Converting Apple][ NTSC to VGA

1. The NTSC TV Standard
2. Apple ][ video signals
3. The VGA “convention”
4. NTSC to VGA conversion
5. The Apple][VGA
6. Future thoughts
1. The NTSC TV Standard

1. monochrome NTSC
   1. Timing
   2. The video signal
   3. Bandwidth

2. Color NTSC
   1. General Thoughts
   2. Making it compatible
   3. Chroma/Luma interference
   4. Quadrature modulation
   5. Receiver matrix
Vertical Timing

- 242 even lines active video
- 2 lines blanking
- 2 lines sync
- 16.5 lines blanking (retrace)
- 242 odd lines (starting and ending with ½ line)
- Another blanking/sync pattern
- Total 525 lines
- => 16.67 ms between syncs
- => 60Hz repetition rate
- Vertical rate has to equal mains frequency for hum suppression
1.1.2. The video signal

- Coax “CVBS” into 75 Ω:
- RF Power:
  - 100% Sync
  - 56 % Black
  - 1% White
1.1.3 Bandwidth

Analog TV has no “pixels”
Try to reproduce square dots at maximum vertical resolution
Aspect is 4:3 => 640 dots per line=>12.5 M dots/s
Video signal will oscillate at half dot rate(6.25 MHz)
NTSC chose 4Mhz to get 6Mhz channel spacing.
With introduction of color, effective bandwidth was reduced to about 2.5MHz.

→ The limited bandwidth is insufficient for square pixel display (e.g. 80-column mode)
1.2.1 Color: General thoughts

- We want compatibility with existing B/W-TVs and transmitters
  - extra bandwidth will be very limited
- The color camera gives us three color signals: R,G,B (primary color signals)
- We need at least the brightness for a B/W TV: Y=R+G+B (We'll call it Luminance or Luma)
- Then we need two color signals. It was chosen to use U=R-Y and V=B-Y, because reduced bandwidth will not be very obvious with these.
1.2.2 Making it compatible

- Signal is split up in a luminance ("luma", Y) component and a two color components (U,V). A monochrome receiver displays this component ONLY.

- These are combined and modulated onto a 3.58 MHz subcarrier and form the chrominance signal ("Chroma", C)

- The signals are mixed before transmission

- The Receiver has to filter the signal to separate the two components
Luma + Chroma = Composite
1.2.3. Chroma-Luma interference

- The quality of a TV set (or its replacement – the Apple][VGA) boils down on its ability to separate luma and chroma.
- Cross-Color is visible as crawling patterns at color edges and as a pattern in intensely colored areas.
- Cross-Luminance is visible as color flicker in high detail areas.
1.2.4 Quadrature modulation I

- Modulate 2 signals on 1 carrier
- 2 color carriers: 45° leading / 45° trailing
- Each carrier is multiplied by one color difference signal
- Both carriers are added.

![Graph showing quadrature modulation]
1.2.4 Quadrature modulation II

- Receiver recovers COLOR REFERENCE from the burst
- Phase error shall be <5° or visible color deviation will occur
  - Hue knob adjusts COLOR REFERENCE phase
- Demodulation by sample-and-hold
  - (R-Y)=”red”-”cyan”
  - (B-Y)=”blue”-”yellow”
- Low-pass filter
1.2.5. Receiver matrix

- Convert U (R-Y) and V (B-Y) to R,G,B
- 1\textsuperscript{st} matrix:
  - \((G-Y)=-(R-Y)-(B-Y)\)
- 2\textsuperscript{nd} matrix
  - \(R=(R-Y)+Y\)
  - \(G=(G-Y)+Y\)
  - \(B=(B-Y)+Y\)
- Combined matrix:
  - \(G=Y-(R-Y)-(G-Y)\)
2. Apple ][ video signals

1. Clocks
2. Text display
3. LORES/DHIRES colors
4. The GS
2.1 Video clocks

- Master clock (14M): 14.31818MHz
- TEXT/HIRES clock (7M): 14M/2 (7.15909 MHz)
- COLOR REFERENCE: 14M/4 (3.5754545MHz)
- PHASE 0 (P0): 14M/14(1.023 MHz)
- Phase of CREF alters for every cycle of P0
- Every line ends with a “long cycle” that ensures a constant phase relationship between P0 and CREF
2.2 Text display

- The Apple ][ uses no interlacing. Every frame has 262 lines. Video is displayed in 192 lines. Other lines are blank.
- A line is 65 P0 cycles long. Video is displayed in 40 P0 cycles per line.
- 40-col TEXT: 1 character per P0 cycle, pixel clock 7M, minimum BW 3.5MHz
- 80-col TEXT: 2 characters per P1 cycle, pixel clock 14M, minimum BW 7MHz
2.3 Color graphics display

- Turn on color burst to enable TV's color circuit
  - Burst is inverted CREF so the TV syncs to **INVERTED** CREF

- **There is no chroma generator in the Apple**

- (D)HIRES: Generate bit patterns in software that will be interpreted as chroma signals

- LORES: Repeat a given bit pattern (LORES color number) in hardware
Apple ][ color burst
<table>
<thead>
<tr>
<th></th>
<th>0 ($0)</th>
<th>1 ($1)</th>
<th>2 ($2)</th>
<th>3 ($3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>black</td>
<td>dark red</td>
<td>dark blue</td>
<td>violet</td>
<td></td>
</tr>
<tr>
<td>0000</td>
<td>0001</td>
<td>0010</td>
<td>0011</td>
<td></td>
</tr>
<tr>
<td>12 ($C)</td>
<td>13 ($D)</td>
<td>14 ($E)</td>
<td>15 ($F)</td>
<td></td>
</tr>
<tr>
<td>---------</td>
<td>---------</td>
<td>---------</td>
<td>---------</td>
<td></td>
</tr>
<tr>
<td>Green</td>
<td>Light Brown</td>
<td>Light Cyan</td>
<td>White</td>
<td></td>
</tr>
<tr>
<td>1100</td>
<td>1101</td>
<td>1110</td>
<td>1111</td>
<td></td>
</tr>
</tbody>
</table>
2.4 The Apple//gs

• True 12-bit RGB color system
• 4 pixel clocks: 7,8,14,16 MHz
• Video output timing like //e
• “old” modes are emulated by “Mega ][“ chip and converted to RGB
• A MC1377 converts RGB to NTSC (and does a fairly poor job because of Apple saving $1)
• S-Video out is available as well as RGB
3. The VGA “convention”

1. Pinout and signal levels
2. CRT Timing
3. LCD Timing
3.1 VGA pinout and signals

<table>
<thead>
<tr>
<th>Pin</th>
<th>Function</th>
<th>Level</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Red Video</td>
<td>0.7Vpp</td>
<td>terminated 75Ω</td>
</tr>
<tr>
<td>2</td>
<td>Green Video</td>
<td>0.7Vpp</td>
<td>terminated 75Ω</td>
</tr>
<tr>
<td>3</td>
<td>Blue Video</td>
<td>0.7Vpp</td>
<td>terminated 75Ω</td>
</tr>
<tr>
<td>5-8,10</td>
<td>GND</td>
<td></td>
<td>Pin 8 open triggers</td>
</tr>
<tr>
<td>13</td>
<td>HSYNC</td>
<td>3.5Vpp (TTL)</td>
<td>no polarity</td>
</tr>
<tr>
<td>14</td>
<td>VSYNC</td>
<td>3.5Vpp (TTL)</td>
<td>specified</td>
</tr>
<tr>
<td>9,11,12,15</td>
<td>DDC</td>
<td>various</td>
<td>Plug'n'Play – don't care</td>
</tr>
</tbody>
</table>
3.2 CRT Timing

- The CRT cares about frequencies ONLY
- Pixel clock is a “soft limit”
  - Higher Pixel clock will result in a blurry picture

<table>
<thead>
<tr>
<th>Monitor</th>
<th>Vsync</th>
<th>Hsync</th>
<th>Pixel clock</th>
</tr>
</thead>
<tbody>
<tr>
<td>NTSC TV</td>
<td>60 Hz</td>
<td>15750 Hz</td>
<td>&lt;5MHz</td>
</tr>
<tr>
<td>Green screen</td>
<td>60 Hz</td>
<td>15750 Hz</td>
<td>&lt;15Mhz</td>
</tr>
<tr>
<td>CGA/RGB</td>
<td>60-70 Hz</td>
<td>15750 Hz</td>
<td>&lt;15Mhz</td>
</tr>
<tr>
<td>Classic VGA</td>
<td>60-70 Hz</td>
<td>31500 Hz</td>
<td>&lt;30MHz</td>
</tr>
<tr>
<td>Low-end VGA</td>
<td>50-100 Hz</td>
<td>30-60 kHz</td>
<td>&lt;100MHz</td>
</tr>
<tr>
<td>High-end VGA</td>
<td>50-152 Hz</td>
<td>30-108 kHz</td>
<td>&lt;400MHz</td>
</tr>
</tbody>
</table>
3.3 LCD Timing

- LCDs need to digitize the video signal
  - Controller measures H and V frequencies and guesses the pixel clock
  - Most controllers don't support modes the LCD would be capable of (e.g. 16 kHz RGB for the GS)
- LCDs have no size controls
  - Displaying at lower resolution will result in part of the screen being unused

<table>
<thead>
<tr>
<th>Mode</th>
<th>VSYNC</th>
<th>HSYNC</th>
<th>Pixel clock</th>
</tr>
</thead>
<tbody>
<tr>
<td>640x480</td>
<td>60 Hz</td>
<td>31.5 kHz</td>
<td>25.3 MHz</td>
</tr>
<tr>
<td>720x400</td>
<td>70 Hz</td>
<td>31.5 kHz</td>
<td>28.6 MHz</td>
</tr>
<tr>
<td>800x600</td>
<td>60 Hz</td>
<td>37.8 kHz</td>
<td>36 MHz</td>
</tr>
<tr>
<td>1024x768</td>
<td>60 Hz</td>
<td>48 kHz</td>
<td>65 MHz</td>
</tr>
</tbody>
</table>
4 Conversion NTSC to VGA

1. Line doubling
2. Timing generation
4.1 Line doubling

- Convert to 640x480 (60Hz V/31.5kHz H)
  - All parameters are equal except HSYNC which is twice as high
  - The IBM VGA card displays each line twice in CGA modes
- A basic converter has to
  - Read every line into memory
  - Output the previous line twice at double speed
  - Generate VGA sync signals
  - Decode NTSC color
4.2 Timing generation

- Extract VSYNC from composite sync pattern
- Time RAM read and write cycles
- Create correct Pixel clocks
  - Lock Pixel clock on HSYNC by PLL
  - Or cheat and get the clock from the computer
- Create VGA HSYNC from Pixel clock
  - Ensuring correct frequency (simple divider)
  - And phase (not so simple)
5. The Apple][VGA

1. Line-doubling operation
2. NTSC decode
3. LCD issues
5.1 Apple][VGA linedoubling

- Double 14M to get 28M (VGA pixel clock)
- Sample the 1 bit video stream at 14M
- Combine 8 bits and store them in memory page 1 (every other CREF high)
- Read from page 2 back and output them (twice) at 28M (every CREF low)
- Swap pages every line
5.2 NTSC decode

- No extra chroma filter
  - So we still have a 1 bit stream
  - Sample/Hold can be a simple D-Flip/Flop
- 1\textsuperscript{st} and 2\textsuperscript{nd} matrix are combined
- Switchable chroma low-pass filter (by relay)
- Switchable luma filters (by 4051 MUX)
  - Additional RGB-card style luma signal from D-FFs
- Mode switching logic (in the CPLD) selects the filter settings after user requests and current display mode
5.2.1 (D)HIRES decode

- Default: Filter luma and chroma
  - Luma filter is a 7M and a 14M (gray) trap
  - Chroma filter is 3 caps (1nF) between the R,G,B lines.

- Monochrome mode or unfiltered luma or chroma both can be selected from software
  - Data is transferred through fast graphics mode switching patterns
  - Monochrome HIRES can be selected by jumper
5.2.2 LORES decode

- No chroma filtering
  - Filtering would create color fringes
- Luma taken from chroma Ffs (like RGB card)
  - Luma is average of last 4 pixels
5.2.3 Filter control

- Chroma filters delay the signal
  - Chroma and luma need to be in phase
  - Switchable luma delay (shift reg)

- Mixed modes
  - Video output is one line late due to doublescanning
  - Mode switching would happen too early

- Software control
5.3 LCD issues

- Apple][VGA uses 28.6 MHz output clock
- LCD expects 25.3 MHz
  - LCD skips every 9\textsuperscript{th} pixel
- LCD expects 640x480, not 560x192
  - Screen can not be filled completely
- Many LCDs fail to detect signal when running the A2VGA in a 50Hz apple
6 Future thoughts

1. Digital Luma filtering
2. Boards for the ][ and //e
3. The //gs
6.1 Digital Luma filtering

- Analog notch filters have advantages:
  - Simplicity
  - Extremely sharp notches possible
- But the required coils can make a lot of trouble
  - Losses reduce effectiveness
  - Interference
  - Detuning
- Solution: Digital filters!
  - FIR filtering: Sum of shift register outputs
6.2 Boards for the ][ and //e

- Combined RAM and VGA boards for the //e's AUX slot (cooperation w/ReactiveMicro)
- Discrete “old-school” boards for the ][
6.3 The //gs

- 12-bit RGB color system
  - About 12 times RAM speed required
- 4 different pixel clocks
  - Require pixel clock switching
  - Require pixel clock conversion
- No video expansion connector available
  - Maybe pulling a chip and inserting a connector (like e.g. the ][ language card)