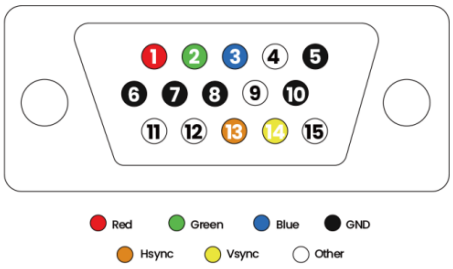
# What is VGA?

**VGA (Video Graphics Array)** is an analog video standard introduced by IBM.

## The interface Signals include:

- **Red, Green, Blue (RGB)** → analog voltages that control pixel colors.
- **HSYNC (Horizontal Sync)** → tells the monitor when a new line begins.
- **VSYNC (Vertical Sync)** → tells the monitor when a new frame begins.




## How the Image is Drawn

- The display is drawn from **left to right, top to bottom**:
  1. Draw 1 line of pixels (640 pixels for 640×480).
  2. At the end of the line, send an **HSYNC pulse**.
  3. After all 480 lines are drawn, send a **VSYNC pulse**.
- After the last line, the beam returns to the top-left corner (called **vertical retrace**).


**Timing Regions per Line (Horizontal)**

Each line (total **800 pixel clocks**) is divided into:

- **Visible area (640 pixels)** → actual image.
- **Front porch (16 pixels)** → short blank before sync.
- **Sync pulse (96 pixels)** → HSYNC low signal.
- **Back porch (48 pixels)** → blank after sync.

**Timing Regions per Frame (Vertical)**

Each frame (total **525 lines**) is divided into:

- **Visible area (480 lines)** → actual image.
- **Front porch (10 lines)** → blank lines before VSYNC.
- **Sync pulse (2 lines)** → VSYNC low signal.

- **Back porch (33 lines)** → blank after sync.

**It's required that the back porch, front porch , sync pulse times that the Red, Green , Blue signals are driven low**

**5. Pixel Clock**

- For **640×480 @ 60 Hz** standard VGA:
    - Pixel clock = **25.175 MHz**, this is your system clock
    - Total pixels per frame = **800 × 525 = 420,000**.

**VGA Signal 640 x 480 @ 60 Hz Industry standard timing**

**General timing**

| | |
|---|---|
| Screen refresh rate | 60 Hz |
| Vertical refresh | 31.46875 kHz |
| Pixel freq. | 25.175 MHz |

**Horizontal timing (line)**

Polarity of horizontal sync pulse is negative.

| Scanline part | Pixels | Time [µs] |
|---|---|---|
| Visible area | 640 | 25.422045680238 |
| Front porch | 16 | 0.63555114200596 |
| Sync pulse | 96 | 3.8133068520357 |
| Back porch | 48 | 1.9066534260179 |
| Whole line | 800 | 31.777557100298 |

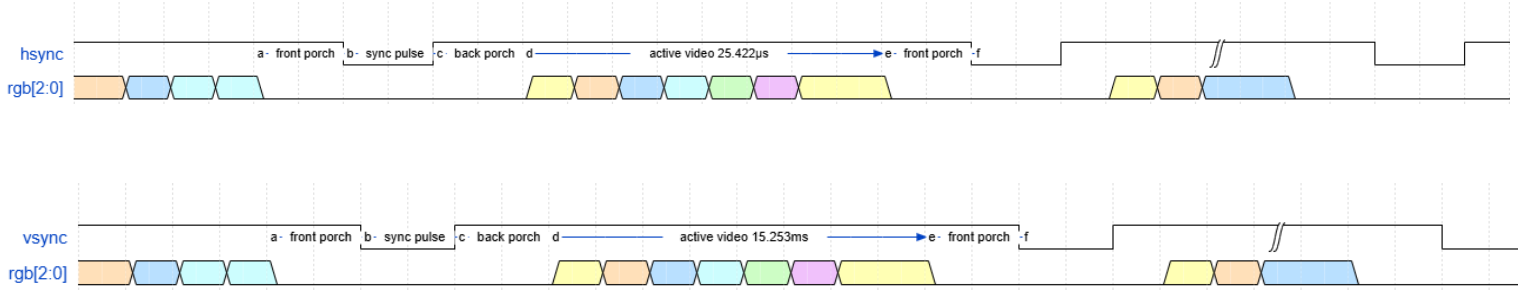
**Vertical timing (frame)**

Polarity of vertical sync pulse is negative.

| Frame part | Lines | Time [ms] |
|---|---|---|
| Visible area | 480 | 15.253227408143 |
| Front porch | 10 | 0.31777557100298 |
| Sync pulse | 2 | 0.063555114200596 |
| Back porch | 33 | 1.0486593843098 |
| Whole frame | 525 | 16.683217477656 |

*figure 1 Industry standard diagram*

## Wave forms

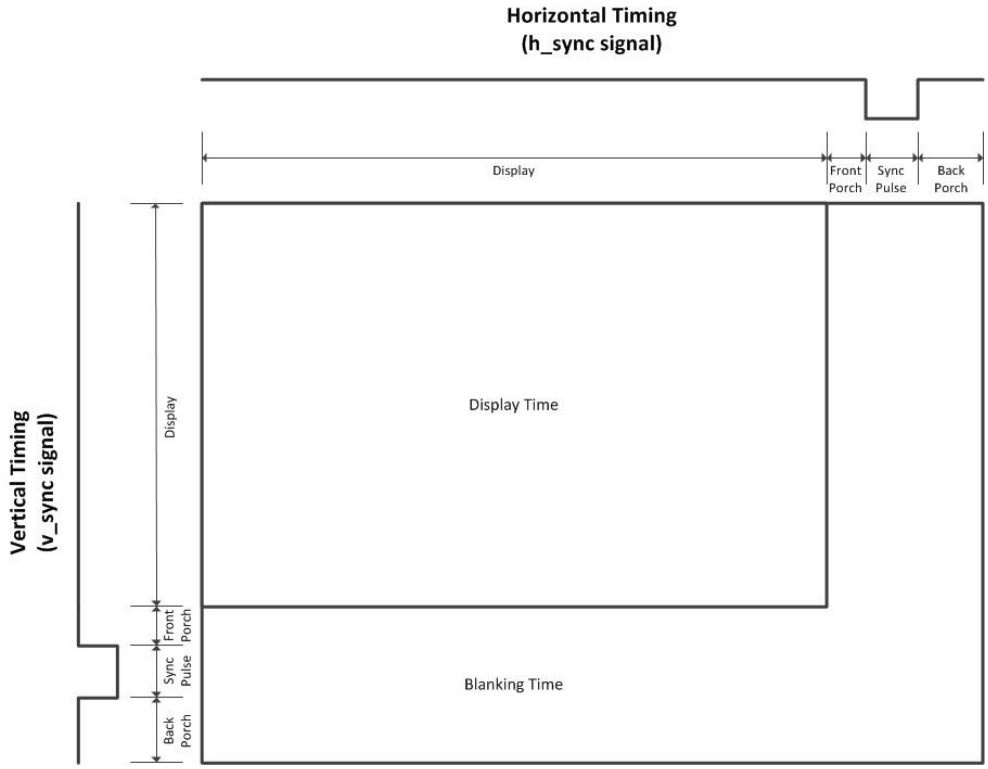



You can check the front porch time, back porch time, pulse time from the standard diagram figure above in µs or in pixel time based on 25.175 MHz pixel clock.

The VGA display can be viewed as a matrix of pixels, where each point on the screen is identified by a pixel number along a line **(0–799)** and a line number within the frame **(0–524)**. A full frame contains **800** pixels per line and **525** lines per frame. However, only a portion of this area is visible to the user: **640** pixels per line and **480** lines per frame. The remaining time is used for blanking intervals, which consist of the front porch, sync pulse, and back porch.

To generate a correct VGA signal, the controller must keep track of its current position on the screen. If the pixel location falls within the visible region, the RGB signals should be driven with the intended color values. If the location is within a blanking interval, the RGB outputs must be forced to zero (black). This guarantees that only the active display area shows visible colors, while the monitor stays blank during synchronization periods.

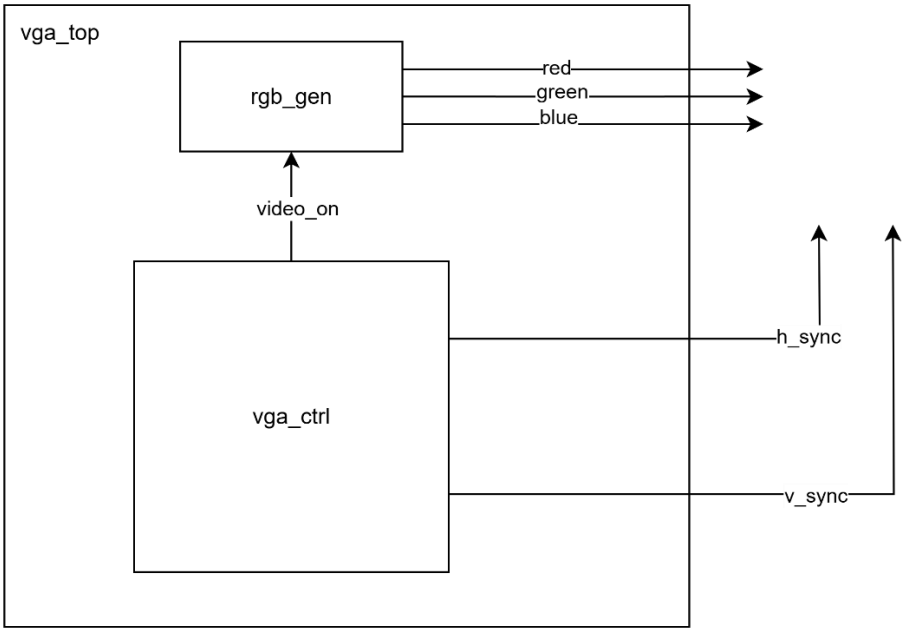
E.g. Pixel 746 is always black as it is in the back porch region.
Line 8 is always black as it is in the front porch region for the vertical coordinates.



# Requirements

Break down the VGA system into the following:

- **VGA Controller (vga_ctrl)**
  - Generate **hsync** and **vsync** signals.
  - Keep track of horizontal & vertical counters.
  - Indicate **active video region**.
- **RGB Block**
  - Decide pixel colors based on simple **switch inputs (SW[2:0]) or any logic you can come up with**.
  - Ensure colors are shown **only when video_on = 1**.
  - Background is black outside display region.
- **Top Module (vga_top)**
  - Connect all blocks together.
  - Expose final signals: **hsync, vsync, red, green, blue**.
  - Verify on hardware: **switches change the screen color in real-time**.




- **A test bench that checks**
  - **RGB values at blank times**
  - **Sync Pulse time, front porch and back porch time**

*As a bonus try to build a self-checking test bench that checks*