How to Compute Bandwidth $\Delta \nu$

- Count Number of Pixels scanned and displayed per Second
  - $= \text{Number of pixels per line} \times \text{Number of lines per frame} \times \text{Number of frames per second}$
  - ($= \text{rows} \times \text{columns} \times \text{frames per sec.}$)
- Divide by 2
  - $= \text{Number of pixels per cycle at maximum}$

Why Divide by 2?

- Two pixels (one bright + one dark) can be represented by one cycle that oscillates at the maximum frequency

Bandwidth of NTSC “Luminance” Signal

- “Black-and-White” Image
- Minimum Oscillation Frequency is:
  - 0 cycles per second $= 0 \text{ Hz}$
- Maximum Oscillation Frequency is:
  - $525 \text{ spl} \times 525 \text{ lpf} \times 30 \text{ fps} \div 2 \text{ spc (spots per cycle))}$
  - $= 4,134,375 \text{ Hz} \cong 4 \text{ MHz}$
What About Color Video?

- Color Image Made from 3 Monochrome Images ("channels")
  - Red, Green, Blue
- Might Expect to Need $3 \times$ B&W Bandwidth
  $$\Delta \nu \approx 12 \text{ MHz}$$
- BUT: this assumes that the color images are completely independent (unrelated)!

Image Channels ARE NOT Independent!

RGB Channels Often Are Very Similar!

Don’t Need All Information in All Images

- Some Image Data Can Be “Thrown Away” Without Noticeable Effect on Image
- Just as in Image Compression
  - Color video transmission uses color image compression
Compute 3 Different Images

- Current Method: Compute the following numbers from the RGB values at each pixel
  - Luminance: $Y = 0.299 R + 0.587 G + 0.114 B$
    - (all weights are positive and add to 1)
    - produces a "weighted sum"
  - Chroma 1: $U = -0.147 R - 0.289 G + 0.436 B$
    - (weights are bipolar and sum to 0)

RGB Color

- Red Channel
- Green Channel
- Blue Channel

Luminance-Chrominance Color

- Lightness = Monochrome Image
- Chrominance 1
- Chrominance 2
Three “New” Images

Monochrome Luminance = Y
Chrominance U
Chrominance V

Now Add Knowledge of HVS

- Spatial Response of Human Visual System to “Details and Edges”
  - Sensitive in monochrome (luminance) image
    - Edges in monochrome image must be sharp
  - Less sensitive in chrominance image
    - Edges in color part of image may be “fuzzy”
- Same principle used in movie “colorization”
  - Artists don’t need to “color within the lines” when colorizing a B&W movie
### Strategy to Transmit Color Video with Reduced Bandwidth

- **Transmit Luminance Image Y** with **Full** Resolution (full bandwidth)
  
  $$525 \text{ spl} \times 525 \text{ lpf} \times 30 \text{ fps} + 2 \text{ spc} \ (\text{spots per cycle})$$
  
  $$= 4,134,375 \text{ Hz} \cong 4 \text{ MHz}$$

- **Transmit Chrominance Images I,Q** with **Less** Resolution (less bandwidth)
  
  $$(\leq 1 \text{ MHz per Image} \Rightarrow \leq \frac{1}{4} \text{ of Pixels})$$

  $$\Rightarrow$$ Total signal requires **6 MHz** of Band

  - Interval between TV Channels in Frequency (MHz)

### Allocation of Electromagnetic Spectrum for Different Uses

### TV Spectrum