The Technology of Broadcast Television and Its Impact

Past, Present and Future

Glenn Reitmeier

October 26, 2020

Sponsored By: **TCF / TCNJ SARNOFF MUSEUM / IEEE PCJS**

Introduction

- Not a technology historian … a student of analog TV development history
- Not an economist … observe market adoption data and trace technology roots
- TV Technologist
  - worked on improving analog broadcasts and receivers
  - leader in digital television standards (ATSC and ATSC 3.0)

…A Technology Perspective on (U.S.) TV Broadcast Standards and Their Impact…

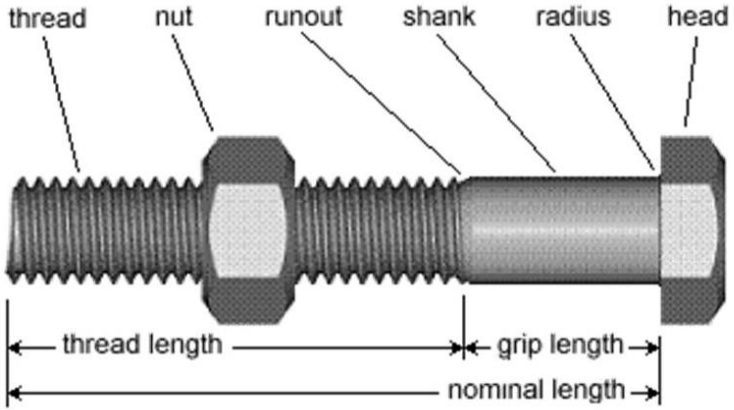
Outline

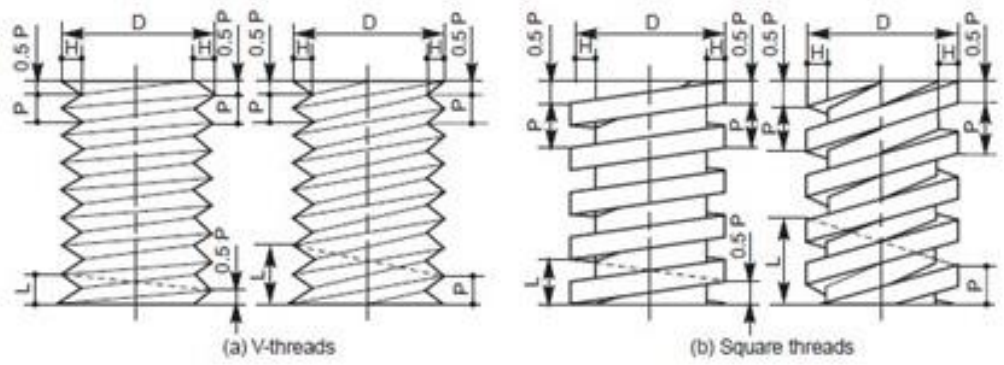
- Background – The Importance of Standards
- Monochrome Television (NTSC monochrome standard)
  - Goals … Challenges … Innovations … History … Technology … Adoption … Impact
- Color Television (NTSC color standard)
  - Goals … Challenges … Innovations … History … Technology … Adoption … Impact
- Digital HDTV (ATSC Standard)
  - Goals … Challenges … Innovations … History … Technology … Adoption … Impact
- Next-Gen TV (ATSC 3.0 Standard)
  - Goals … Challenges … Innovations … History … Technology … Adoption
- Future Predictions

The Importance of Standards

Standards

…every manufactured item in the modern world is based on technical standards…

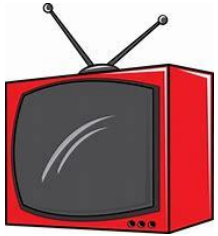




Compatible … Interchangeable … Interoperable

Broadcast Standards

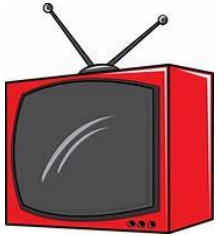
…specify the signal that is sent by a transmitter to receivers…



TV Stations can be received by different manufacturers' TVs

Broadcast Standards

…specify the signal that is sent by a transmitter to receivers…

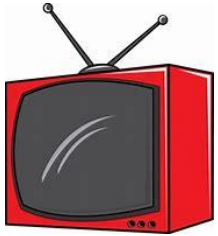


TV Stations can be received by different manufacturers' TVs

Consumers' TV can receive different TV Stations

Broadcast Standards

…specify the signal that is sent by a transmitter to receivers…



TV Stations can be received by different manufacturers' TVs

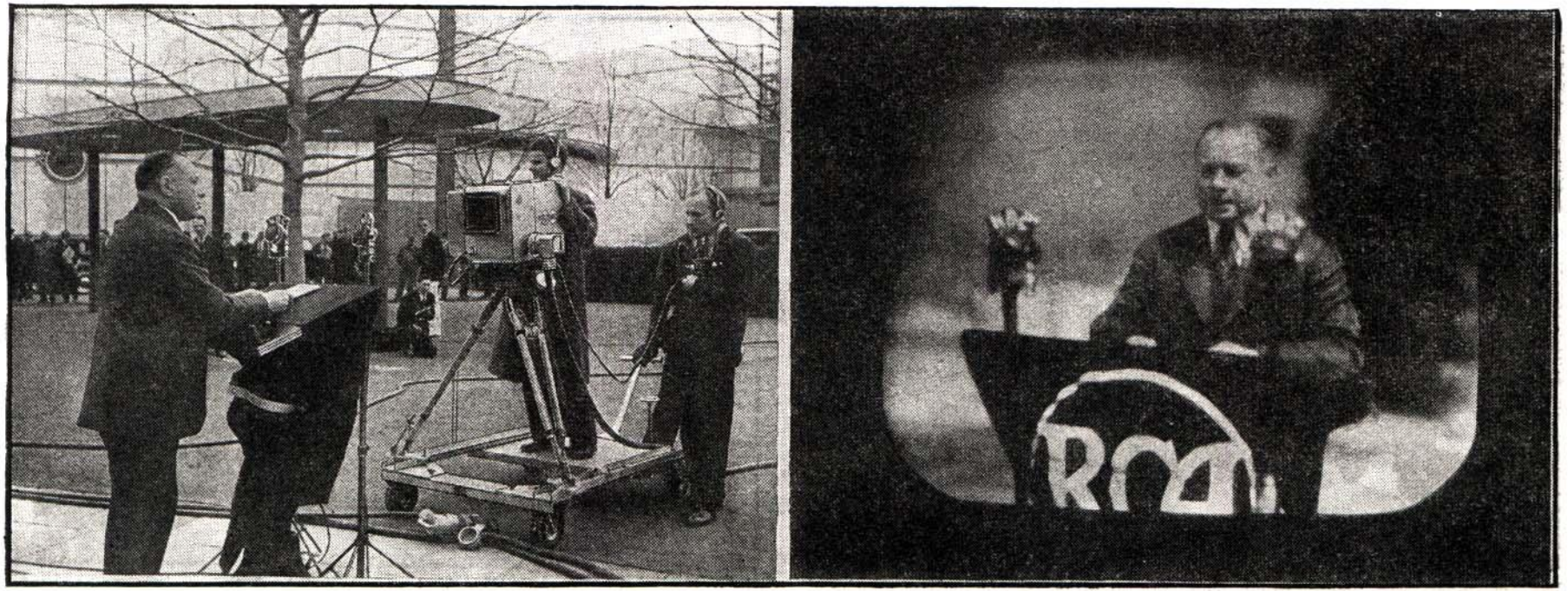
Consumers' TV can receive different TV Stations

Monochrome Television

Television Goals

1920s – 1930s

…add sight to sound…



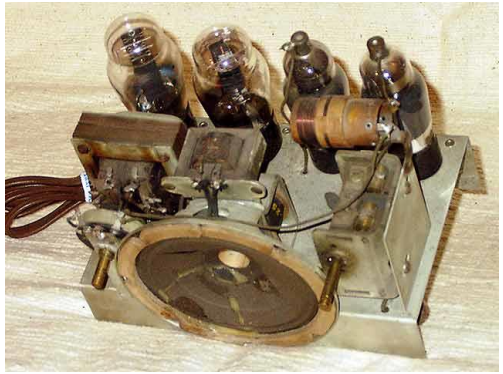
DAVID SARNOFF WAS PHOTOGRAPHED . . . AND TELEVISED, AT THE N. Y. WORLD'S FAIR

It's a downright fib to say "the camera doesn't lie," at least insofar as it concerns catching on a photographic film the same sort of image our eye perceives when viewing the phosphorescent end of a cathode-ray television receiving tube. ***Radio-Craft*** can attest, from having witnessed by television 8 miles away the dedication program, in connection with the RCA Exhibit Building, at which these photos were taken, that the image photo at top-right (and reproduced on cover) does not convey the same impression of "photo fidelity" which was experienced when the image was viewed directly on any one of 15 receivers. The reasons for this result are given elsewhere in this department.

Television Technology Challenges

- 280x more information than radio (4.2 MHz vs. 15 kHz)
- 200x more radio spectrum (6 MHz vs. 30 kHz)
- High Power Transmitters, High Antennas
- Rooftop receive antennas
- Affordable receivers
- Multiple Systems Proposed

Typical Tube Radio c. 1930s



Television Technology Race

1936 – RMA Standard

- In 1936, the Radio Manufacturers Association (RMA) proposed that U.S. television channels be standardized by the FCC
- 6 MHz bandwidth
- 441-line, interlaced, 30 frame-per-second system
- 2.8 MHz visual bandwidth
- AM audio

Television Technology Race

1936 – RMA Standard

- In 1936, the Radio Manufacturers Association (RMA) proposed that U.S. television channels be standardized by the FCC
- 6 MHz bandwidth
- 441-line, interlaced, 30 frame-per-second system
- 2.8 MHz visual bandwidth
- AM audio

Television Technology Race

1936 – RMA Standard

- In 1936, the Radio Manufacturers Association (RMA) proposed that U.S. television channels be standardized by the FCC
- 6 MHz bandwidth
- 441-line, interlaced, 30 frame-per-second system
- 2.8 MHz visual bandwidth
- AM audio

1941: NTSC Standard

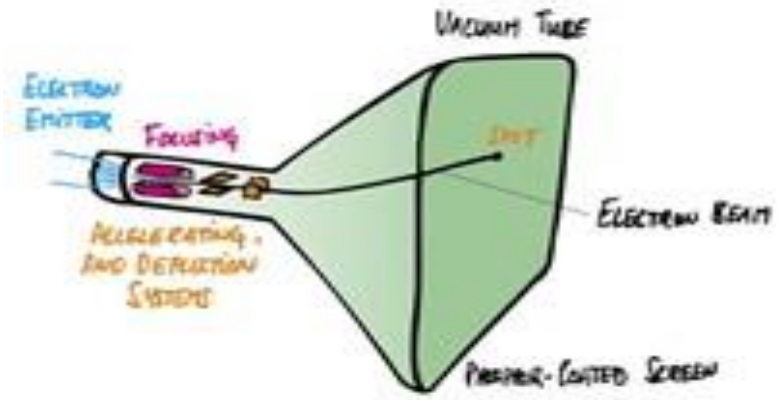
National Television Systems Committee

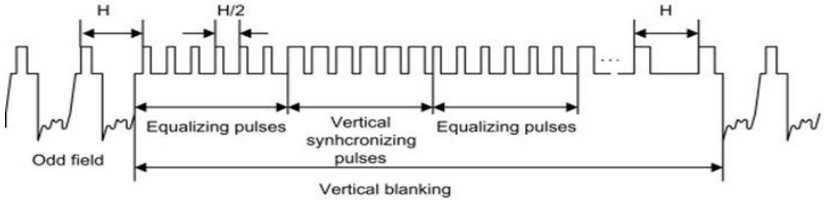
- 6 MHz bandwidth
- Vestigial Sideband modulation
- 525-line, interlaced, 30 frame-per-second television system
- 4:3 picture aspect ratio
- FM audio

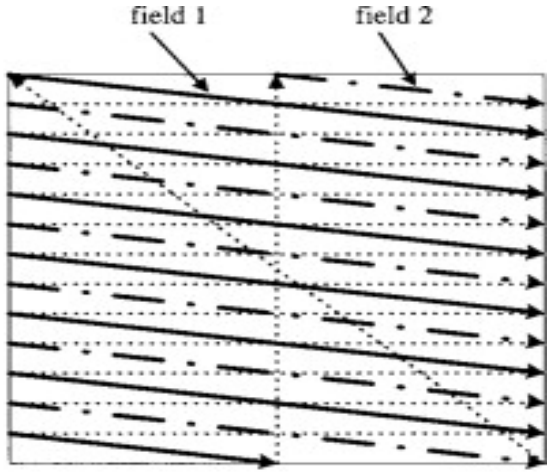
(after great debates about the relative benefit of increased horizontal resolution vs. the number of scan lines)

Monochrome TV Technology Innovations

1930s – 1990s: Analog Video Signals Based on Tubes







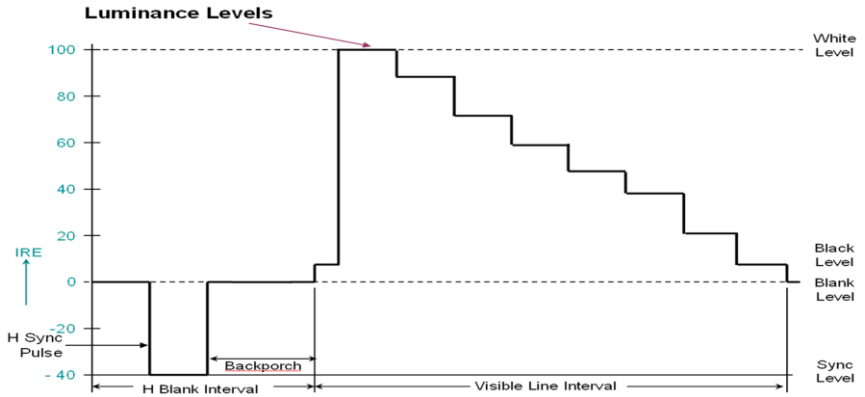
Interlaced

480 visible scan lines (525 total)

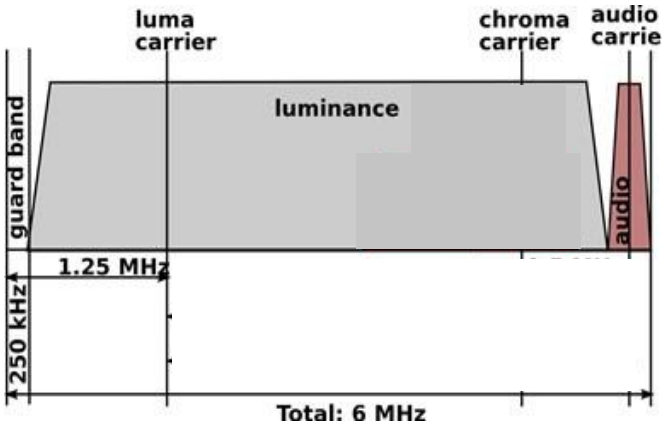
- CRT electron beam – spot brightness and location controlled by broadcast signal
- Interlaced scan avoided display flicker
- 525-line (480 visible), 60 Hz system

More Monochrome TV Technology Innovations

1940s – 1950s



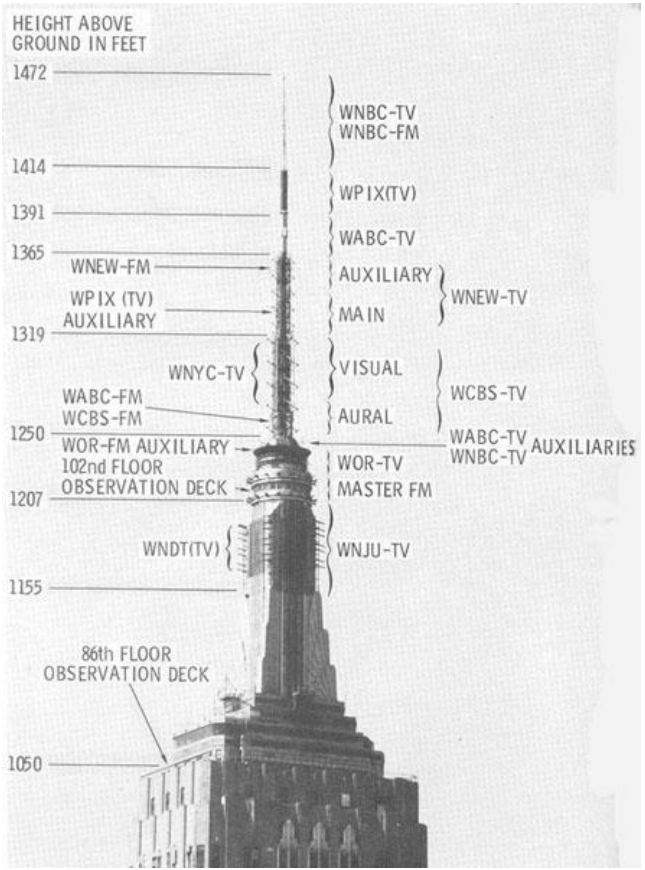
- "Gamma corrected" signal accounts for nonlinearity in CRT brightness – coincidentally aligned with human perception
- Vestigial Sideband Transmission for spectrum efficiency
- Inverted RF signal for power efficiency



Analog Television Broadcast Standards

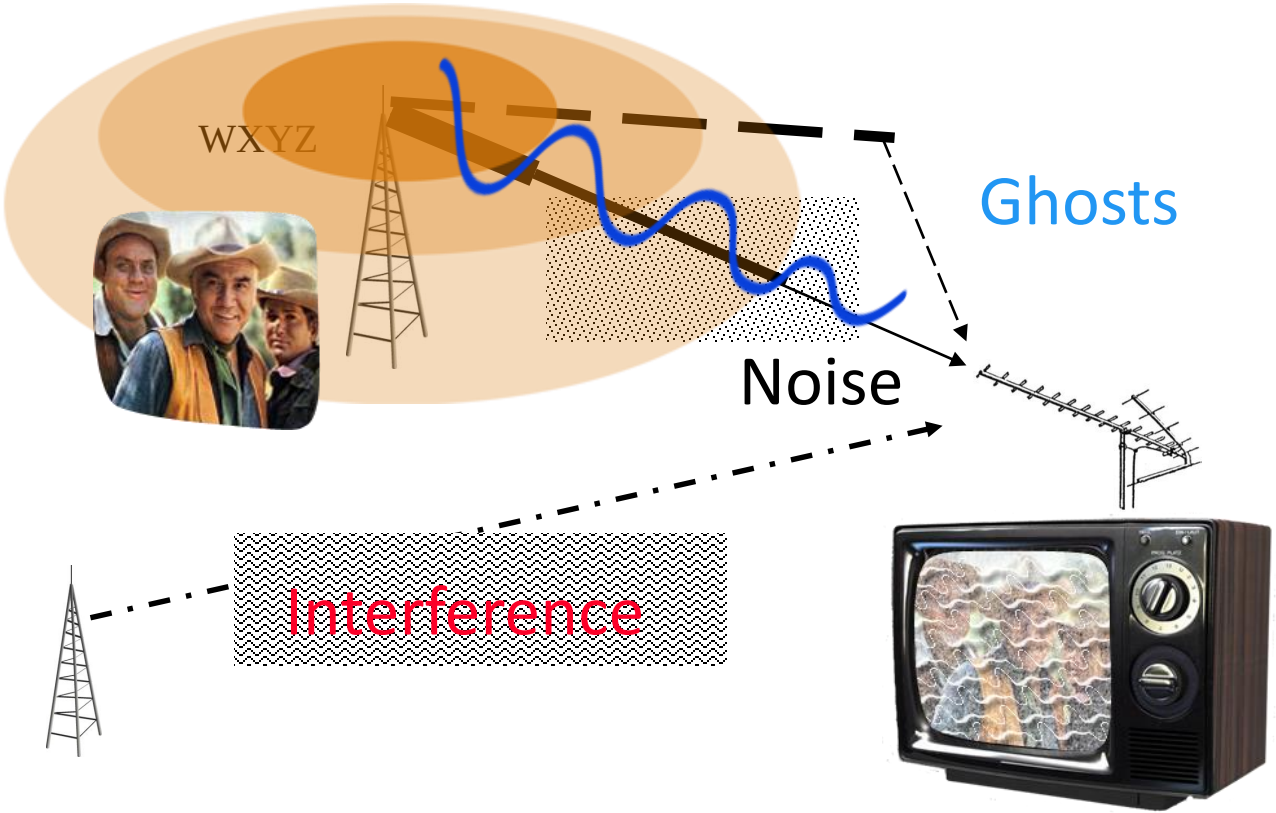
1942: NTSC Monochrome

National Television Systems Committee



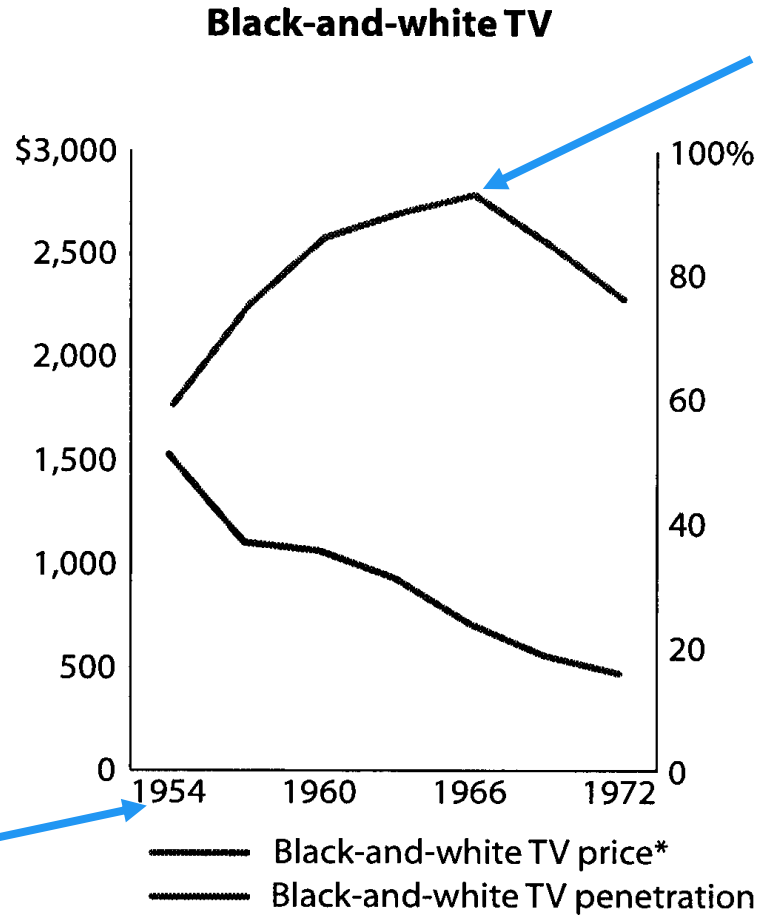
Analog Television Transmission Impairments

...transmission impairments project directly into the picture...



But the FM audio part of the signal was extremely robust

Consumer Adoption



Color Television

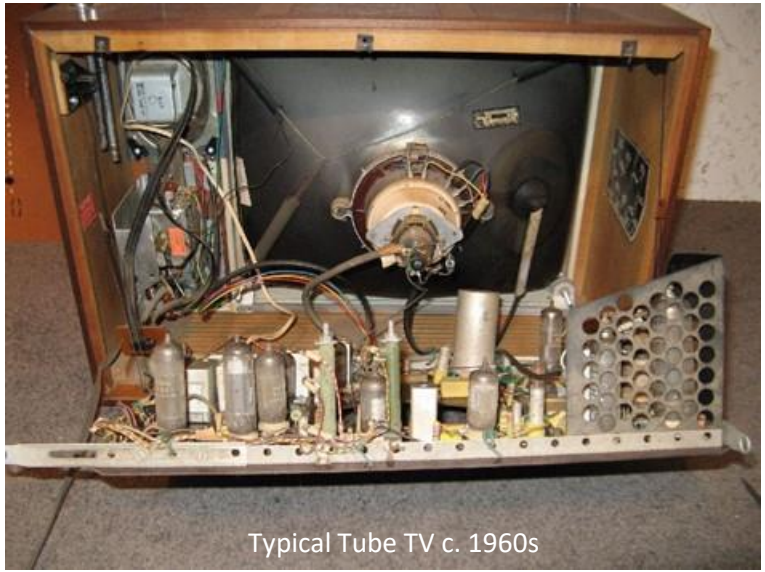
Color Television Goals

1940s – 1950s

…add color in a backward-compatible manner…

Color Television Technology Challenges

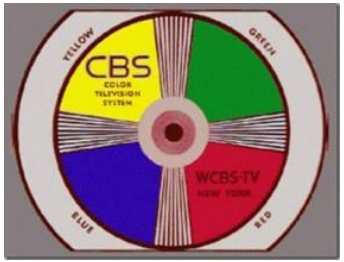
- 3x more information than monochrome TV
  (Red, Green and Blue)
- Fit in the same radio spectrum (6 MHz)
- Backward-compatible with monochrome TV receivers
- Multiple systems proposed



Typical Tube TV c. 1960s

Color TV Technology Race

1950 – CBS Color Wheel System



- Based on a mechanical, rotating color wheel

Color TV Technology Race

1950 – CBS Color Wheel System

- Based on a mechanical, rotating color wheel

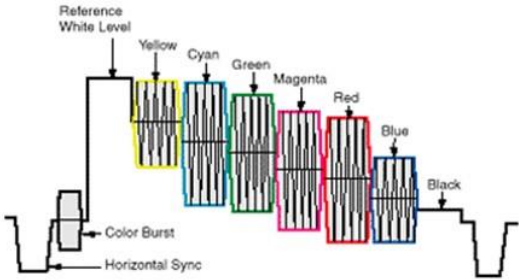
Color TV Technology Race

1950 – CBS Color Wheel System

- Based on a mechanical, rotating color wheel

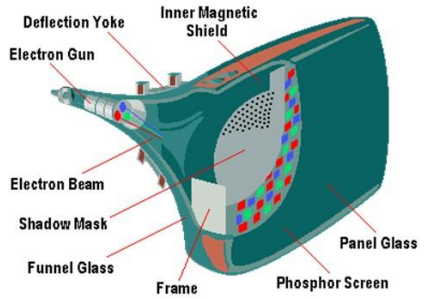
1953: NTSC Color Standard

National Television Systems Committee



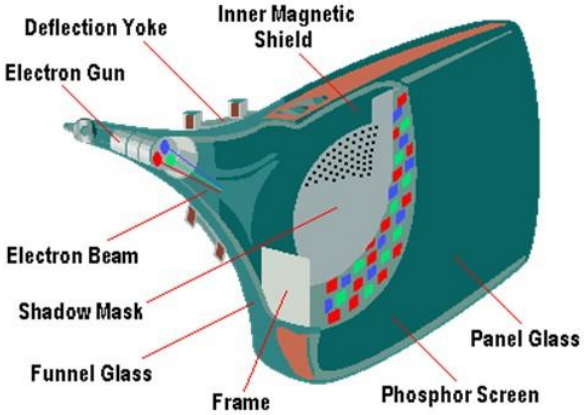
- All-electronic system

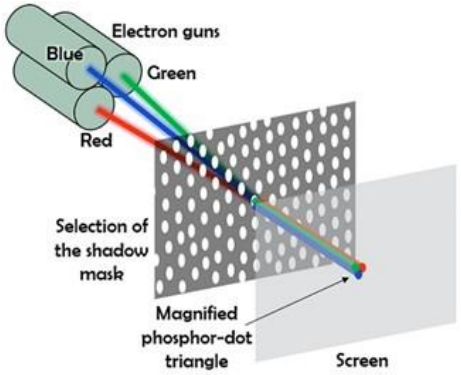
(after great debates about the details of color modulation and synchronization)



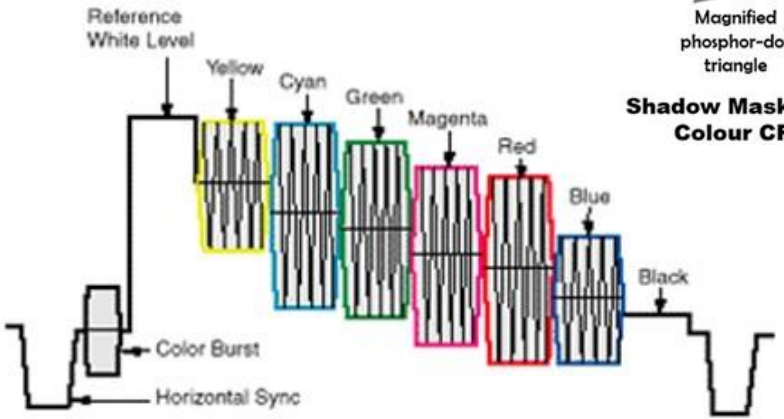
NTSC Color Innovation

- Color phosphors for CRT
- Shadow mask CRT allowed three electron guns (Red, Green and Blue
- Compatible signal format uses principles of human vision color perception
  - Lower resolution in color
  - Most of the monochrome color comes from Green
  - R,G,B → Y, R-Y, B-Y
    - Y luminance
    - R-Y and B-Y color difference signals have lower bandwidth





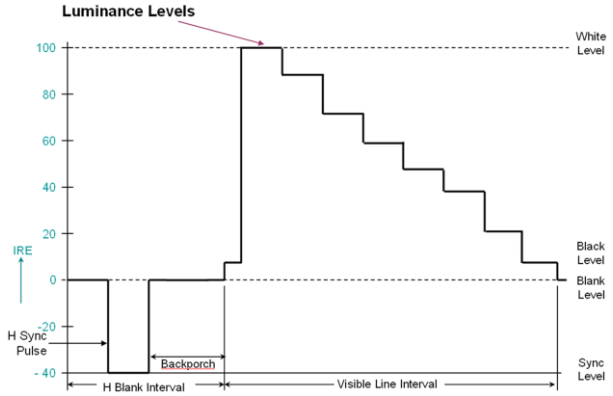
Shadow Masking in Colour CRT

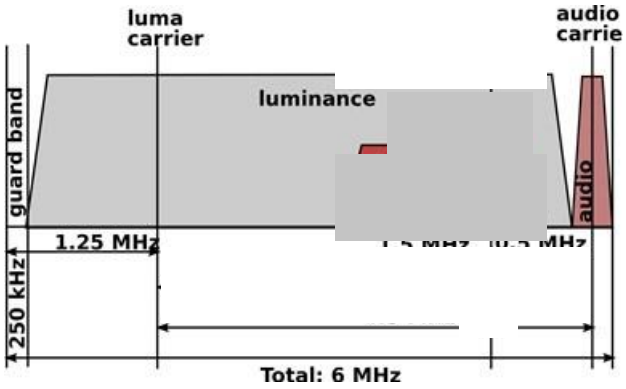


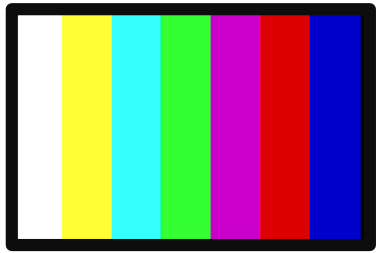
NTSC Color Television Innovation

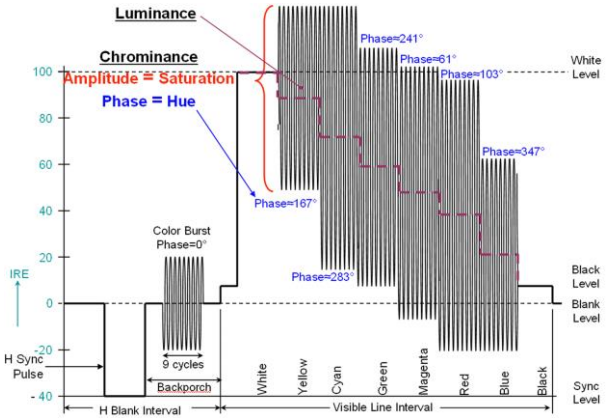
1940s – 1950s

…add color in a backward-compatible manner…

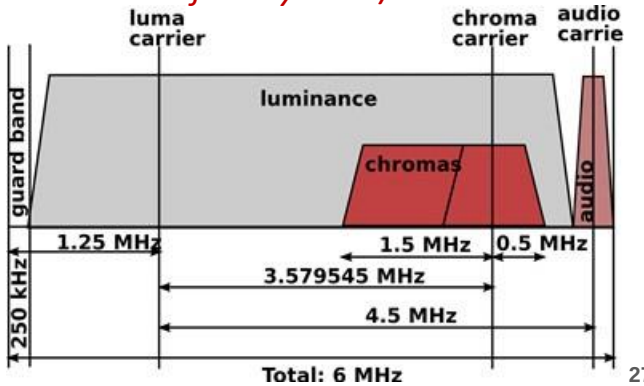




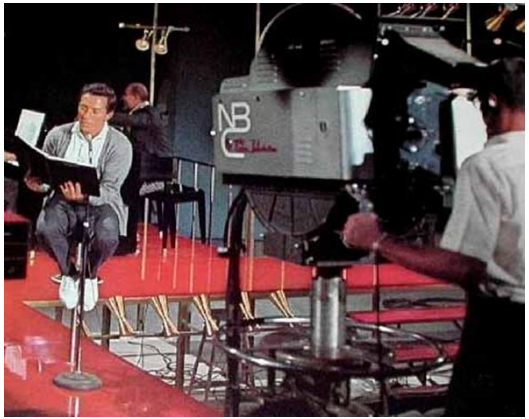


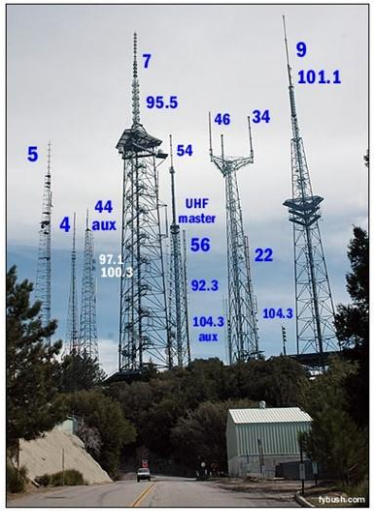


Picture Rate shifted by 1000/1001 to 59.94 Hz



Color TV Adoption





Mount Alta, from the west

stereo sound added in 1986

Color TV Consumer Adoption

1954

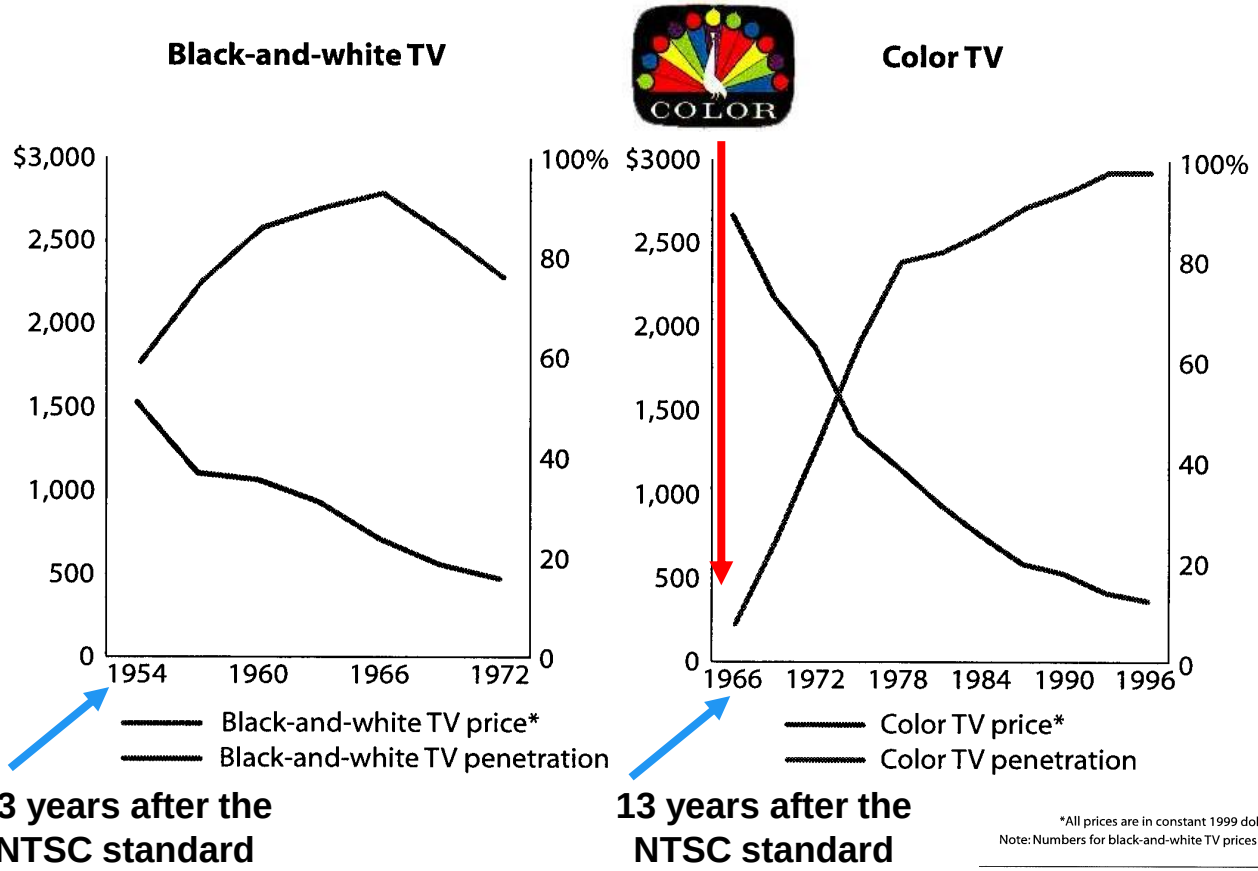
=

1966

<

over $2600 in 1999 dollars

Color TV Consumer Adoption



*All prices are in constant 1999 dollars using the GDP Deflator Index
Note: Numbers for black-and-white TV prices and penetration are not available after 1972

Source: Forrester Research, Inc. with historical data from Statistical Abstracts of the United States and the Consumer Electronics Manufacturers Association

Color TV Impact – Subsequent Innovations

Live global broadcast via satellite (1967)

UHF

Cable TV

VCR

Camcorders

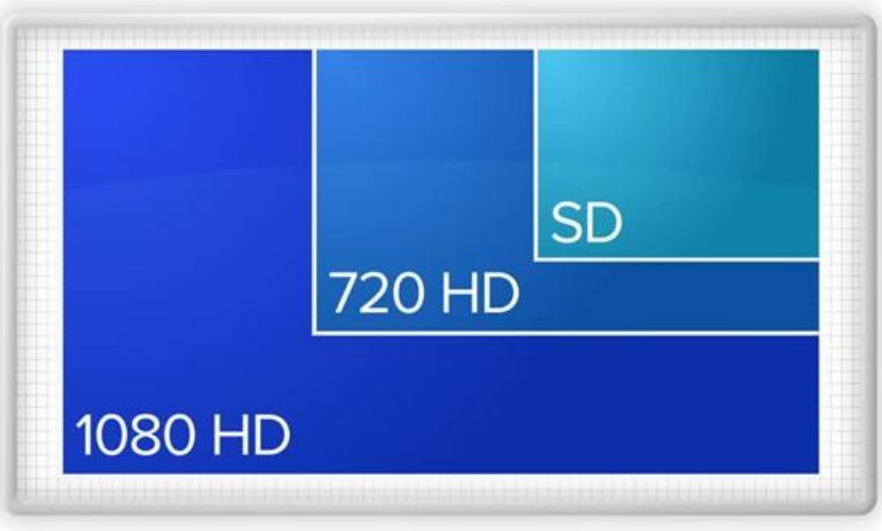
(Digital) High-Definition Television

High-Definition Television Goals

1980s – 1990s

…higher resolution, widescreen format and surround sound…

- 2x horizontal resolution and 2x vertical resolution
- Wide 16:9 aspect ratio
- Theater-quality surround sound



HDTV Technology Race

1987 – Broadcasters Petition FCC

- FCC Advisory Committee on Advanced Television Service (ACATS)
- 23 competing analog systems …

Improved-Definition

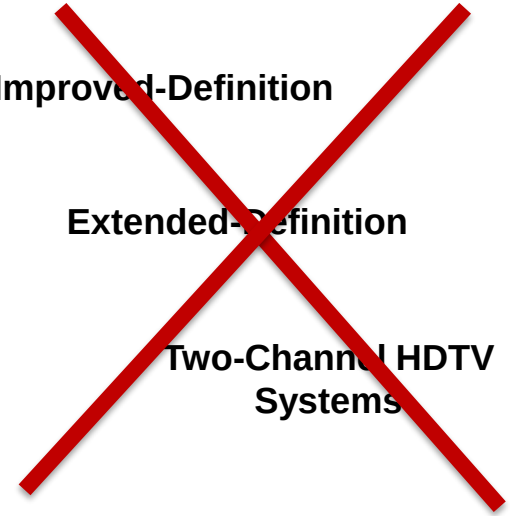
Extended-Definition

Two-Channel HDTV Systems

HDTV Technology Race

1987 – Broadcasters Petition FCC

- FCC Advisory Committee on Advanced Television Service (ACATS)
- 23 competing analog systems …



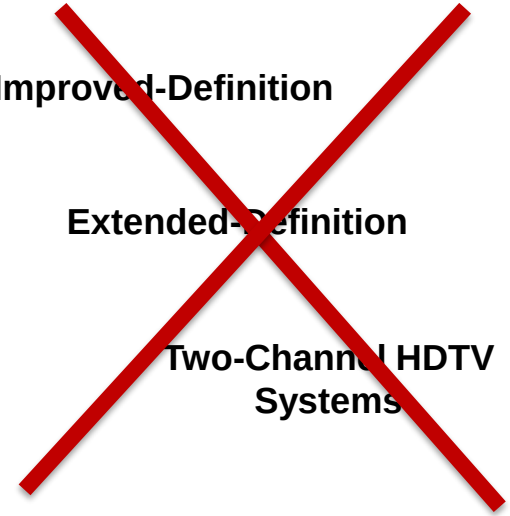
1990 – FCC Clarifies Policy Goals

- Full HDTV
- One 6 MHz transmission channel
- No additional spectrum

HDTV Technology Race

1987 – Broadcasters Petition FCC

- FCC Advisory Committee on Advanced Television Service (ACATS)
- 23 competing analog systems …



1990 – FCC Clarifies Policy Goals

- Full HDTV
- One 6 MHz transmission channel
- No additional spectrum

Four Digital System Emerge

- DigiCipher (General Instrument)
- Advanced Digital HDTV (Sarnoff, Thomson, Philips, NBC)
- Digital Spectrum-Compatible (Zenith, AT&T)
- DigiCipher Progressive (General Instrument, MIT)

HDTV Technology Race

- 1992 – System testing and demonstrations
- Jan 1993 – ACATS recommends a digital system…
- But cannot select a winner from the four digital systems

1993 Advanced Digital HDTV System

HDTV Technology Race

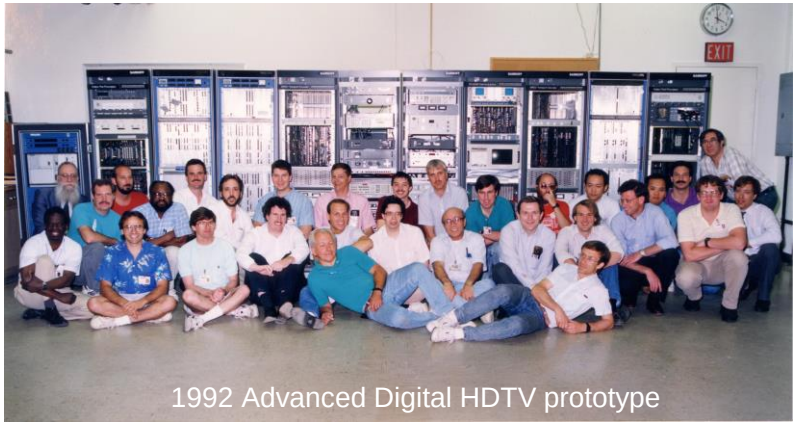
- May 1993 – Digital HDTV Grand Alliance formed
- April 1995 – Grand Alliance HDTV system world premiere
- Sept 1995 – ATSC Standard (Advanced Television Systems Committee)
- Dec 1996 FCC approval


1995 Grand Alliance Demonstration to FCC

…ATSC was the world's first digital television standard…

HDTV Technology Challenges

- 5x more information that conventional TV
- Limited transmission spectrum capacity available
- HDTV transmissions must not interfere with legacy NTSC service
- HDTV transmissions must be robust to survive interference from legacy NTSC service
- Affordable receivers
- Multiple systems proposed



1992 Advanced Digital HDTV prototype

Digital HDTV Was A Revolutionary Approach

NTSC TV – 1953 analog transmission standard
CRT tube displays

Computer
DOS … Windows 3.1

Cell Phone
Analog 2G

Dial-up
Modem
19.2 kbps

VCR - analog

Digital HDTV Was A Revolutionary Approach

NTSC TV – 1953 analog transmission standard
CRT tube displays

2M Pixels – 5x VGA
16M colors – 1,000,000x

Computer
DOS … Windows 3.1

Wireless
Digital

Cell Phone
Analog 2G

19.4 Mbps
1000x faster

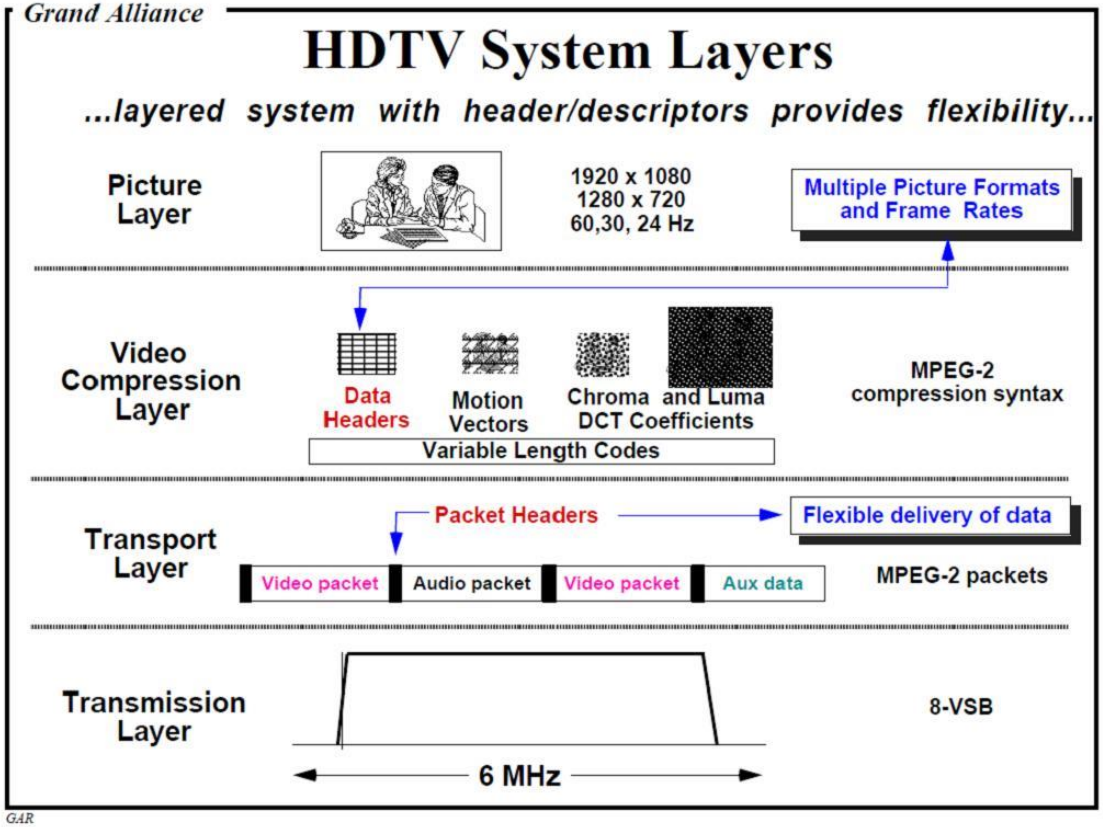
Dial-up
Modem
19.2 kbps

Compressed
Digital Video

VCR - analog

ATSC Digital Technology Innovations

- Multiple Picture Formats
  - HD and SD resolutions
  - Progressive and interlaced scan
  - 5.1 channel surround sound
- Digital Video and Audio Compression
- Data Packet Transport layer
  - Flexibility
  - Multiple TV streams in a channel
- 8-VSB digital modulation
  - Same coverage with 1/16th power



Digital Video Compression Challenge

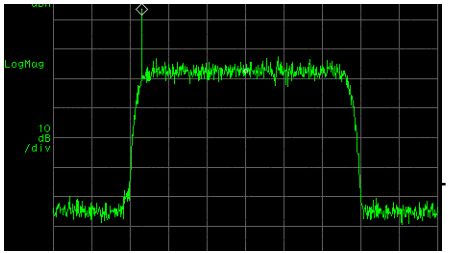
Production &
Post-Production

1920 x 1080 /60

~1 Gbps

50:1 Compression
...only 2% of the original data...

Transmission

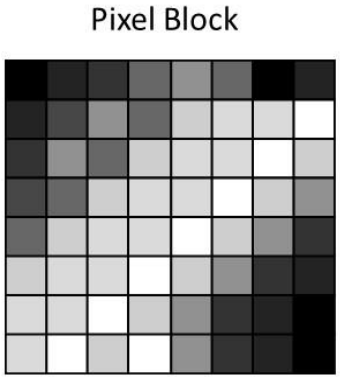


6 MHz

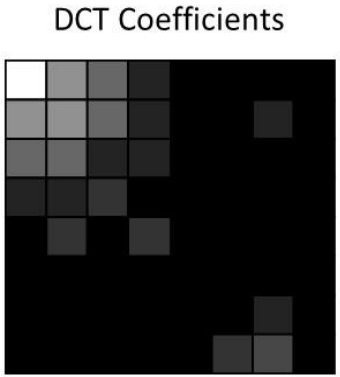
19.4 Mbps

Digital Video Compression Innovation

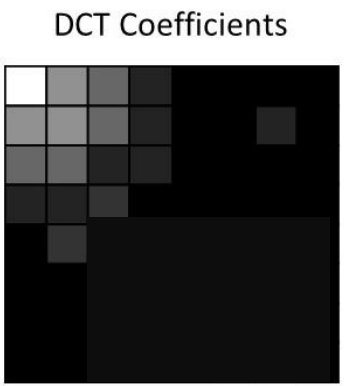
…blocks of pixels compressed with DCT…



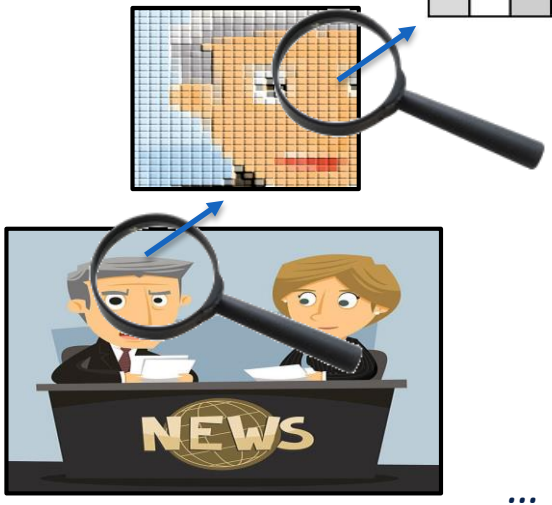
Discrete Cosine Transform



Quantization



Discrete Cosine Transform Coefficients (like JPEG)



$$DCT(i,j) = \frac{1}{\sqrt{2N}} C(i)\, C(j) \sum_{x=0}^{N-1} \sum_{y=0}^{N-1} pixel(x,y) \cos\left[\frac{(2x+1)i\pi}{2N}\right] \cos\left[\frac{(2y+1)j\pi}{2N}\right]$$

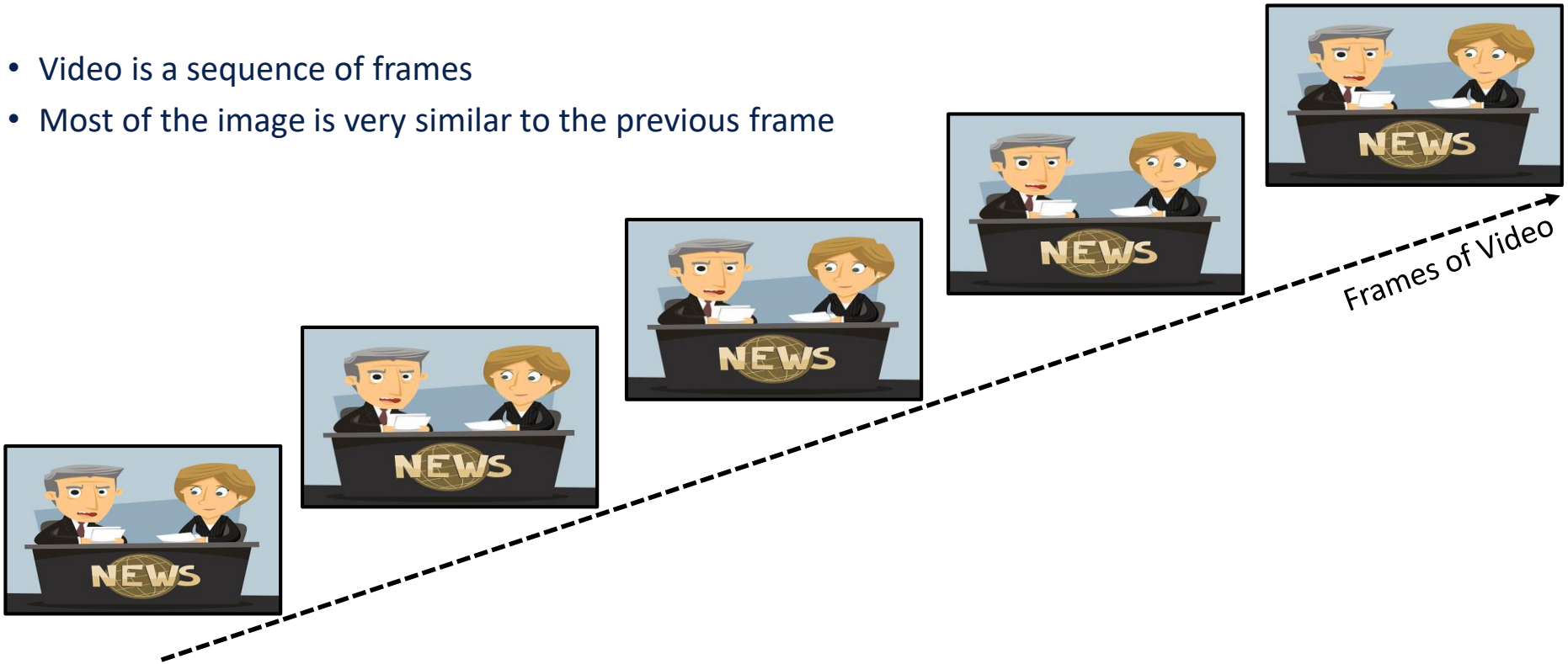
$$C(x) = \frac{1}{\sqrt{2}} \text{ if } x \text{ is } 0, \text{ else } 1 \text{ if } x > 0$$

… but even more compression is needed …

Digital Video Compression Innovation

…video is a sequence of frames…

- Video is a sequence of frames
- Most of the image is very similar to the previous frame



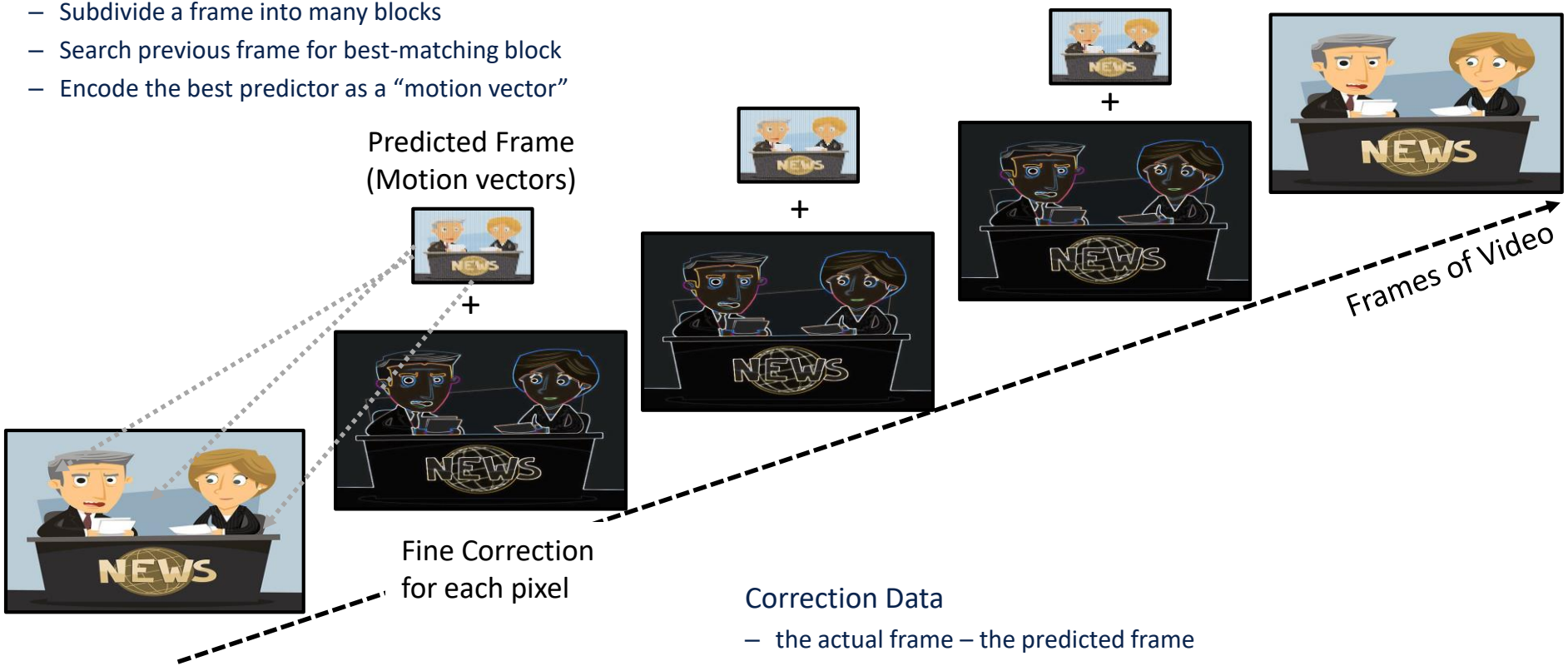
In analog systems, each frame is sent independently

Digital Video Compression Innovation

…send data once for many frames…

Motion Prediction

- Subdivide a frame into many blocks
- Search previous frame for best-matching block
- Encode the best predictor as a “motion vector”



Correction Data

- the actual frame – the predicted frame

In digital systems, most frames are composed of Prediction + Correction data

Digital Video Compression Innovation

…blocks of pixels compressed with DCT…

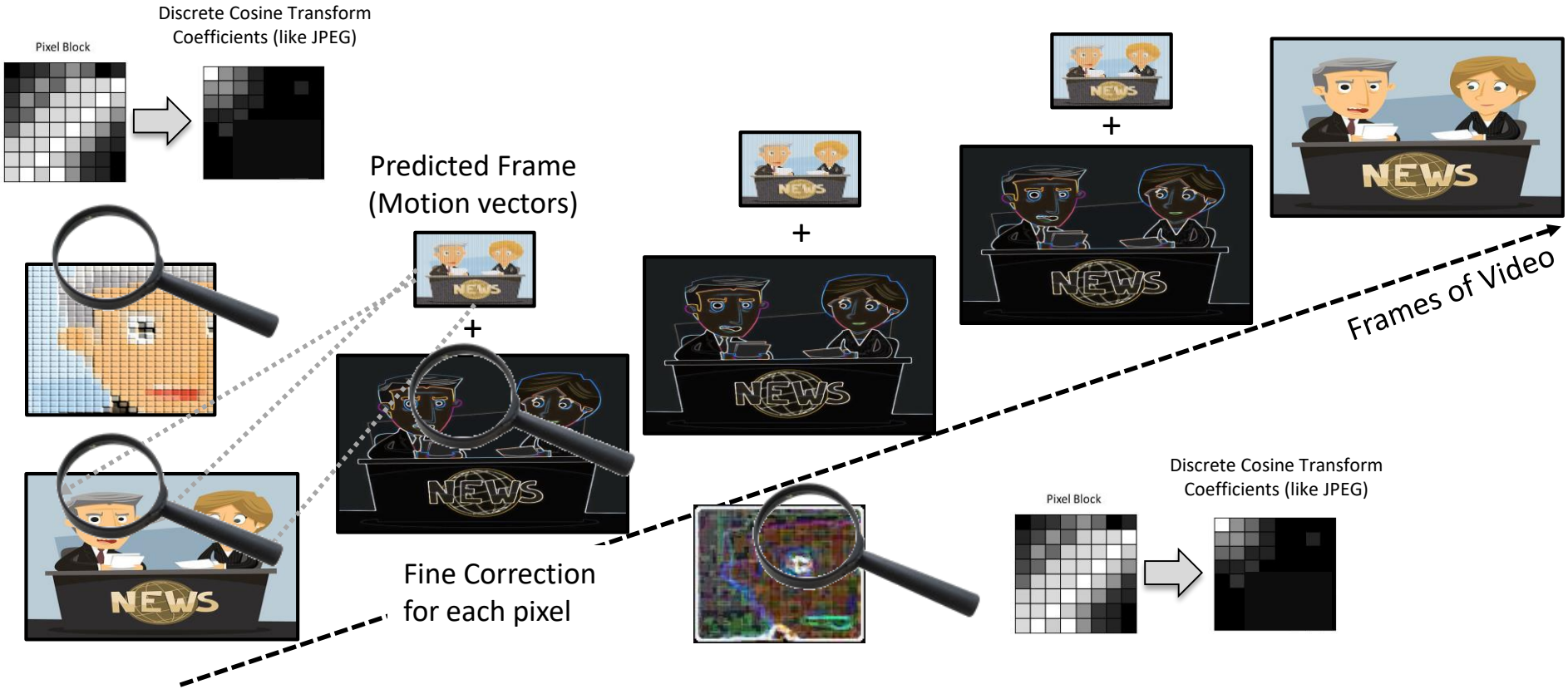
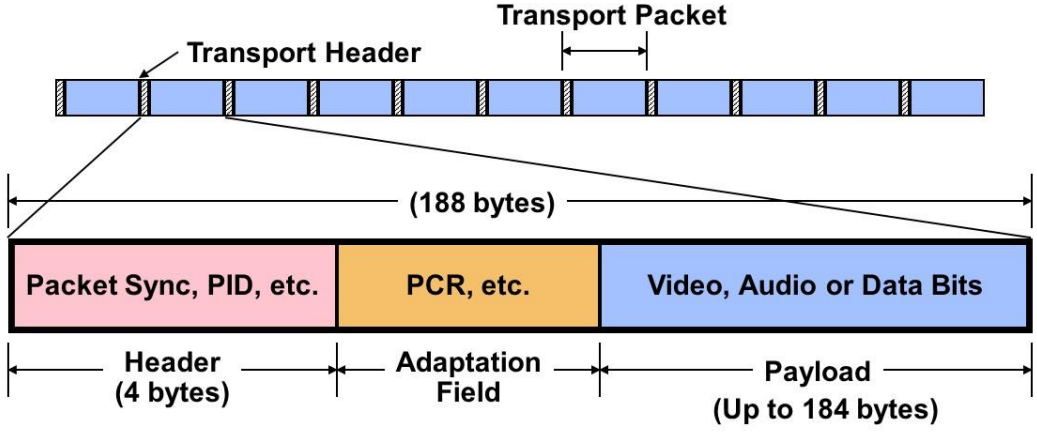


Image and predicted pixel blocks are compressed with the DCT

Data Packet Innovation

…key to broadcaster flexibility – no longer a single program in a transmission...

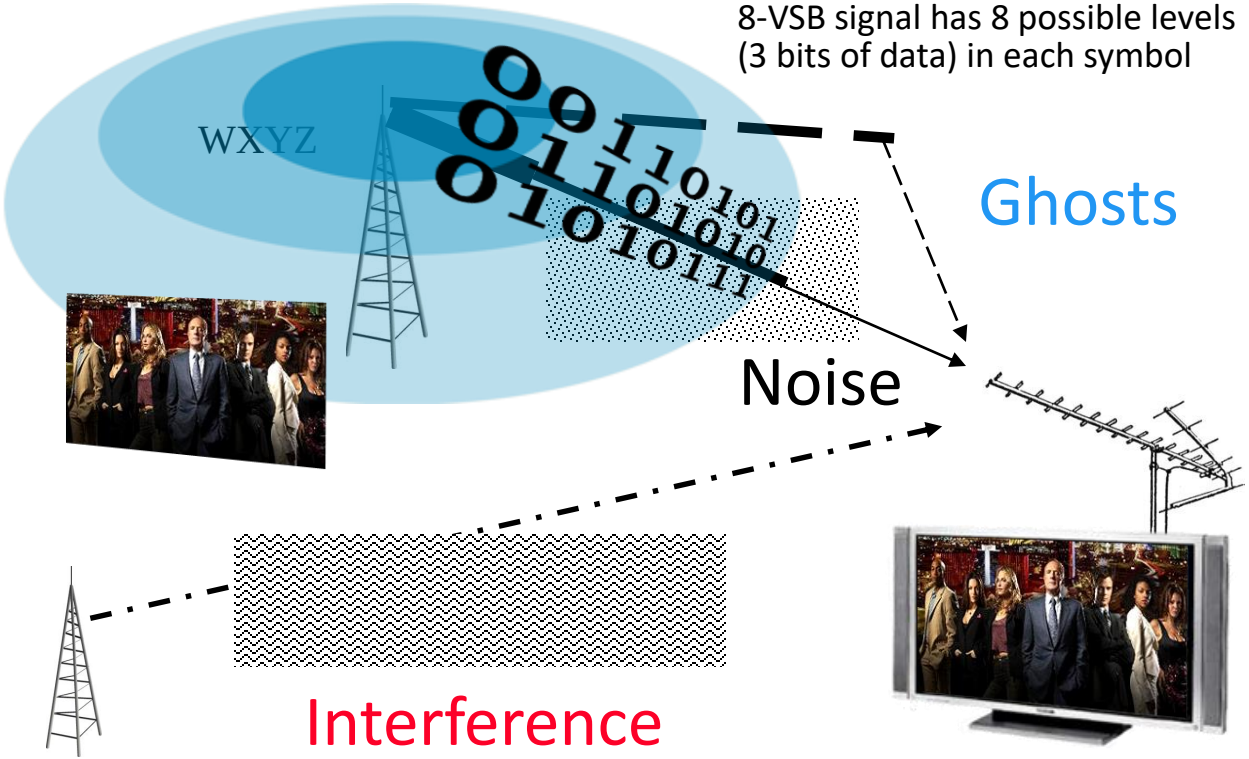
- 188 Byte fixed length packets
- Packet ID (PID) tells what type of data the packet is carrying
- PCR clock reference for receiver time synchronization
- Global standard - MPEG-2 Systems



PAT: Program Association Table repeated in PID 0
list of « services » in the TS, i.e.. TV channels or data channels
service id and PMT PID
PMT: Program Map Table
technical description of one service
list of elementary streams in the service

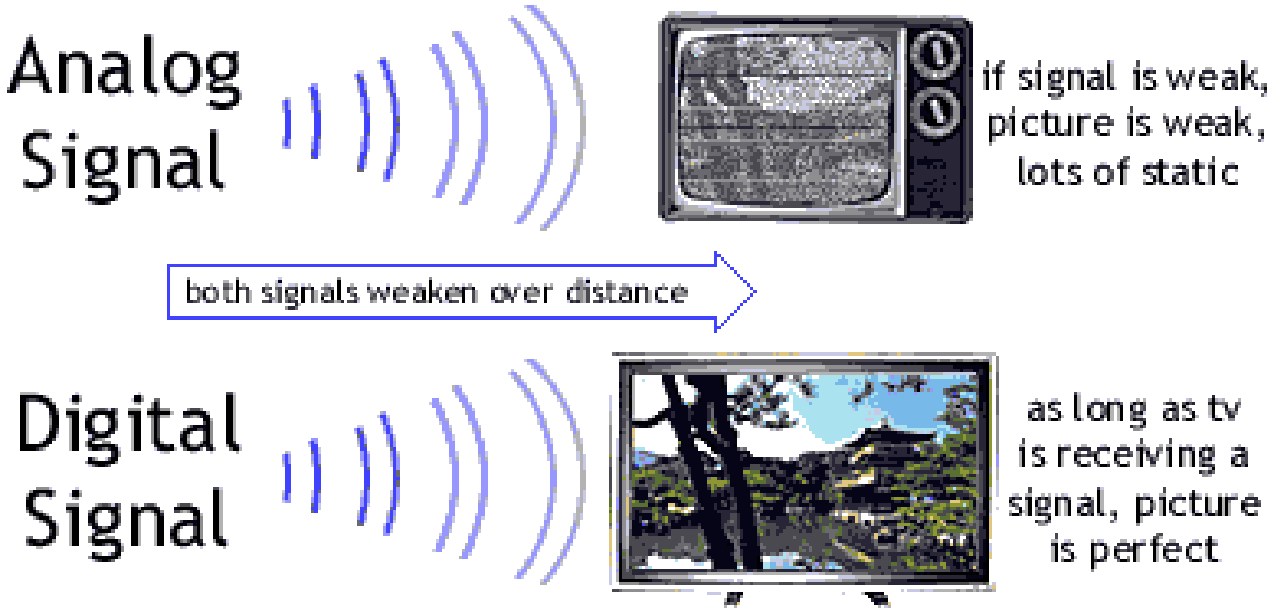
Digital Transmission Innovation

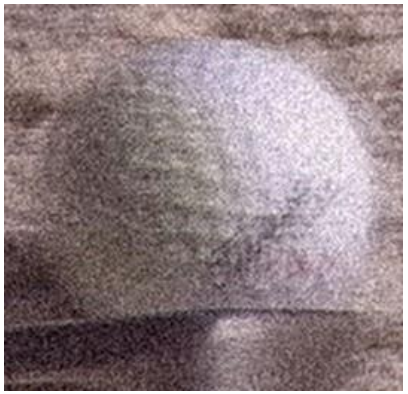
…reception is all or nothing...



Digital HDTV Broadcast

1996: atsc Advanced Television Systems Committee





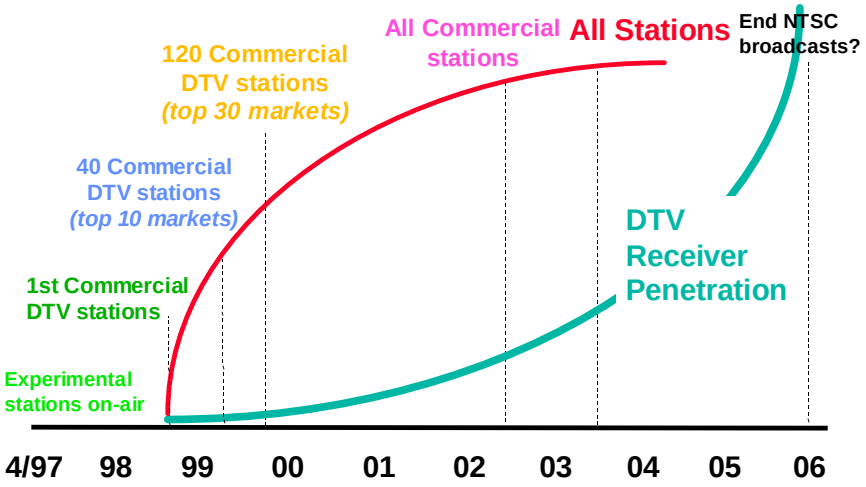
[25th Anniversary of the Digital HDTV Grand Alliance]

[Overview of Digital Television Worldwide, Proceedings of the IEEE Jan 2006]

[Digital HDTV Grand Alliance History]

FCC Transition Requirements

…simulcast in channels that are unsuitable for analog TV due to interference…



FCC – DTV Broadcaster Requirements

Top 10 Markets

New York	Boston
Los Angeles	Washington
Chicago	Dallas/Ft Worth
Philadelphia	Detroit
San Francisco	Atlanta

30% US Households

Additional Top 30 Markets

Houston	San Diego
Seattle/Tacoma	Raleigh/Durham
Cleveland	Hartford/New Haven
Minneapolis/St. Paul	Orlando/Daytona
Miami/Ft Lauderdale	Charlotte
Phoenix	Baltimore
Tampa/St Petersburg	Portland
Denver	Cincinatti
Pittsburg	Indianapolis
St. Louis	Sacramento/Stockton

50% US Households

FCC – DTV Tuner Requirements

July 1, 2004 – 50% of large screen sets (36” and higher)
July 1, 2005 – all large sets and 50% of mid-size sets (25 – 36”)
March 1, 2006 – all mid size sets
March 1, 2007 – all new TV sets and other TV receivers

HDTV Consumer Adoption

1998

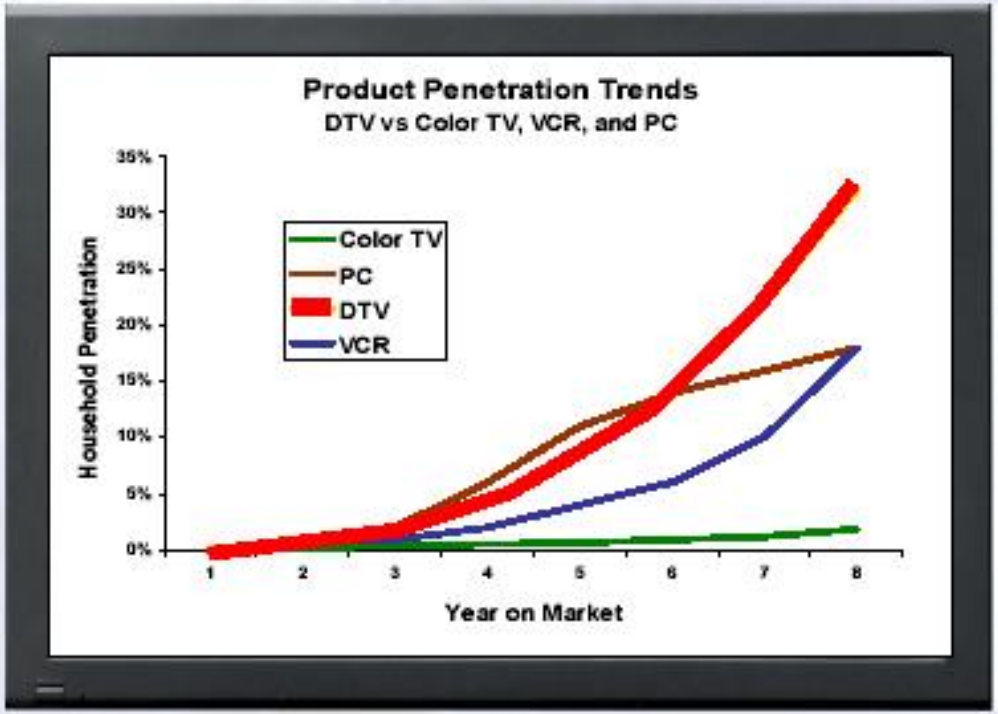
under $9,000

HIGH DEFINITION TELEVISION
HDTV
MONITOR

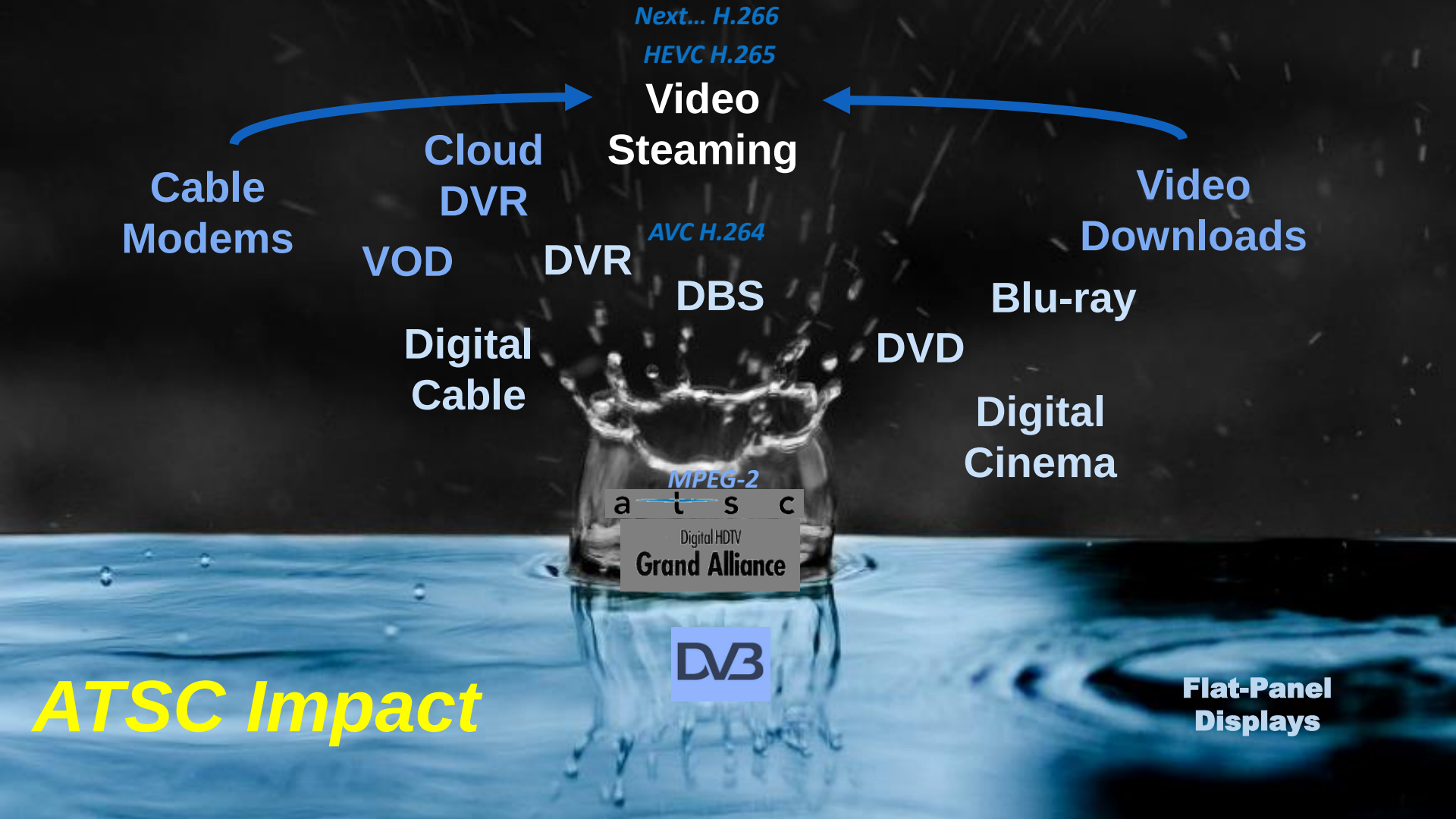
<<

DTV In Perspective

The DTV adoption rate surpasses that of the PC, the VCR and the Color TV.



- Government “Converter Box” coupon program
- June 2009 - Analog Broadcasts end


Next… H.266
HEVC H.265
Video
Steaming
Cable
Modems
Cloud
DVR
VOD
DVR
AVC H.264
DBS
Digital
Cable
Video
Downloads
Blu-ray
DVD
Digital
Cinema
MPEG-2
a t s c
Digital HDTV
Grand Alliance
DVB
ATSC Impact
Flat-Panel
Displays

Next-Gen Television

The "Modern" Digital World of the 21st Century

… Rapid Advances and Ongoing Disruptions …

Cable & DSL Modem
Up to 100 Mbps

WiFi 802.11ac 1300 Mbps

1999: 802.11b (11 Mbps)
2009: 802.11n (600 Mbps)
2013: 802.11ac (1300 Mbps)

HDTV Digital – Smart TVs
4k LED & OLED displays

4G Networks
12 Mbps

5G Networks
Coming Soon…

SmartPhones

2007: iPhone (4Gbytes)
2014: iPhone 6 (128 Gbytes)

Computer

Tablets

2010: iPad (16 Gbytes)
2014: iPad Air 2 (128 Gbytes)

Wearables

ATSC 3.0 Goals

- Modern “App” experience – personalization and interactivity
- Ultra High Definition (4k) resolution with High Dynamic Range
- Immersive Audio
- IP-based for interoperability with modern digital devices
- New flexibilities in data transmission capacity vs. robustness
  - Options for greatly improved indoor reception
  - On-channel repeaters (SFN)
  - Options for mobile/automotive reception
- Targeted advertising insertion
- Affordable receivers

ATSC 3.0 Effort Began in 2012

FCC Approved in 2017

ATSC 3.0 Technology Challenges

- Leveraging modern internet technologies and standards
- 4x more information in Ultra High Definition (4k) resolution
- 25% more information in High Dynamic Range video (10-bit vs. 8-bit)
- 4x more information in Immersive Audio (22.2 channel vs. 5.1 channel)
- Transmissions must be robust to survive interference from on-channel repeaters
- Mobile reception capabilities
- No additional spectrum
- No temporary spectrum
- Affordable receivers
- ~~Multiple systems proposed~~ Collaborative industry process

Broadcaster “App”

The TV Screen is a Web Page

ATSC 1.0

- Pictures, Graphics and Sound are “burned in”
- Same experience for entire audience

ATSC 3.0

- HTML5/Internet screen composition / graphics
- Hybrid delivery - merge broadcast & internet
- Dynamic Ad Insertion
- Personalized Graphics
- Interactivity
- Synchronized second-screen applications
- Personalized Audio - user control of tracks and mix
- Audience Measurement capabilities – audio watermark triggers

Picture and Sound

Better Pictures & Sound and/or More Services

ATSC 1.0

Standard Dynamic Range and Color
100-nit color grading, Rec. 709 color, 8 bits/pixel

- Allows HDTV & 1-2 SD multicast
- Dolby Digital (AC-3) 5.1 surround sound

ATSC 3.0

High Dynamic Range and Wide Color Gamut
1000-nit color grading, Rec. 2020 color, 10 bits/pixel

- >300% more capacity with HEVC video compression
- UltraHD and/or HD and/or SD multicast
  - 1 Ultra HD … 4 HD … flexible mix of HD and SD
  - High Dynamic Range
- Dolby AC-4 (ATMOS) Audio (Personalized …Immersive)

Ultra High Definition (4k) Means Sharper Pictures

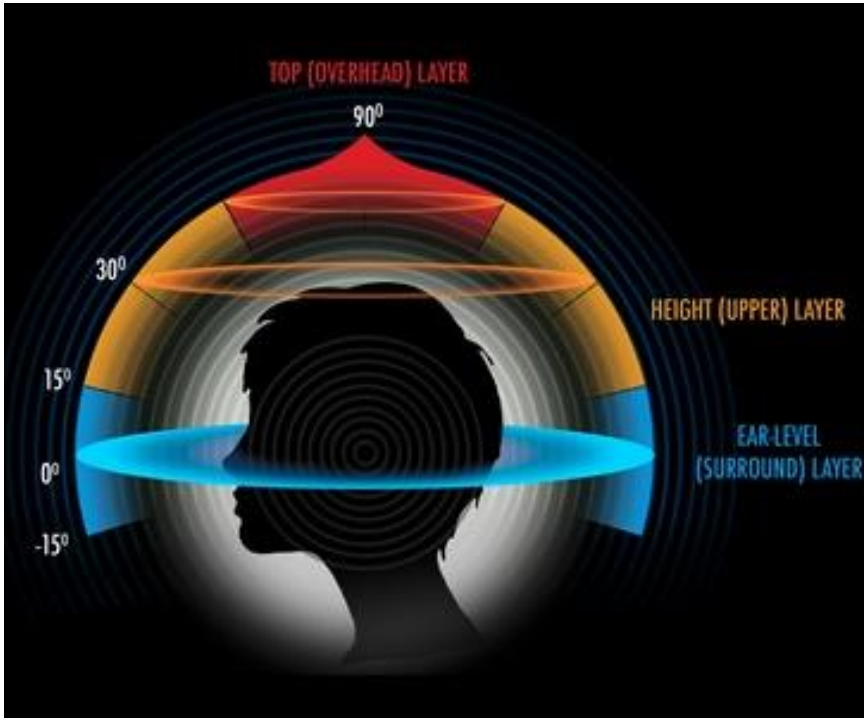
High Dynamic Range (HDR) and Wide Color Gamut (WCG)

Standard Dynamic Range

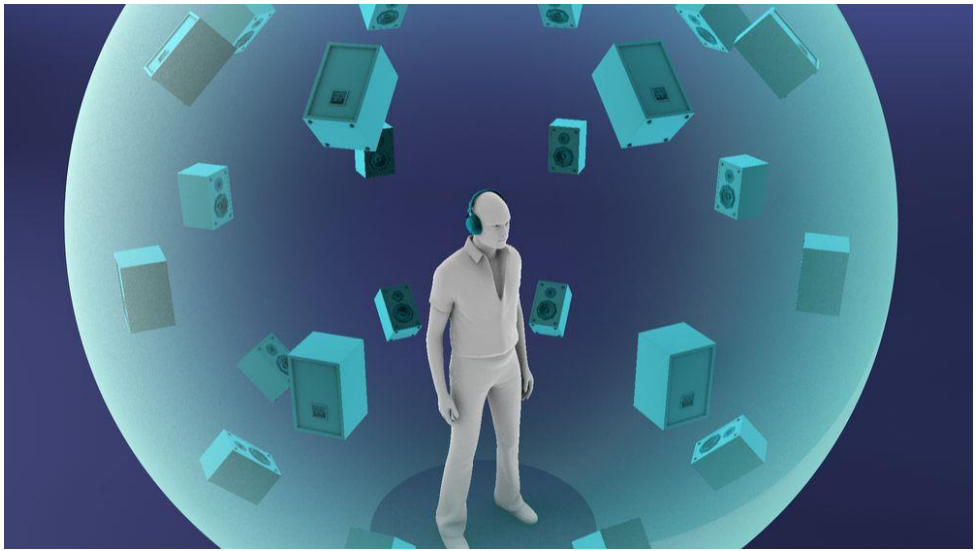
High Dynamic Range

Immersive Audio and Personalized Audio

…channels and/or objects from any location in space…



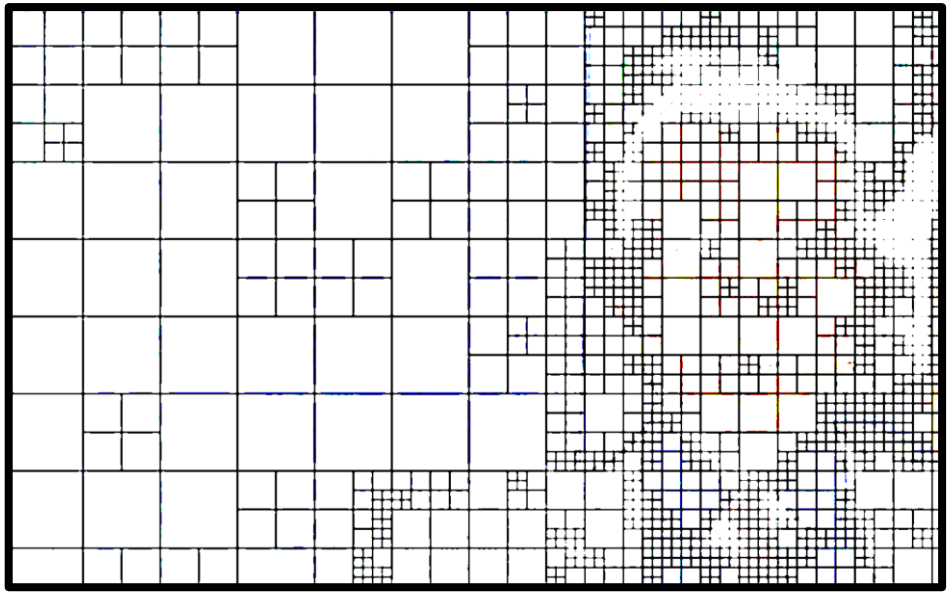
- Rendered for the speaker environment by the device

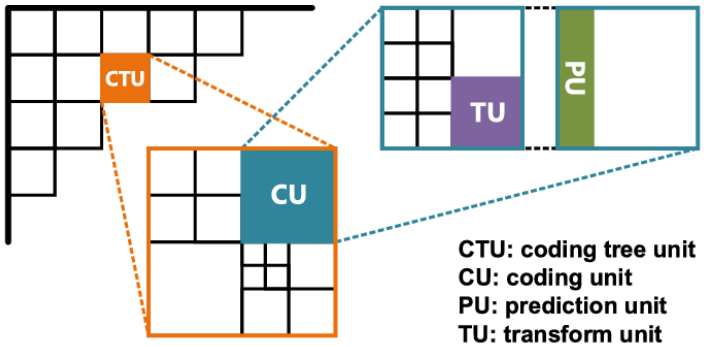


…listeners can personalize their experience … different announcers for a sporting event

ATSC 3.0 High Efficiency Video Compression Innovation

- Variable size “Prediction Units”
  - better and more efficient motion prediction
- Multiple Block sizes and structures
  - Coding Tree Units up to 64x64 with flexibly subdivided Coding Units
  - Coding Units have separate Prediction Units and Transform Units

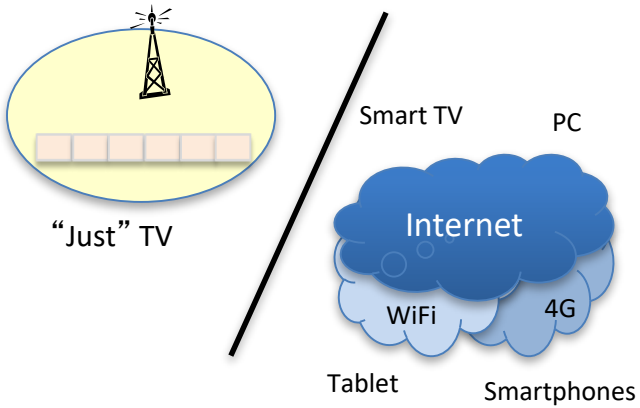




IP Data Format Innovation

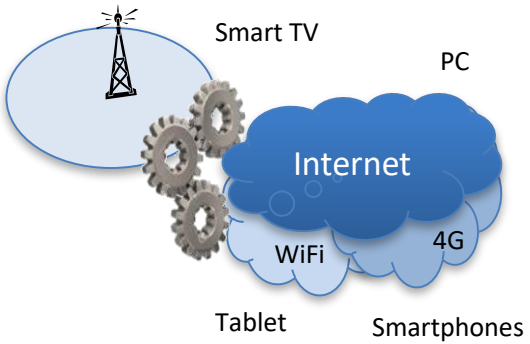
Broadcasting Becomes Part of the Internet

ATSC 1.0



- MPEG-2 Transport Stream provides service flexibility for multicasting
- But Broadcasting isn't part of the internet
- No simple way for broadcast content to reach new IP-connected consumer devices

ATSC 3.0

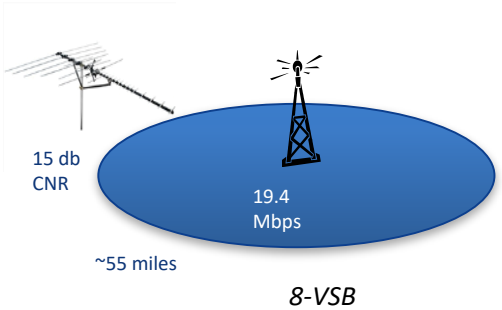


- Uses Internet Protocol - enable broadcasting to become PART OF the wireless internet
- Enables personalized and interactive content and targeted ads
- Easily retransmitted throughout home on WiFi
- With an ATSC 3.0 tuner, Broadcast IP streams complement 4G and WiFi
- **3.0 is a broadcast AND broadband standard**

Over-The-Air Transmission Innovation

More Bits To More Places

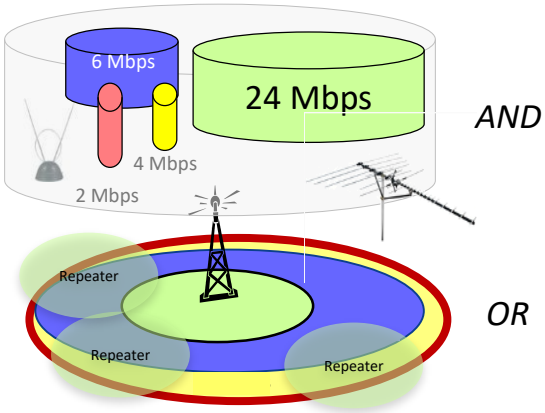
ATSC 1.0



8-VSB

- One bit rate – 19.39 Mbps
- One coverage area (rooftop antenna)
- Service flexibility – HDTV, multicast, data

ATSC 3.0

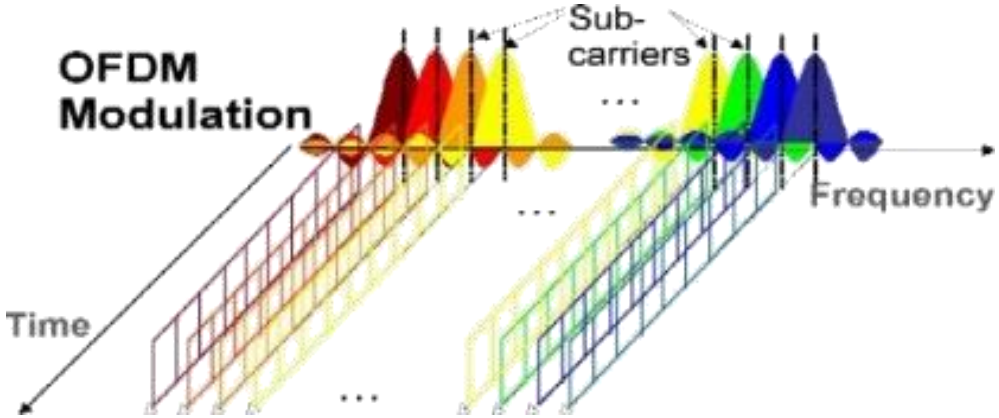


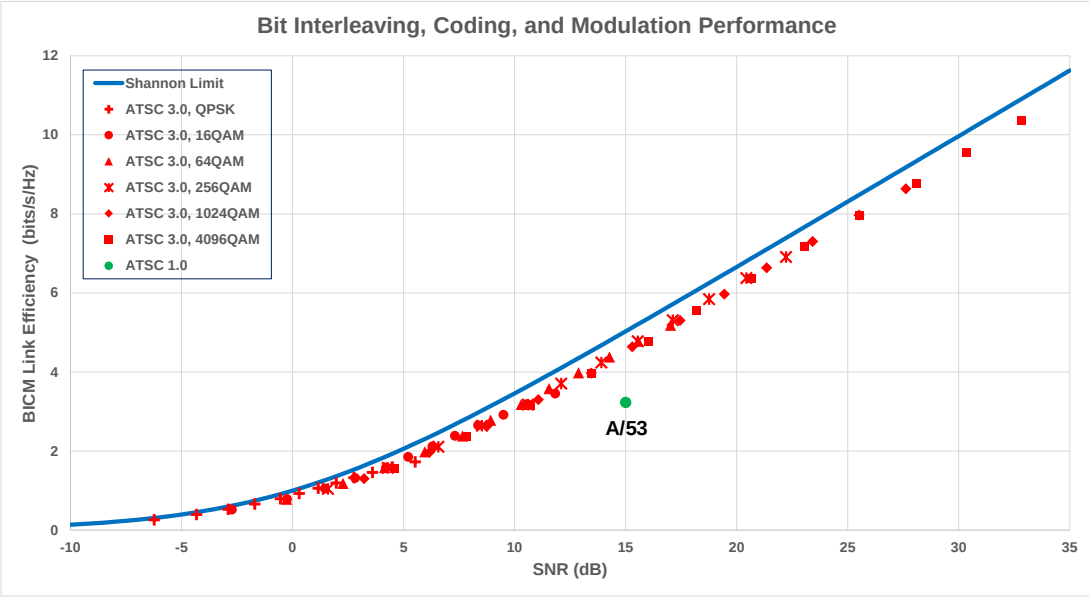
More Capacity, Greater Reach, New Services

- >20% more bits for the same coverage area
- Flexible bit rate & coverage area choices
  - More bits / less coverage … or
  - Fewer bits / more robust reception … or
  - Flexible mix in different parts of the signal
- Optional on-channel repeaters for robust indoor & mobile reception over entire DMA

OFDM Modulation

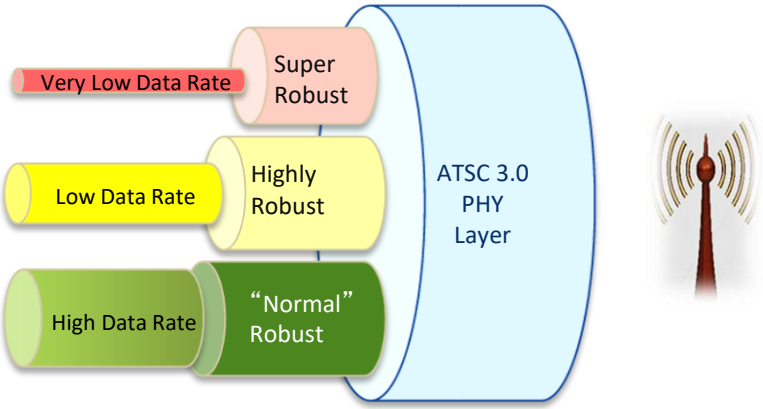
- ATSC 3.0 transmission uses OFDM (Orthogonal Frequency Division Multiplex) with 8k, 16k or 32k carriers
- A variable Guard Interval enables OFDM to operate with strong on-channel repeaters, which constructively add to signal strength
- Carriers can use QPSK, 16 QAM, 64 QAM, 256 QAM or 1026 QAM – providing a flexible choice of data rate / CNR noise threshold



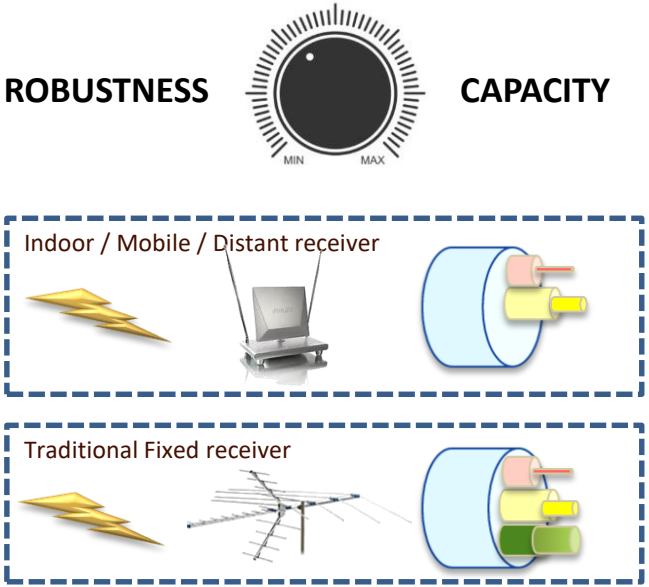


Physical Layer Pipes

- Physical Layer Pipe (PLP) is a set of OFDM carriers with the same modulation parameters
- ATSC 3.0 signal can be configured with up to 4 PLP “virtual channels”



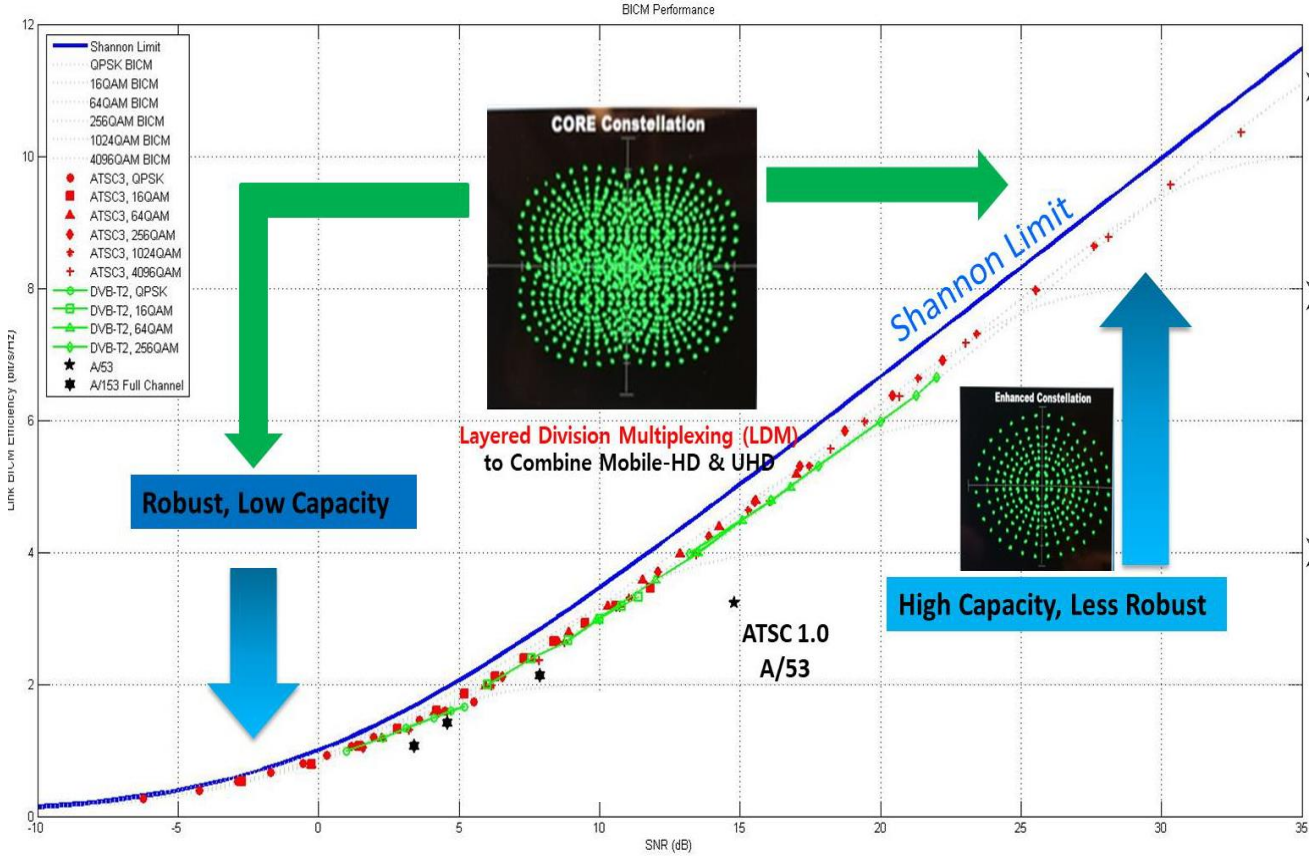
- Broadcasters can deliver different services at different bit rates and robustness levels within the same transmission



Signal can be configured for Various Services, Considering Geography, Terrain and Receivability Factors

Layer Division Multiplex

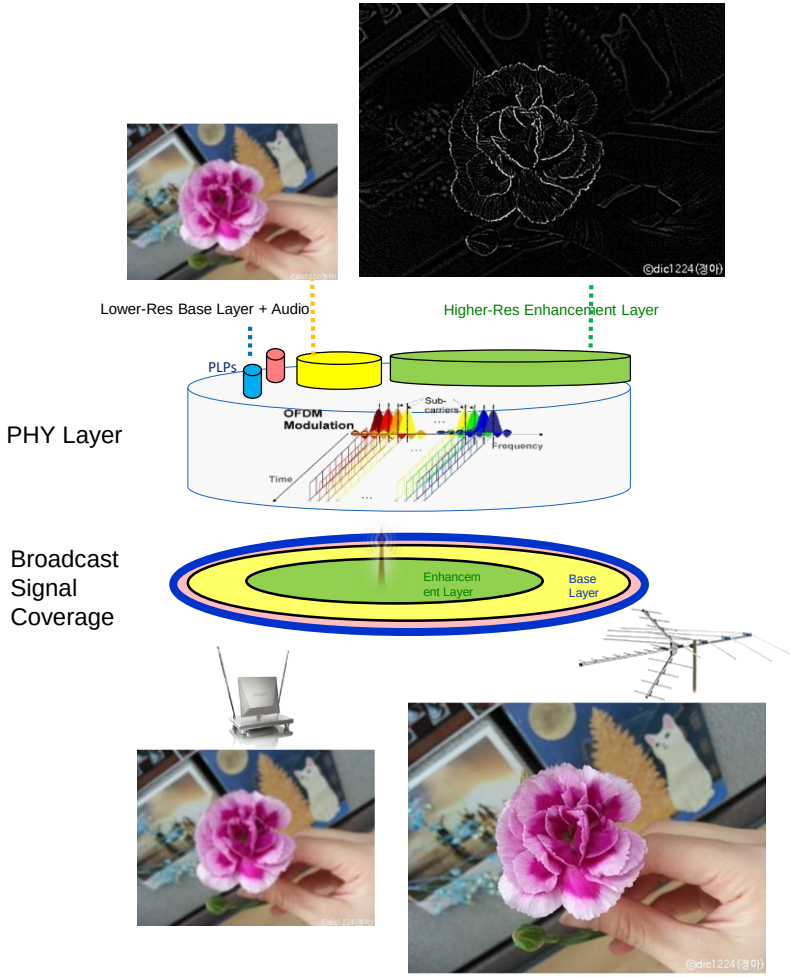
- Layer Division Multiplexing (LDM) superimposes two OFDM signals at different power levels
- The more robust signal is detected and subtracted out to obtain the less robust signal



Layered Service Configurations

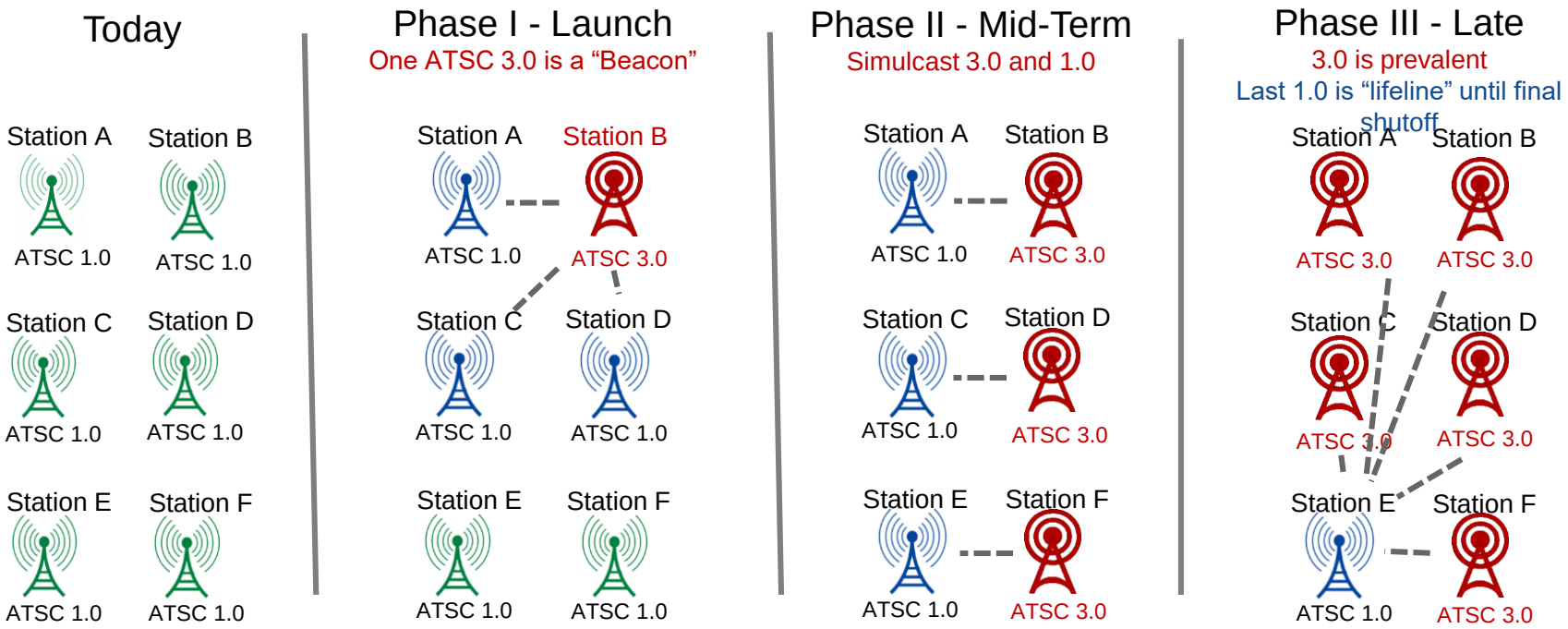
- SHVC “Spatial Scalability” compression
  - Lower-Resolution Base Layer (e.g., Standard-Def)
  - Higher-Resolution Enhancement Layer (e.g., High-Def)
- Requires less capacity than simply simulcasting multiple resolutions

Robust indoor / portable and mobile reception are new capabilities for Broadcasters



ATSC 3.0 Transition Plan – Voluntary Industry Transition

…create simulcast capacity for a transition by sharing channels…

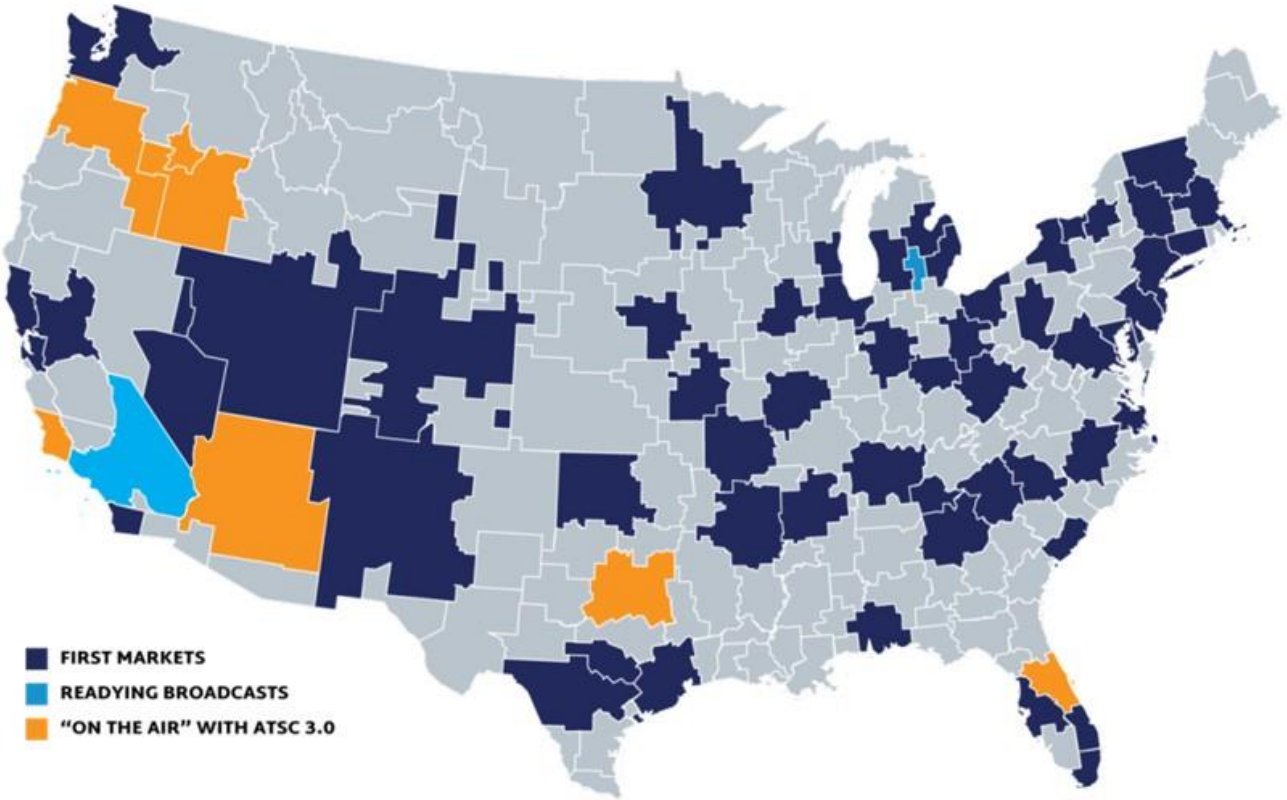


- ATSC 1.0 channel can be shared to create new capacity (at reduced quality)
- ATSC 3.0 channel can be shared as a "lighthouse"

NextGen TV Launch Status

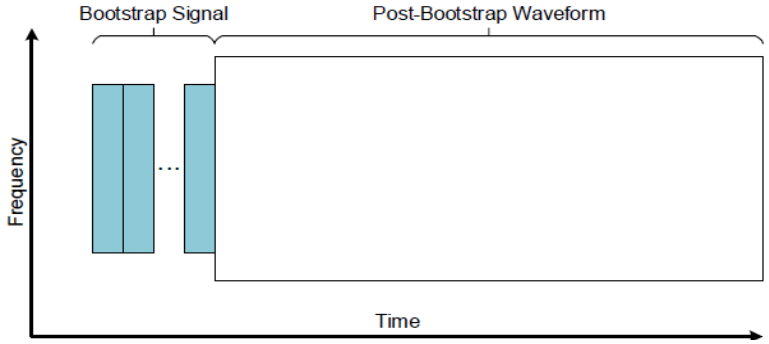
Nov. 2020

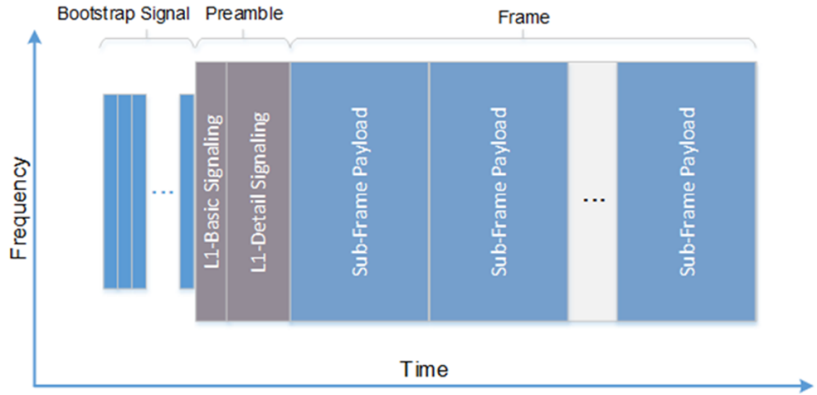
…60 television stations in 16 markets…



Bootstrap Signal

- Bootstrap for signal discovery and control signaling
  - extremely robust
  - synchronization symbol at start of each data frame
  - Indicates number of symbols in a variable-size time-slice of RF waveform
  - Data frames subdivided into subframes
  - daisy-chains across data frames
- 3.0 standard currently defines OFDM modulation
- Enables future use of currently undefined waveforms for in-place evolution of the RF channel





Future Predictions

NextGenTV … 20 Models Launching in 2020

Receiver Implementations Already Compact

at CES 2020

Set-top Box

NXP ATSC 3.0

TV Tuner

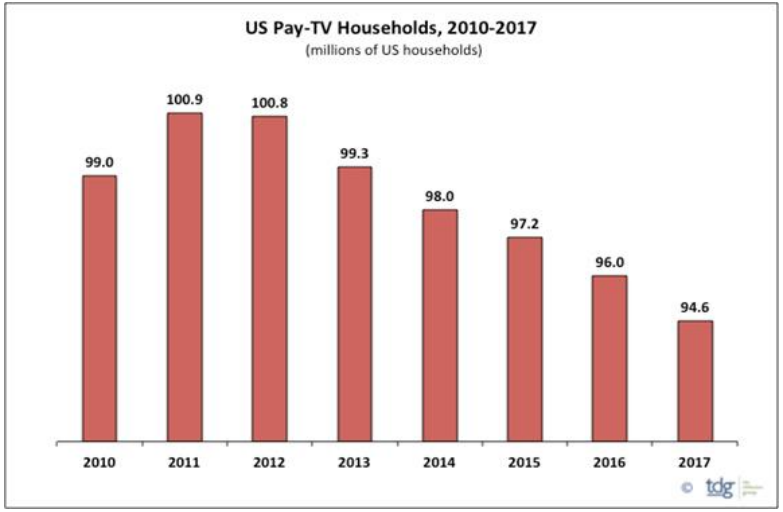
ATSC 3.0

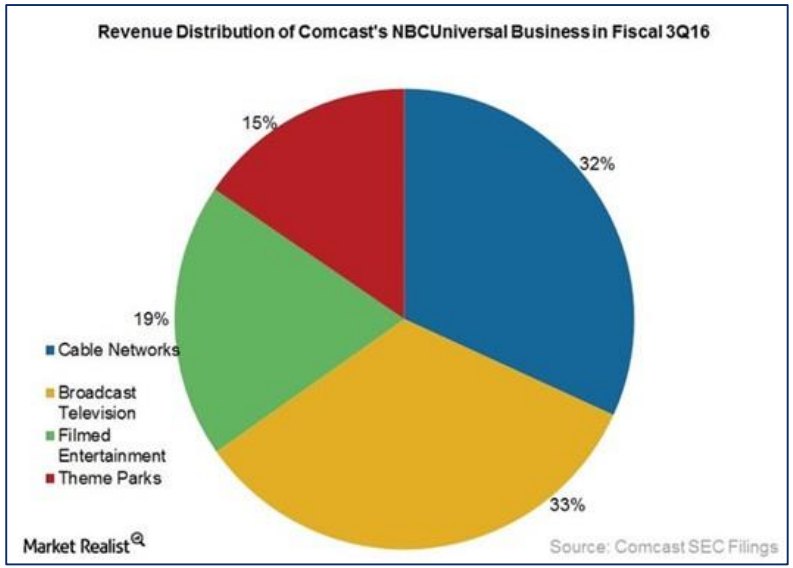
ATSC 3.0 Module

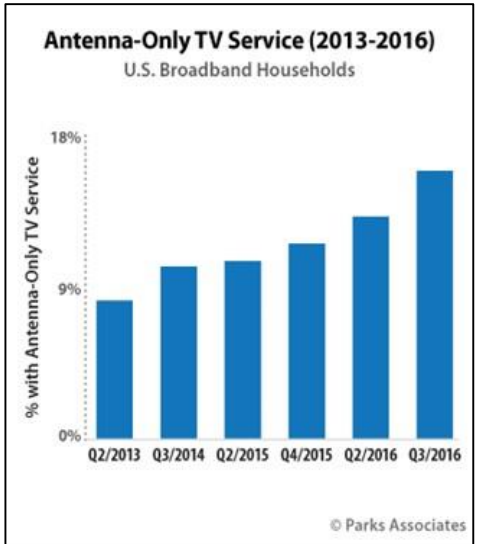
ATSC 3.0

Broadcasting is Alive and Well

- Pay TV households are shrinking
- Over 17M antenna-only households and growing
- Another 4-5M antenna TVs in pay-TV homes
- OTT + OTA is a growing combination
- Broadcast Networks reach virtually all households – highest reach for national advertisers







New Product Innovations – TV Gateways

- TV Home Gateway Concept
- WiFi Hub that can receive over-the-air (OTA) NextGen TV signals and redistribute to any smart device in the home via WiFi
- Facilitates OTA + OTT combination

NextGen TV is a Platform

Wrap Up

TV Standards – 80 Years of Progress

1941 Monochrome TV — **NTSC** — *Added sight to sound*

1953 Color TV — **NTSC Color** — *3x the picture information - compatibly*

1987 Color TV Stereo Sound — *2x the sound information - compatibly*

1996 HIGH DEFINITION TELEVISION HDTV — atsc ADVANCED TELEVISION SYSTEMS COMMITTEE — *Digital transmission, multiple programs 5x the picture info, 3x the sound info, in channels unsuitable for analog TV*

2020 NEXTGENTV — ATSC 3.0 — *Flexible digital transmission 5x the picture info, 4x the sound info, Multiple Services for different devices Modern App-based user experience*

More Information

- History of monochrome TV development
  - *The Great Television Race: A History of the American Television Industry, 1925-1941* (Udelson)
- History of color TV development
  - *And Part of Which I Was: Recollections of a Research Engineer* (Brown)
- History of digital HDTV development
  - *Defining Vision* (Brinkley)
  - *High Definition Television: The Creation, Development and Implementation of HDTV Technology* (Cianci)
  - https://www.glennreitmeier.tv/grand-alliance-hdtv-home
- Technical papers
  - Overview of Digital Television Worldwide, Proceedings of the IEEE, Jan 2006
  - Video Compression and Its Role in the History of Television, SMPTE Journal Aug 2016 (Reitmeier, Sullivan)
  - ATSC 3.0 Standards Usher in Next Gen TV Era, SMPTE Journal, July 2019 (Noland)
- Society of Motion Picture and Television Engineers virtual course
  - Understanding ATSC 3.0 - NextGen TV and the Future of Broadcasting (Reitmeier, Cugnini, Siegler)
    https://www.smpte.org/virtual-course/understanding-atsc-30-nextgen-tv-and-future-broadcasting

Thank You

Questions?