My Goal today

• Leave you with the conviction that consumer electronics in general and television in particular are exciting, powerful examples of the engineering art.
  – Loaded with compromises

• Quickly brush over the fundamentals

• Motivate you to dig further
My Message

- Television has changed the world
- Television technology is fascinating
  - Case study in engineering compromise
  - Patents are critical
- It’s still evolving, innovating
A brief aside

• Scientist vs Engineer
  – Extreme scientist: just want to know
  – Extreme engineer: just want to do
    • Build it, make it work! – The Engineering Compromise

• We’re all part scientist and part engineer

• Edisonian Engineering:
  – “Applying science for a profit”
    • Need to understand economics, a behavioral science
    • Need to understand business fundamentals
    • Need to understand patents
A brief aside

• Patents – In the U.S. Constitution
• A time limited monopoly in exchange for revealing sufficient details about an invention to allow anyone to do it
  – Patents prevent the big guys from stealing the inventions of the little guys (and from one another)
  – Meant to motivate innovation and invention
• A right to prevent anyone from “making, using, or selling” your invention for a limited period of time
A brief aside

• To be patentable
  – Useful, novel, non-obvious

• Patent parts
  – Specification: detailed description in words and diagrams so “one of ordinary skill in the art” can practice the invention
  – Claims: carefully worded ultimate definition of the invention in as board a way as possible

• Patent Suit
  – Law suit to enforce patent rights, only way!
  – Defense: not novel, obvious, none-enabling

• Patent License
  – Right to use the invention under negotiated terms
A brief aside

• Recommendations: “Flash of Genius”
• See the movie:
Back to the Television Story
Analog & Digital TV details

• Over 12,000 sold, 4 lbs each, 24 tons!
Television has changed the world

畫意能達萬言

An advertisement by Barnard appears in the March 10, 1927 issue of the advertising trade journal *Printers' Ink*, with the phrase

"One Picture is Worth Ten Thousand Words,"

where it is labeled a Chinese proverb.
Television has changed the world

• Images are powerful communicators
• Moving images can be more compelling
• Instantaneous moving images from a distance have changed the world!

– That’s *Television*

• Now it’s even portable, in your pocket
Television has changed the world

• Positive impact
  – Can’t hide the news
    • Visual impact
    • Instantaneous coverage
  – Cultural norm setting
  – Educational TV

• Negative impact
  – Couch potato
  – Bias, others do our thinking for us

“We’re not happy until you’re not happy”
Television has changed the world

- Broadcast TV follows Radio
  - Museum of Television and Radio, New York
    - http://www.mtr.org/
- Cable & satellite TV
  - Niche programming
  - A channel for everyone
- Personal Control
  - TiVo & DVRs
  - Personal video, Portability
Early TV History

- Many experimenters, inventors, patents
- Mechanical Television (Yes, **MECHANICAL**)
  - 1883 Paul Nipkow, scanning disk
    - German patent 30,105, applied 1/6/1884, not built
  - 1923 John Logie Baird & Charles Jenkins
    - demonstrate mechanical television in UK

![Nipkow disk operation](image)
Early TV History

Figure 2.3 Only one hole at a time is exposed to the image on the sending side and the light source on the receiving side.

Build your own Nikow scanning disk

• http://www.televisionexperimenters.com/yourdisk.html
Early TV History

• Actual working mechanical televisions
  – http://www.earlytelevision.org/

The 2009 Early Television Convention will be May 1, 2 and 3. Mark your calendars.
Early TV History

• Electronic Television
  – 1923 Zworykin electronic television patent 2,141,059, but issued after Farnsworth’s
  – 1927 Philo T. Farnsworth, patent 1,773,980
    • Patent claims better written, critical lesson
    • Image Dissector
  – 1929 Vladimir Zworykin, RCA, kinescope
  – 1931 Zworykin iconoscope
Early TV History

• Broadway play: 2007 - 8
  • “The Farnsworth Invention”
    – Some artistic license
    – Farnsworth as a boy plowing his fields
      • Later, an inventor with very limited resources
    – Zworykin
      • Backed by giant RCA & Sarnoff
Early TV History

• As a teenage boy, Farnsworth was interested in technology
• While plowing his father’s field, he envisioned converting a two dimensional image into a one dimensional electrical signal by scanning
• *Raster* picture analysis and synthesis
Early TV History

• Massive **patent fight**
  – Farnsworth vs Zworykin
    • Actually, vs RCA and Sarnoff!
    • Years and million of $$
    • Many books and articles
    • Emotional proponents on both sides!
  – It’s about who is the “father of television”?

• **Key:** how well the patent is written
  – Farnsworth’s patent had critical text
the invention includes all such modifications and changes as come within the scope of the following appended claims.

1. The method of television which includes forming an electrical image, and traversing each elementary area of the electrical image by an electric shutter at a velocity sufficient to cover the entire image within the optical period.

2. The process of television which comprises forming an electrical image, moving said electrical image at a uniform speed in more than one direction, superimposing a plurality of frames at the rate of one frame per second, and thereby obtaining a television image containing all the details of the original picture.

3. The method of television which comprises analyzing an image on the surface of a photo-electric cell, forming a train of electrical oscillations corresponding to the image, and projecting said oscillations on a screen to produce a visual image.

4. An apparatus for producing television images comprising a plurality of photo-electric cells, each cell having a photo-sensitive plate, and a plurality of grids, each grid being connected to a different part of the image.

5. A method of television which comprises forming an electrical image of a scene, analyzing said image into elementary areas, producing a train of energy varying according to the intensity of light of said areas, and utilizing said electrical potential of substantially straight line wave forms to correlate successive portions of said light.

6. A method of television which comprises producing two electrical potentials of different frequencies, each of said electrical potentials having substantially straight line wave forms, causing said electrical potentials to analyze an image into elementary areas, producing a train of energy varying according to the intensity of light of said areas, and converting said train of energy into light varying according to the light of said areas.

7. A method of television which comprises producing two electrical potentials of different frequencies, each of said electrical potentials having substantially straight line wave forms, causing said electrical potentials to analyze an image into elementary areas, producing a train of energy varying according to the intensity of light of said areas, and converting said train of energy into light varying according to the light of said areas.

8. A method of television which comprises producing two electrical potentials of different frequencies, each of said electrical potentials having substantially straight line wave forms, causing said electrical potentials to analyze an image into elementary areas, producing a train of energy varying according to the intensity of light of said areas, and converting said train of energy into light varying according to the light of said areas.

9. A method of television which comprises producing two electrical potentials of different frequencies, each of said electrical potentials having substantially straight line wave forms, causing said electrical potentials to analyze an image into elementary areas, producing a train of energy varying according to the intensity of light of said areas, and converting said train of energy into light varying according to the light of said areas.

10. A method of television which comprises producing two electrical potentials of different frequencies, each of said electrical potentials having substantially straight line wave forms, causing said electrical potentials to analyze an image into elementary areas, producing a train of energy varying according to the intensity of light of said areas, and converting said train of energy into light varying according to the light of said areas.

11. A method of television which comprises producing two electrical potentials of different frequencies, each of said electrical potentials having substantially straight line wave forms, causing said electrical potentials to analyze an image into elementary areas, producing a train of energy varying according to the intensity of light of said areas, and converting said train of energy into light varying according to the light of said areas.

12. In a system of television, analyzing an image into elementary areas by causing a scanning device to scan all elements of said image successively at a substantially uniform velocity, and transmitting successively portions of said image to a receiver, thereby forming a television image.

13. A method of television which comprises forming an electrical image, moving the image in two directions over an electrical shutter having a small aperture, thus forming an electrical current which is a function of the intensity of the portion of the electrical image at said aperture.

14. A method of television which comprises forming an electrical image, impressing upon said image two electrical potentials of different frequencies, thereby causing said image to move in two directions successively respect the electrical shutter and forming an electrical current from the portion of the electrical image registered with the electrical shutter.

15. An apparatus for television which comprises means for forming an electrical image, and means for scanning such elementary area of the electrical image, and means for producing a train of electrical energy in accordance with the intensity of the elementary area of the electrical image scanned.

16. An apparatus for television which comprises means for forming an electric image, and
Early TV History

• Critical Claim 15 of Farnsworth’s 1,773,980 patent

• 15. An apparatus for television which comprises means for **forming an electrical image**, and means for scanning each elementary area of the electrical image, and means for producing a train of electrical energy in accordance with the intensity of the elementary area of the electrical image being scanned.

• Only television patent licensed by Sarnoff
  – Personal battle, defeat
Use of Basic Farnsworth Patents in Modern Television Receivers

Note: The asterisks denote several of Farnsworth’s most important contributions.
Source: "Use of Farnsworth Patents in Modern Television Receivers" (Fort Wayne, Indiana: Farnsworth Television and Radio Corporation, circa 1948, pp. 6–7).
Early TV History
And then a miracle happened!

image dissector
schematic representation of the image dissector

iconoscope
schematic representation of the iconoscope
Early TV History

• Both are fundamentally the same
  – Image dissector moves the image cloud past the scanning aperture
  – Iconoscope moves the electron beam across the charged image plate
  – Relative motion!

• A fortunate accident
  – Technician left the plate in the oven too long
  – Surface melted and beaded up
    • Individual capacitors
    • Integrate the light!
Analog Television Transmission

• We have the image as a linear string of voltage generated by scanning

• NTSC, National Television Systems Committee Time Line
  – Formed in 1940 by FCC,
  – B&W standard March 1941
  – Considers color, January 1950
  – Approves CBS Field Sequential, October 1950
  – Color TV manufacturing suspended by Korean War
  – Compatible NTSC Color approved Dec 17, 1953
  – Stereo Sound, 1984 (FM stereo radio, April 1961)
  – Closed Captioning adopted 1990, mandated 1993

• ATSC adopted October 1995
  – Analog Shut Down scheduled February 17, 2009
Analog Television Transmission

- NTSC details
  - 525 scan lines, 486 visible, rest for synchronization
  - About 440 lines of resolution horizontally
  - 2:1 interlace, 60 fields per second, 30 fps
  - 4:3 aspect ratio
  - FM Sound, farther range than the video
  - AM video modulation, white at minimum power
  - AM in Vestigial Side Band, 6 MHz channels
    - Baseband video: 4.2 MHz
Analog Television Transmission

• Vestigial Side Band Modulation
  – Scientist would say: can’t be done
  – Engineer would say: just watch me do it

• AM math results in double sideband
  – $2 \times 4.2 \text{ MHz} = 8.4 \text{ MHz}$, but channel is 6 MHz
  – Filter most of the bottom sideband out!
  – Yes, there’s distortion, but have you noticed it?
    • Fine example of an engineering compromise
Analog Television Transmission

- If you want 4.2 MHz of video, you need almost 9 MHz of RF – fewer channels
- If you want more channels, it looks like you are stuck with about 2.5 MHz of video – not good
Analog Television Transmission

- Beautiful compromise
- No distortion in big areas
- Some distortion in small areas
  - Where you can hardly see it!

![Diagram of Analog Television Transmission](image)
Analog Television Transmission

• Color TV is possible because of tricks
  – Multiple compromises, fine example of the engineering art
  – Color is related to the frequency of light
  – BUT, fortunately for color television (and color photography) the human eye has three sets of color receptors
    • Red
    • Blue
    • Green
Analog Television Transmission

• First attempt at a US Color TV standard
• **CBS Color Sequential**
  – Send the Red, Blue and Green pictures one after the other
  – 405 scan lines, 144 fields per second, interlace
    • 24 frames per second
  – **NOT compatible** with B&W TVs
  – FCC approved it, Korean war interrupted roll out
  – CBS withdrew, FCC reversed
  – NTSC Color replaced it
• But, *Apollo Moon camera* used such a system
• **Current DLP projectors** use such a system
Analog Television Transmission

- CBS-Columbia 12CC2 Field Sequential Color Receiver (1951) front view
Analog Television Transmission

• **Compatible Color** Television
• How to squeeze in three times the info
  – *Scientist* would say: can’t be done
  – *Engineer* would say: just watch me do it
• How it’s done:
  – First, reduce the info
  – Eye most sensitive to brightness, luminance
  – Eye more sensitive to some colors than others, skin tones
  – Create a signal that matches the eye
Analog Television Transmission

- Where to put the new signal?
  - Fourier analysis yields the spectrum
  - TV spectrum clustered around H rate
- Almost "holes" in between the clusters

Figure 2.12 Video spectral energy clusters around harmonics of horizontal scan frequency, $f_h$, all the way up to the upper
Analog Television Transmission

- Color information will be clustered too
  - Shift the color spectrum over
  - so it fits into the luminance holes

**Figure 2.28** Luminance spectral energy clusters around harmonics of horizontal scan frequency $f_h$ all the way up to the upper band edge. Chroma spectra energy components cluster around odd multiples of half horizontal scan frequency and are interleaved with luminance.
Analog Television Transmission

- Overall spectrum for analog color TV
  - 3 video signals, Luminance, I & Q, different bandwidths
    - Q has flesh tones, is a Vestigial Sideband; I Double Sideband
    - Chroma carrier, 3.579545 MHz, 455<sup>th</sup> odd multiple of H/2
  - They are matrixed from R, B, & G
    - To match human visual response
    - To minimize required bandwidth
- There are distortions all over the place
  - But almost no one notices
  - Excellent example of the engineering compromise art

Figure 2.30  Location and bandwidths of the luminance and chroma signals.
Analog Television Transmission

• Shadow Mask Picture Tube
• Almost simultaneously invented by RCA and Zenith, but RCA got to the patent office first! (legend: same day!)
Digital Television

• Motivated by HDTV
  – Japan was the original HDTV proponent
    • MUSE system, 9 MHz bandwidth, analog
  – Advanced Television Systems Committee, ATSC, 1982
  – FCC forms Advisory Committee in 1987
    • 23 analog proposals
    • Zenith hybrid
      – digitize low frequencies, which have most of the power
      – Leave high frequencies analog, which is cheaper
  – Moving Pictures Experts Group, MPEG forms May 1988
    • MPEG-1 approved for computers November 1992
    • MPEG-2 approved for television November 1994
Digital Television

• ATSC progress
  • General Instruments proposes all-digital in May of 1990
    – By 1991, four digital and two analog proposals left
  • February 1993, Advisory Committee decides it’s digital
  • May 1993, digital proponents form a “Grand Alliance”
  • Standard Definition TV added, multiple programs per 6 MHz
  • ATSC approves system 1995, FCC adopts 12/24/96
  • Digital Broadcast TV launched November 1998

• Analog Shut Down scheduled for 2/17/09
  – 12 years after digital standard approved!
    • Reception problems, some predict demise of broadcast TV
Digital Television

• The main thing digital technology brings to Television is **cheap, abundant, memory**
  – Now we can do really interesting things
  – Digitize standard definition
    • Usually 4 times chroma subcarrier 4 x 3.58 MHz
    • Usually at least 8 bits
    • Usually luminance and the chroma separately
    • *Direct digitization explodes the bandwidth!*

• Discrete Cosine Transform, DCT
  – See my book for details!
Digital Television

• **DCT** is a form of Fourier Transform
  – relies heavily on lots of cheap memory
  – Is lossless
    • Until the coefficients are approximated
      – Becomes lossy

• **Image Redundancy Reduction**
  – **Intra frame** coding, a picture at a time
  – **Inter frame** coding, between pictures
    • The genius of it all
    • Can **eliminate 98% of the digital data!**
      – Reconstruct the signal from only 2% of the data
Digital Television

- Couldn’t do this in analog because we had no memory!
Digital Television
Digital Television

• Now for some real fun!  **Time Warp!**
• Three kinds of frames
  – **I Frame**, Initial, only whole frame
  – **P Frame**, predicted
  – **B Frame**, Backwards looking
• If we never changed channels and had zero errors, we’d need only one I Frame!
  – But we live in the real world
Digital Television

• Going from b to c uncovers some sky
  – Need to know what is in the uncovered sky!
  – By the way, don’t need to re-transmit the airplane, it’s in memory
Digital Television

– The uncovered sky exists in c,
  • but c comes after b
    – No problem with digital memory
    – Introduce some delay to the stream
      » Then shuffle the order of transmission
      » A: display order  B: transmission order

Figure 3.21 Order of transmission and display of I, P, and B frames. (a) Frame type and display order. (b) Frame type and transmission order.
Digital Television

• Some very high technology we don’t have time to consider here:
  – Forward Error Correction
  – Huge time domain equalizers
    • Multipath, ghosts
    • Went thru five versions before satisfactory
      – Might not be satisfactory yet!
  – Spectrum shaping to avoid NTSC cross interference
Digital Cable Television

• Don’t have time to cover cable history and development, see the book!

“I’m so old I can remember when telephone calls came over a wire and television programs came over the air”
Digital Cable Television

• Compression allows us to
  – Put 4 or 5 SDTV’s in Broadcast 6 MHz
  – **Put 10 to 15 SDTV’s in Cable’s 6 MHz**
    • Cable downstream spectrum
      – 52 MHz to as much as 1,000 MHz, 948 MHz!
        » 948/6 = 158 6 MHz slots
        » 1,580 to 2,370 SDTV “channels”
    • Cable can also convey 2 to 3 HDTVs in 6 MHz

• **Cable node** serves 100 to 1,000 homes
  – Video on Demand, VOD,
    • Individual video data stream per home
    • individual control of the stream, pause, fast forward, rewind
Digital Cable Television

• Other digital television wonders
  – Personal Digital Recorder
    • Hard Drive storage
  – TiVo, an originator of the concept
    • Three visible forward and reverse speeds
      – Fastest is a second per minute, hour in a minute
    • Program guide
      – “Season ticket”
      – Key Word Search

• Switched Digital Video
  – Only provide the channels requested on each node!
Digital Displays

• HDTV has 5 times the video data compared with SDTV
  – NTSC is a 5 times picture height compromise
    • Don’t see artifacts if you’re that far away
  – HDTV is 1.5 to 2 times picture height
    • Need BIG displays to enjoy HDTV
  – The good old CRT is history!
    • Flat screen is it!
Digital Displays

• Flat Screens
  – No longer scanned, Pixel addressed
    • No Raster distortion, perfect geometry
      – Issue with 4:3 vs 16:9

• Major types
  – Plasma
  – LCD
  – LED, current hot topic: Organic LEDs for TV
  – Projection
    • With LCDs
    • Micro-mirror

• My mantra applies:
  “There are no solutions, only trade-offs”
Digital Displays

• Excellent free resource
  – Magazine of the Society for Information Display
  – Current issue: Relevant article
    • The Outstanding Potential of OLED Displays for TV Applications
Digital Displays

• Issues with digital displays
  – “Burn in”
  – Contrast ratio
  – Speed, blurring
  – Color gamut
  – “Rainbows”
  – Life, expensive light bulbs

• No matter what you buy, there will be a better one next year for less money!
Digital Displays

- Pick one interesting example
- Micro-Mirror
- Glenn 1973 patent, 
  - 3,882,271
- Commercialized by TI 
  - DLP, Digital Light Processor 
  - http://www.dlp.com/includes/demo_flash.aspx
Digital Displays

• Micro-mirrors, one for each pixel
  – HDTV 1080 x 1920 = 2,073,600 pixels
    • How many pixels in your digital camera?
    • How big are the pictures you normally view?

• A transistor for each pixel
• Electrostatic deflection, binary, on / off
• Reflects light or doesn’t
• “Pulse width modulation” $2^n$ Shades of gray
• Color wheel, like CBS color system!
Digital Displays

• Amazing optics, very shallow box
Digital Displays

• Exciting applications
• 3-D TV, Current hot topic
  – 3-D HDTV from Mitsubishi and Samsung
  – Active glasses synchronize to the display
• Does NOT require twice the bandwidth
  – The two images are very similar

• Also: His & Her TV on the same display!
Digital Displays

- This tells the story for “place shifting”
- Future is portability, it’s happening now!
Digital Displays

- Cell phone laser projector!
Thank you

• I hope you are convinced that consumer electronics in general and television in particular are exciting, *powerful examples of the engineering art.*
  – Loaded with compromises

• I hope you are motivated to dig further
Since I became project manager, no one has returned my calls or responded to my e-mails.

Luckily, I'm an I.I.T. graduate, mentally superior to most people on earth, so I finished the project myself.

Are you tired? I am trained to only sleep during national holidays.