Lab Assignment

- Build half adder from logic gates
  - Basic function of calculator (all operations use your gates!)
- Embedded system checks correct implementation
  - Manual calculation
  - Automated test
- What you need to do:
  - Pick up kit in Knowles 211C (available later this week)
  - Do lab (instructions provided)
  - Take picture of you and working system
  - Submit picture on Moodle
Digital Camera

- Digital imaging technology
  - Capturing visual information in digital systems
- Today’s lecture:
  - Charge-coupled device
    » Sensor for light
  - Digital camera
    » Storage, user interface to sensor, etc.

Importance of Images

- Why is “a picture worth a thousand words”? 
Importance of Images

- Sight is an important human sense
  - Color and brightness
- Sight important for perception of environment
  - 2-D image used for object recognition and interpretation
  - Depth perception derived from using both eyes

Images as Rays of Light

- Projection of light from object onto screen
  - Convex lens gathers light from object
  - "Screen" can be retina, image sensor, cinema screen, etc.

- Need to capture light and represent in electronic domain
Sensing Light

- **Human eye**
  - Lens project image onto retina
  - Photoreceptors in retina translate light into nerve impulses
  - Sensor types
    - "Rod" (brightness)
    - "Cone" (color)

- **Electronic sensor**
  - Light becomes charge in chip
    - Same idea as solar cell
  - Readout
    - Charge amplifier (charge-to-voltage converter)
    - Sampled, digitized, stored

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2-D Image sensor

- How to extend sensor to capture 2-D image?
CCD Sensor

- Charge-coupled device (CCD)
  - Sensor to capture light
  - Clever design to move charges of pixels to amplifier
- Inventors received 2009 Nobel prize in physics

CCD Design

- Need 2-D design that can be put on CMOS chip
  - 2-D array of light sensors
  - 2-phase operation: exposure and readout
  - Readout:
    » move charge from each pixel sequentially to edge
    » Measure charge at edge/corner of chip

From http://www.microscopyu.com/articles/digitalimaging/ccdintro.html
CCD Design

- Moving charge:

  ![Diagram of CCD design showing moving charge]

CCD Operation

- 2-D operation to move charge to corner of chip
  - Single amplifier/A-to-D converter
Colors

- Separate light by different colors
- Bayer filter
  - Single CCD sensor
  - Different pixels sense different colors
- 3CCD separates colors
  - Tricroic prism assembly
  - One CCD sensors per color

RGB Decomposition

- Intensity of red, green, and blue channel:

  original  red  green  blue
Color Spaces

- RGB is not the only color space
  - Example: YCbCr
    » Luma (Y)
    » Blue-difference chroma (Cb)
    » Red-difference chroma (CR)
- Linear transformation between spaces

Image Sensor Uses

- Photographic cameras
  - Scientific application: CCD
    » CCD uses specialized fabrication process for light capture
  - Consumer cameras: CMOS imager
    » CMOS imager has charge-to-voltage conversion per pixel
  - Different sensor sizes
- Video cameras
- Astronomic telescope
  - Large arrays of CCDs
- Microscopes
  - ...
Interesting Uses of Image Sensors

- Lensless cellular imaging (Prof. Salthouse, ECE)
  - “Because the pixels of modern imagers are even smaller than cells, blood samples can be analyzed by flowing the sample directly on top of the imager without a microscope.”

Digital Camera

- Camera contains optics and electronics
  - Optics project image onto sensor
  - Electronics read and process sensor information
Digital Camera Operation

- Camera opens shutter to expose sensor to light
  - Choice: longer or shorter time of open shutter (exposure)
  - Choice: wider or smaller opening of shutter (aperture)
  - Choice: more or less sensitive readout of sensor (ISO)
- Readout: conversion into image file
  - Image file contains light intensity measurements
- Tradeoffs: contrast, depth of field, etc.

Courses in ECE Curriculum

- ECE 344 – Semiconductor Devices & Materials
- ECE 572 – Optoelectronics
- ECE 597BE – Bioelectronics
Upcoming...

- Next week: Internet
  - Network protocols
- Moodle quiz