# Electrons, Photons, Phonons, Wave, Bits, and Industrial Design: Microsoft Kinect Sensor

**Hot Chips 23**

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# Topics

1. User Experience Goals
2. Design Considerations
3. Product Requirements
4. Design Tactics
5. System Overview
   - Major components & IC's
   - Depth
   - Audio
   - Thermal
   - Tilt
   - Mechanical structure
6. Other Considerations
   - Robustness
   - Test and Validation
   - Manufacturing and Supply chain

# User Experience Goals

- Development of first large scale Natural User Interface System
  - Gesture, video and audio
  - State of the art
    - 3D Imaging
    - Array Microphone (Beam forming & Echo cancellation)
- New requirements
  - Play space range and field of view
  - Ambient light
    - Low lighting for video
    - High lighting for depth dynamic range
  - All room, clothing, etc.
  - Background noise
- Reliable and Affordable

# Design Considerations

- Approachable (technology is hidden)
- Fits in with user environment
- Placement of device
- Ease of setup
- Discovery & ease of use
- Self recovery/diagnostics
- Graceful degradation
- Error notification
- Works with all Xbox 360 consoles
- Extensible for future applications and uses

# Product Requirements

- Regulatory (EMC, RFI, RoHS,…)
- Reliability over time & cycles
- Operating temperature
- Hot spots
- Humidity
- Shipping stresses (vibration/shake/shock)
- User abuse
  - Drops
  - Dust

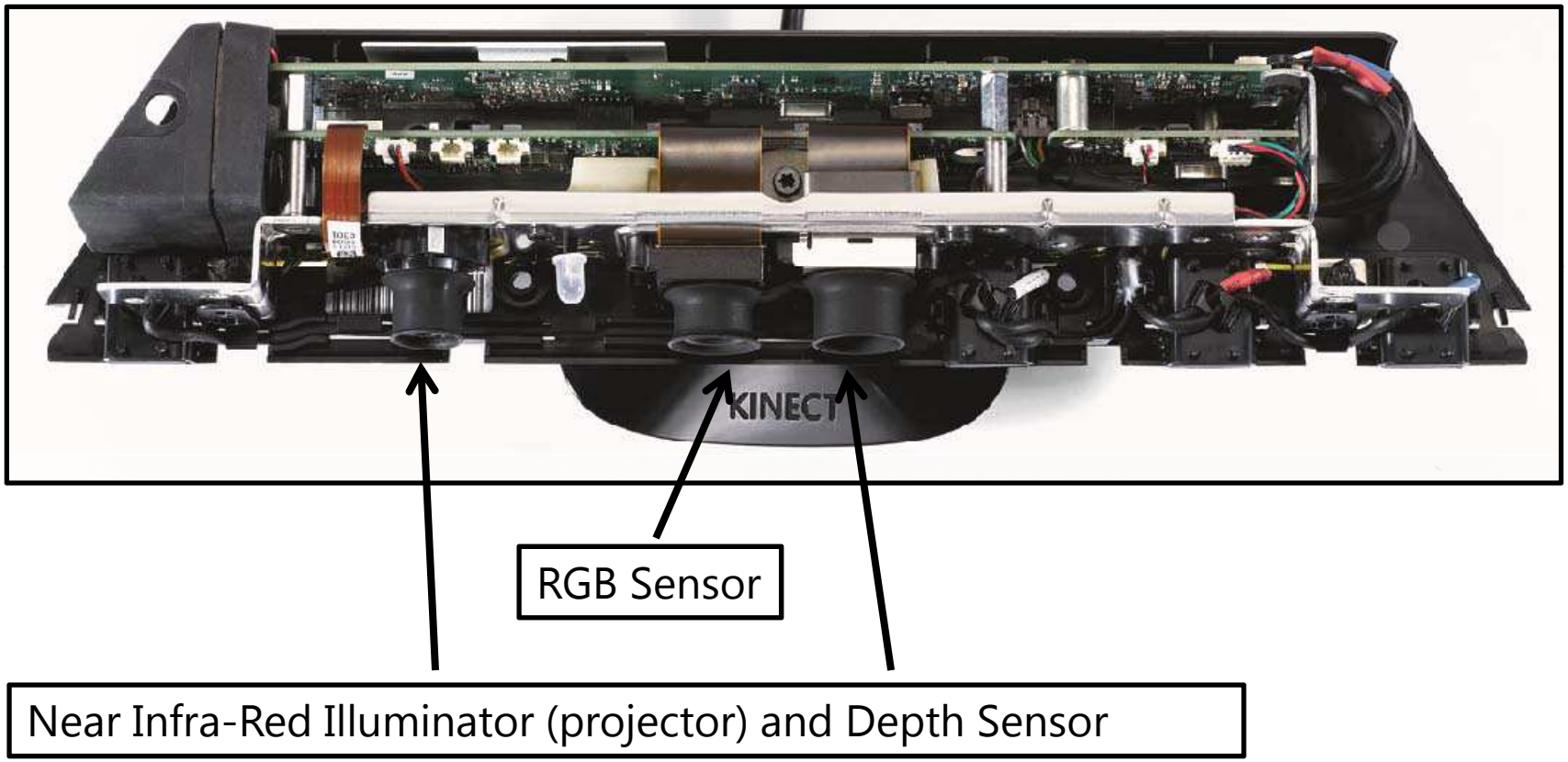
# Design Tactics

- Don't know:
  - Future application requirements
  - User base (new segment)
  - User expectations (about performance)

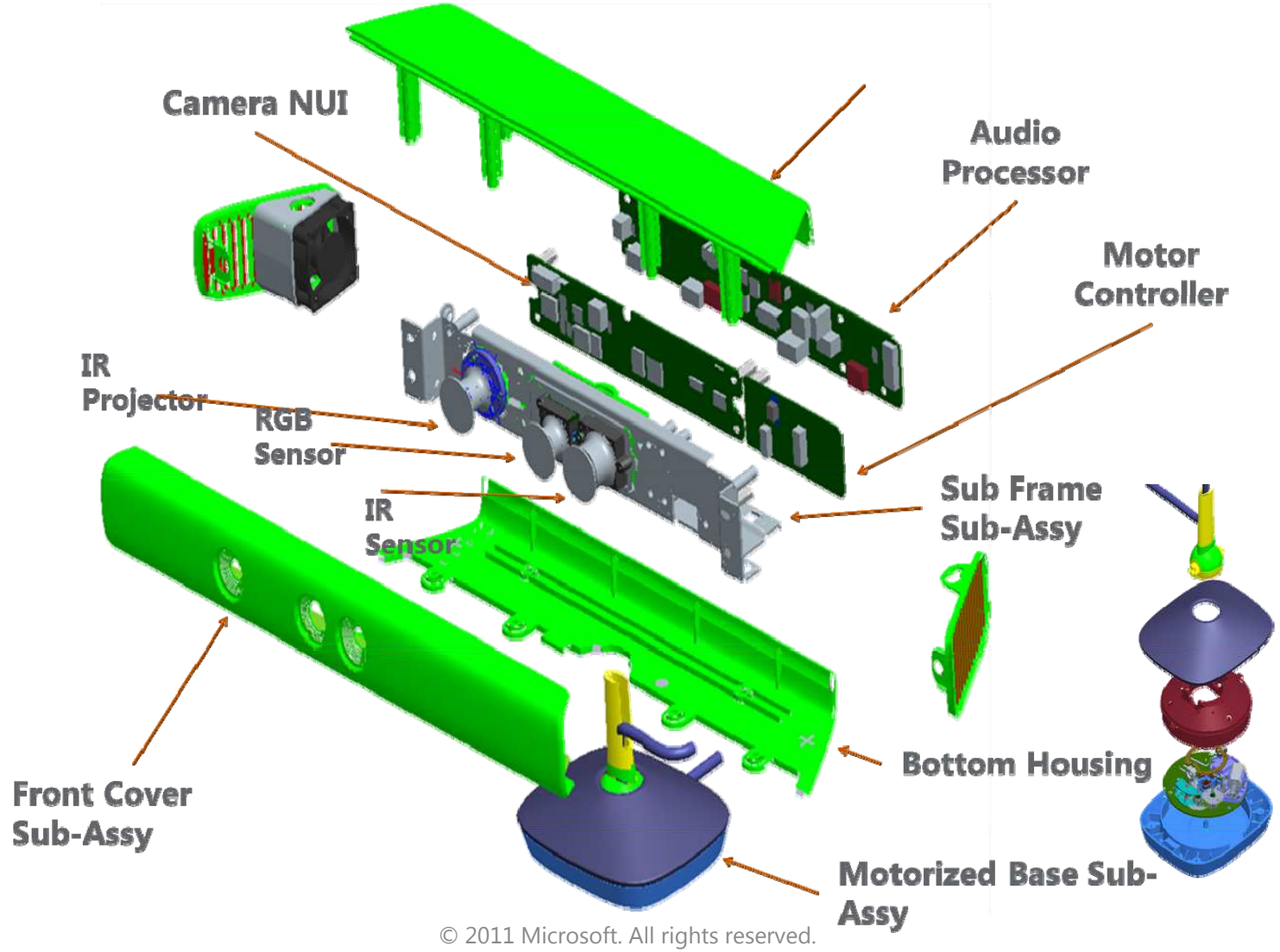
- Do know:
  - Physics
  - Basic function
  - Schedule
  - Cost target
  - Manufacturing and supply chain constraints

- Approach:
  - Work by design (versus work by test)
  - Understand material limits
  - Understand technical limits
  - Control what you know
  - Design margin /conservative design

# System Overview

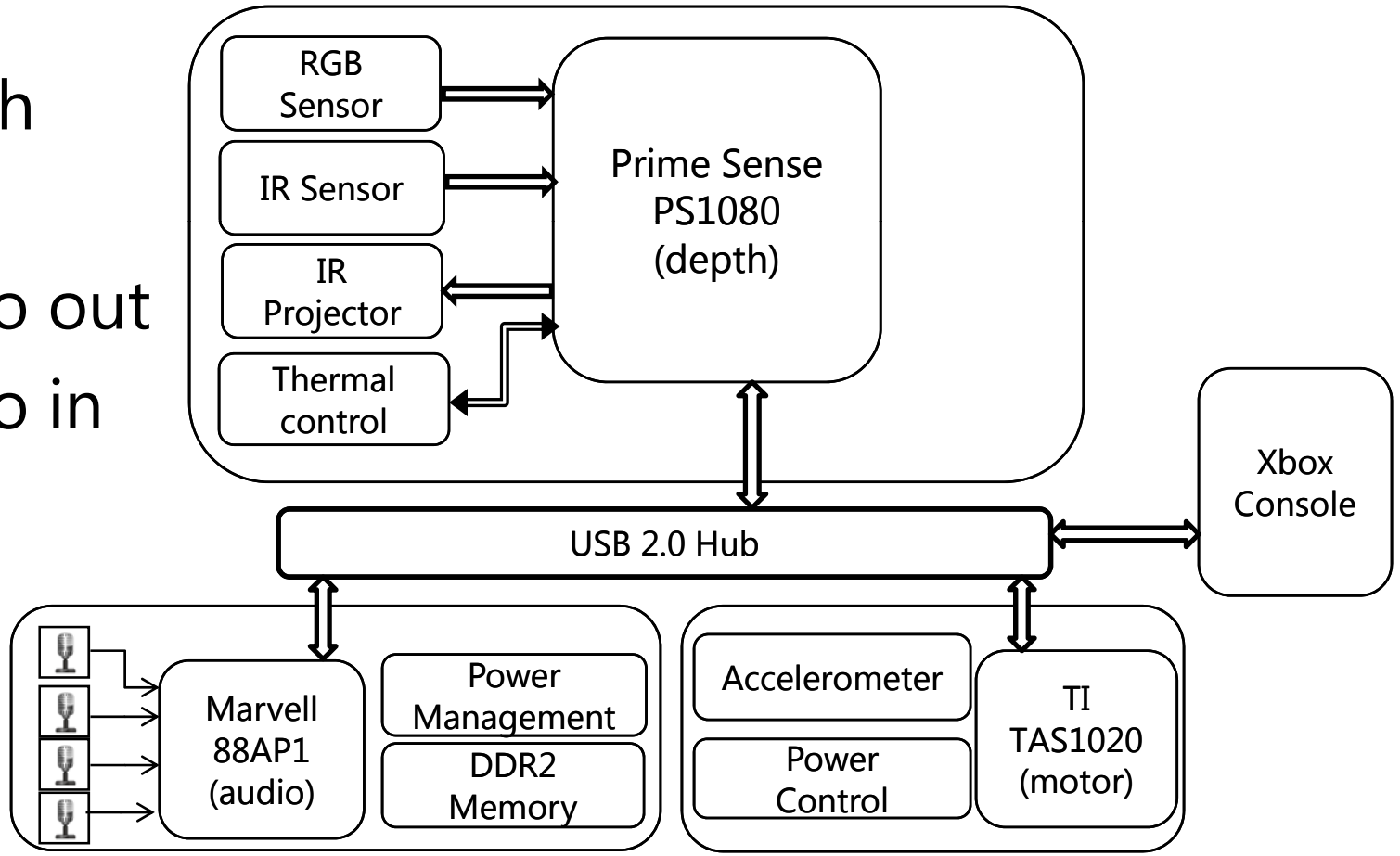


# System Overview:
# Overall Assembly & Major Components



# Major Components & IC's

- USB 2.0 interface (Hub)
- Data
  - Depth
  - RGB
  - Audio out
  - Audio in
  - Tilt



# Depth: Overall Depth Sensor Design

- An infrared projector combined with a monochrome CMOS sensor allows Kinect to see the room in 3-D

- Structured Light
  - Illumination source
  - Pattern generation
  - Detector/sensor

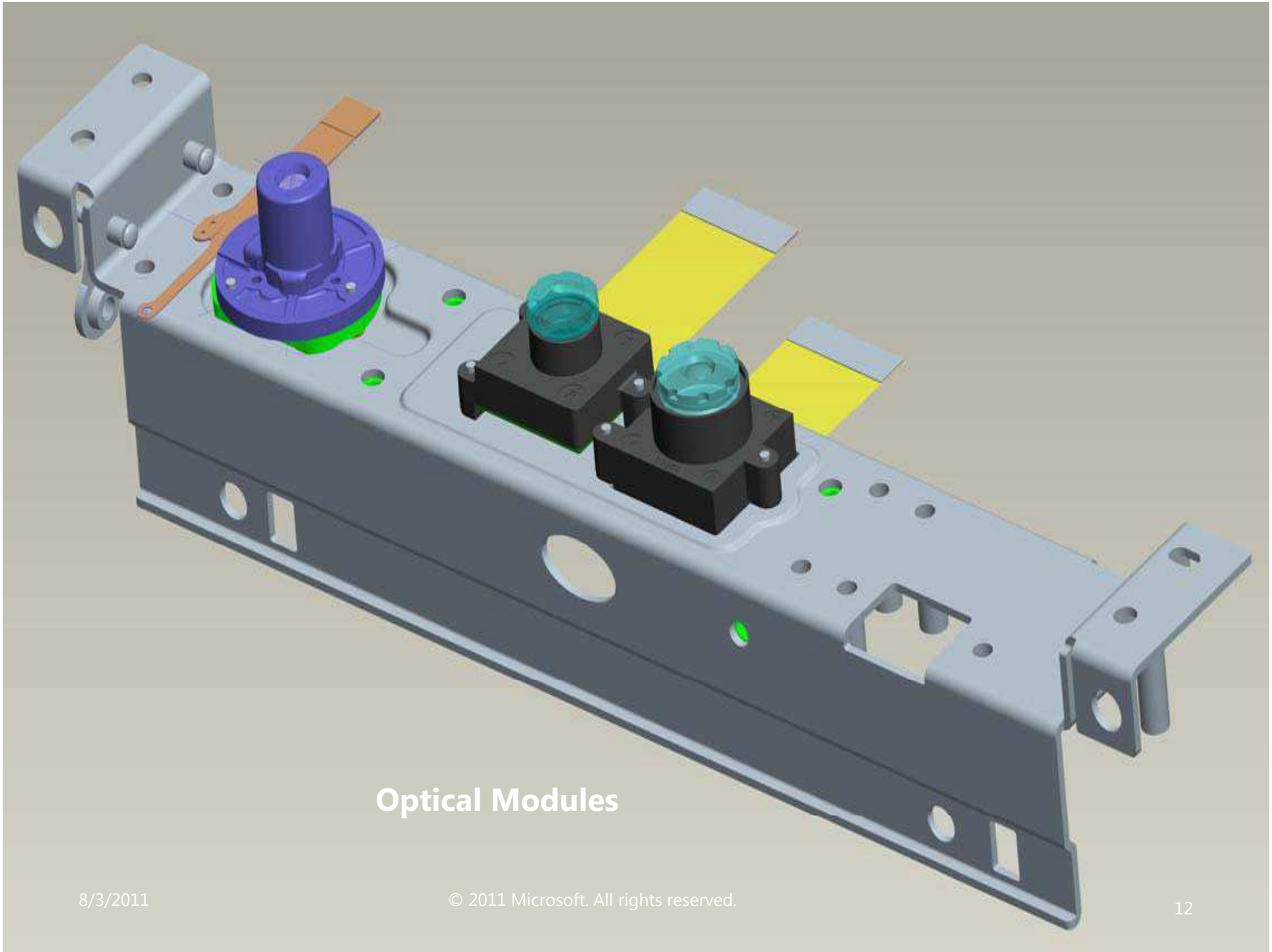
- IR Sensor
  - High sensor responsivity reduces power consumption
  - Large FOV with low distortion and high MTF lens system
  - Narrow band pass filter reduces interference from ambient incandescent lighting

- Infrared Projector
  - Near IR Laser Diode
  - Laser diode Considerations
    - Temperature control (hold to fraction of degree C)
    - Over operating temp range within boot time
    - Mode Hoping
    - Feedback from other optics
    - Slow ramp
    - Immune to transients
    - Over power/current → catastrophic optical damage (COD)

# Depth: Radiometric Design

- Sensor Power Budget
  - Ambient light (Incandescent & Halogen lights, Sun) - SNR
  - Quantum efficiency of sensor (responsiveness in amps generated /optical watt of power)
  - Near vs. Far (dynamic range of sensor) – $1/R^2$
  - Corner vs. Center (optics) – $\cos^4(q)$
  - Minimum object size (resolution, illumination) (FOV/pixels)
  - Reflectivity of objects
  - Contrast of Imaging System (MTF)

- Narrow band pass optical filter
  - Blocking undesired ambient light
  - Passing illumination source wavelength
  - Incident angles – wavelength/transmission shift with angle



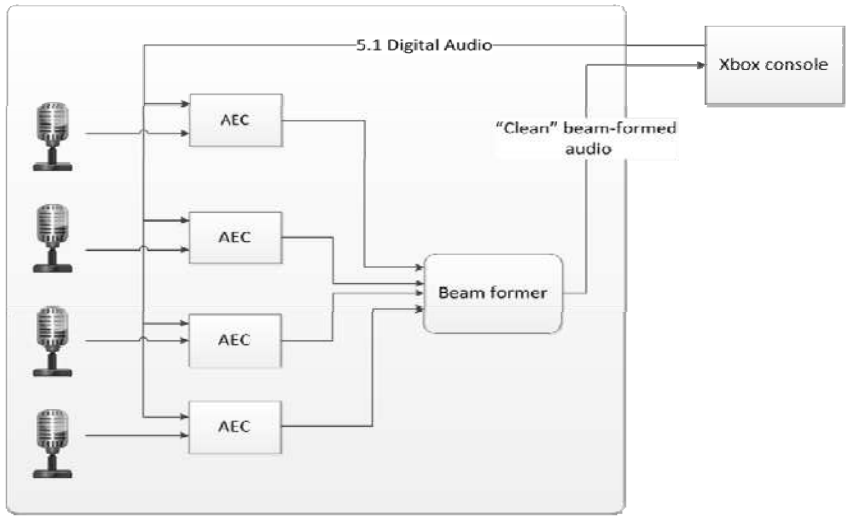
## Optical Modules

# Depth: Depth Error

- Calibration will ensure uniform accurate depth leaving the factory
- Must guarantee Uniform Across FOV, Temp, Time, Shake/Shock/Drop
- Mechanical alignment
  - Structured light principle is to measure illumination shift to sub-pixel levels so…
  - Sub-pixel shifts are important – tolerances measured in microns
  - Micron type deflections change depth
    - Drop
    - Temp cycles
    - Shipping
    - Metals and plastics
    - Change in lenses
    - Unintended stresses

# Audio

- **Speech** commands (speech recognition)
- **Game chat** (directed full duplex with playback)
- **Video Conferencing** (further back, wider field, full duplex)
- Wideband audio 16kss @24bits
- 4 element beam forming input audio
  - Response matched to dB as built
  - Need to AEC each channel BEFORE beam forming
- Synchronization of Console 5.1 audio output with 4 microphone streams




- Latency
- Received FAN noise
  - e.g. quiet talker @ 3m -> equivalent at sensor

# Tilt

- Determine the play space (see the floor)
- Tall & shorter players
- Motor
- Accelerometer
- Speed tilt to target
- Accuracy
- Power draw (peak vs. RMS)
- Wear /thermal effects
- Reliability
- Acoustic noise

# Mechanical Structure

- Industrial Design
- Surface fit and finish
- Manufacturing & Assembly (DfX)
- Physical acoustics (microphone, fan)
- Thermal
  - Component operation and reliability
  - Optical elements, Depth error, Case temperature
  - Fan acoustics, vibration & air turbulence (speech, chat, video conferencing)
- Optical alignment
- Shake/shock/shipping/storage
- Impact
- Weight

# Other Considerations: Robustness

- Watchdog timers
- Shutdown events
- Recovery from (unintentional) thermal overload
- Error event logging
- Power delivery
  - 12v and 5v for Xbox 360s
  - 5v from Xbox 360 + auxiliary 12v supply
  - 3m extender cable (voltage & power budget)
  - Peak loading (i.e. motor moves)
  - Transient immunity
- Firmware updates
- Ongoing reliability testing

# Other Considerations: Test and Validation

- New category, new technology, new methods
- Stress validation (electrical/mechanical/optical/acoustic)
- USB stress (throughput/lost packets)
- Mechanical changes over temperature (optical, acoustic, cooling, tilt)
- Thermal stress & thermal capacity
- Stable operation time from cold or hot start

# Other Considerations: Manufacturing and Supply chain

- Unknown new market - skepticism
- “Telecom quality and reliability at consumer price points”
- New suppliers – different industries
- Stretched supply chains (cross-applications)
- Blind & Buried VIA’s
- New assembly processes (molding, stamping, casting, coatings, glues (Tg & modulus, UV, outgassing)

# Acknowledgement