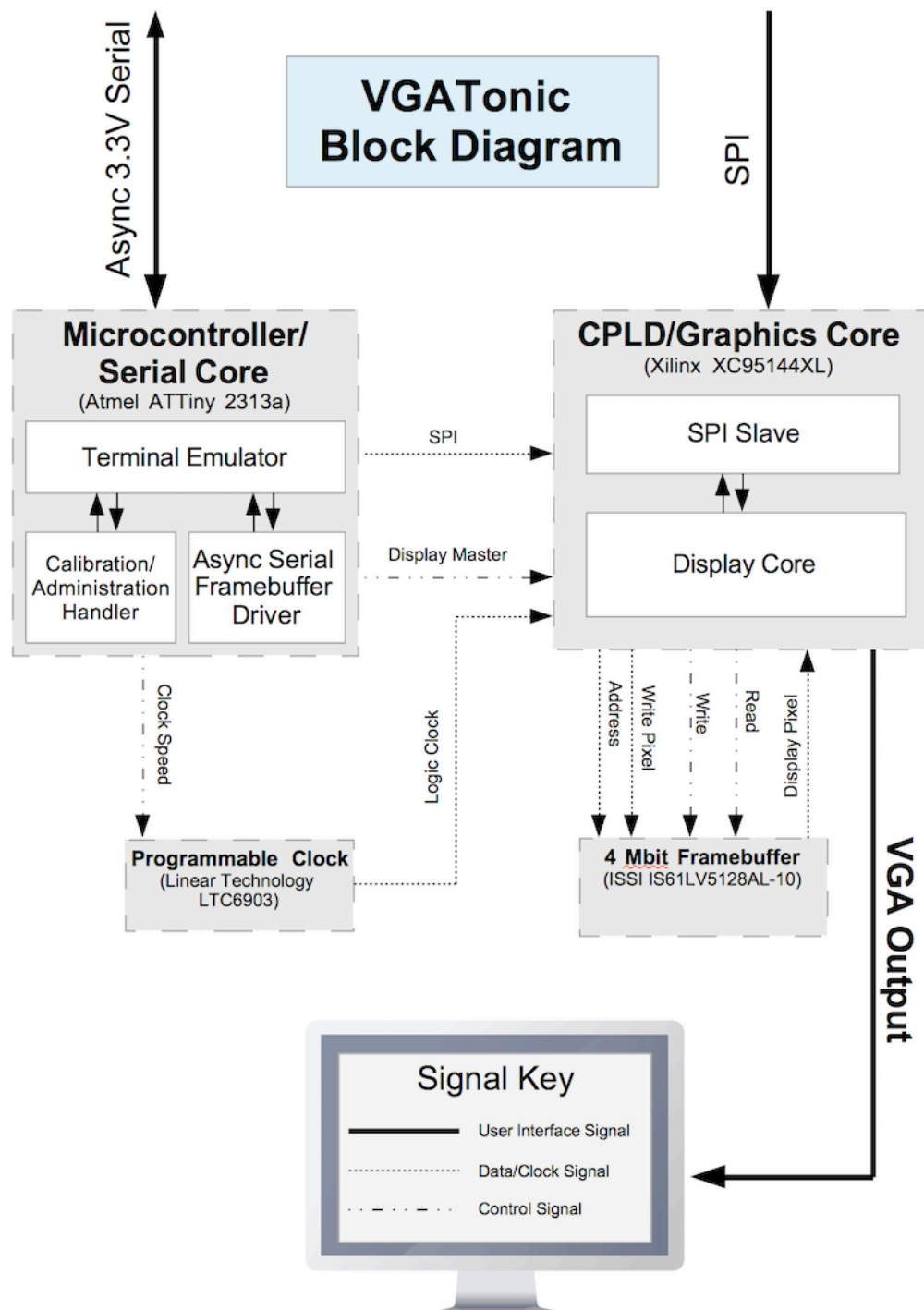- VT52 Compatible Terminal Emulator Escape Codes

4. Parts Selection

(Footprints/PCB Part Labels are in Github)

1 × Xilinx XC95144XL 144 Macrocell CPLD
1 × Atmel Corporation ATTiny 2313a Microcontroller
1 × ISSI IS61LV5128AL-10 100 MHz 4MBit Static Ram
1 × Linear Technology LTC6903 Programmable Oscillator
1 × ON Semiconductor NCP1117ST33T3G 3.3V Low Dropout Voltage Regulator
12 × 0.1 uF Capacitor 0603 Capacitor
2 × 10 uF Capacitor 1206 Capacitor
1 × 47 uF Capacitor 1206 Capacitor
1 × 1 uF Capacitor
1 × Bourns MF USMF075-2 .75 Amp PTC Fuse
1 × USB-B Jack Power Supply, Multicomp USB-B-S-RA
1 × VGA Port TE Connectivity 1734344-1
6 × 10k Ohm Resistor 0805
1 × 4.7k Ohm Resistor 0805
4 × 510 Ohm Resistor 0805
5 × 1k Ohm Resistor 0805
4 × 2k Ohm Resistor 0805
1 × 4k Ohm Resistor 0805
1 × 1.5k Ohm Resistor 0805
1 × RCA Jack (Optional) Switchcraft PJRAN1X1U04X (For future optional firmware swap)

(Please see the User's Guide for a detailed build guide.)

5. System Block Diagram

VGATonic
Block Diagram

Async 3.3V Serial

SPI

**Microcontroller/
Serial Core**
(Atmel ATTiny 2313a)

Terminal Emulator

Calibration/
Administration
Handler

Async Serial
Framebuffer
Driver

Clock Speed

Logic Clock

Programmable Clock
(Linear Technology
LTC6903)

SPI

Display Master

CPLD/Graphics Core
(Xilinx XC95144XL)

SPI Slave

Display Core

Address

Write Pixel

Write

Read

Display Pixel

4 Mbit Framebuffer
(ISSI IS61LV5128AL-10)

VGA Output

Signal Key

User Interface Signal

Data/Clock Signal

Control Signal

6. Future Work

There are two main places VGATonic could build towards:

VGATonic has sufficient GPIOs to develop RCA/component output, albeit not at the same time as VGA output. Eventually, it would be nice to have an alternative firmware for NTSC output. PAL output should also be doable.

VGTonic has sufficient framebuffer memory to target 800x600 at 8 bit color resolution. This mode isn't supported to the degree that 640x480 at 60 Hz is, but would be a valuable additional firmware for users to install for specific cases where more resolution was needed.