ATSC 8VSB Over-the-Air HDTV

IEEE June 27, 2006

Roy Trumbull – Broadcast Engineer – roy547@msn.com

Retired assistant chief engineer KRON-TV

Diagrams courtesy of www.atsc.org, www.opencable.com, www.zenith.com, www.motorola.com, www.terayon.com, www.trivenidigital.com

SMPTE - SF

- Meetings are at various venues
  - June meeting was at ILM
  - Majority of meetings are on the Peninsula
- SF website: members.aol.com/SMPTEsf
  - Anyone can sign up to our listserver for notification of posted meetings.
- National website: www.smpte.org

Information on the Web

www.atsc.org (Advanced Television Systems Committee)
click: News & Information or Standards
click: Papers

There are numerous downloadable pdf files at this site including:

"Status of Digital Cable Interoperability" – outlines problems and lists many reference documents

www.opencable.com (a Cablelabs site)

click: Documents

click: "Open Cable Overview" and PDF file
OC-SP-HOST-CFR-I11-021126

8VSB Seminars

- 1 Day Seminars
- Conducted by Gary Sgrignoli formerly with Zenith.
- For information: www.MSWdtv.com
- Gary.sgrignoli@IEEE.org

Stations on Air

Nationwide 1566 Stations are broadcasting DTV

San Francisco-Oakland-San Jose Stations

	NTSC	DTV		NTSC	DTV
KTVU	2	56	KICU	36	52
KRON	4	57	KCNS	38	39
KPIX	5	29	KBHK	44	45
KGO	7	24	KSTS	48	49
KQED	9	30	KKPX	65	41
KNTV	11	12	KTLN	68	47
KDTV	14	51			
KBWB	20	19			
KTSF	26	27			

Note Adjacent Channels

	DTV	Adj.		DTV	Adj.
KTVU	56	57 (DTV)	KICU	52	51 (DTV)
KRON	57	56 (DTV)	KCNS	39	38 (NTSC)
KPIX	29	30 (DTV)	KBHK	45	44 (NTSC)
KGO	24	25 (both)	KSTS	49	48 (NTSC)
KQED	30	29 (DTV)	KKPX	41	42 (NTSC)
KNTV	12	11 (NTSC)	KTLN	47	48 (NTSC)
KDTV	51	50 (NTSC)			
KBWB	19	20 (NTSC)			
KTSF	27	26 (NTSC)			

NTSC Ch 48 has DTV adj. above and below
DTV Ch 51 has NTSC Ch 50 below and DTV Ch 52 above

Taboo Channels

Under NTSC rules there were minimum distances before co-channels and adjacent channels could be assigned. Also relationships of 2, 3, 4, 5, 7, 8, 14, 15 channels removed (taboo channels) weren't permitted because of known frequency beats.

Adjacent channels weren't assigned in the same market and the taboo relationships resulted in many channels not being used at UHF. All that is just a memory.

To provide "loaner channels" for the DTV transition. Minimum spacing rules and taboo rules were made secondary to the need to provide channels. Some DTV assignments definitely interfere with NTSC co-channels.

Adjacent Channels Co-Located

Greatest harm is done when a strong taboo channel interferes with a weak desired channel

For this reason, the majority of the adjacent channel assignments were co-located.

Example: Adjacent channels at Sutro Tower

19 –20, 29-30, 38-39, 44-45, 56-57

Loaner Channels

- During transition to DTV, each NTSC station is loaned an additional channel
- At end of transition (2009), one channel is kept
- Channels above 51 go away
- DTV stations assigned above 51 will have to construct facilities twice

No Room For Each Station to Mount a New Antenna

Tower space at a premium

Room for antennas and transmission lines

Building Space Tight

Need to add second transmitter for DTV

Additional AC power capacity

Additional HVAC

Space needed for heat exchanges for water cooled transmitters

Solutions

Build a totally new shared facility for a group of stations

Example: DTV Utah

New Tower & New Building

Multiple stations share common antennas by using diplexers

Example: Sutro Tower

Four stacked panel antennas with two to three stations per antennas

Pattern has three overlapping lobes like a clover with the stem being a null toward the ocean

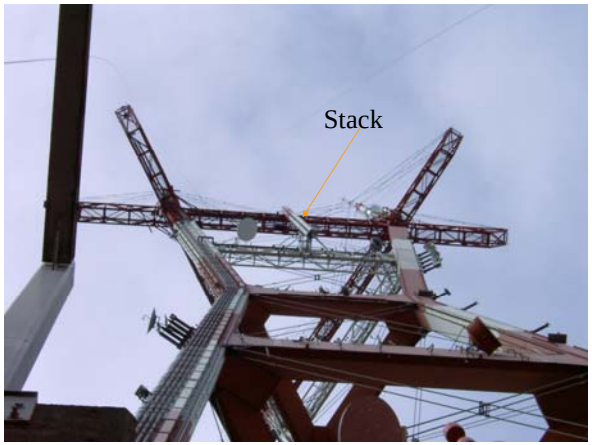
Hardware required

- High power lo pass filter at xmitter output
- Mask filter to control out of channel emissions
- Combiner with ports for each station using the antenna
- Switched dummy load for testing

Channel Skirts

- -47 DB below in-band average transmitted power at channel edge
- Using typical averaging function on spectrum analyzer this appears as -36 DB, 11 DB below theoretical average power
- Out of band emissions -110 DB >6 MHZ from channel edge

Sutro DTV Antenna Stack



DTV Stack

IOT Transmitters

Inductive Output Tubes

Cousins of Klystrons

Water Cooled - Actually Bug Juice Cooled - Industrial Grade Antifreeze (Dow & Union Carbide products)

Operating Voltage is 35KV at 1 to 2 amps

Mains voltage is 480 volts 3 phase

When transmitters become mismatched to the transmission line the damage requires replacing the transmission line.

VSWR detection is needed between the combiner and the transmission line.

IOT Mounted in Carriage

IOT Tuning

- Input cavity extremely critical. Best tuned using a network analyzer for centering and BW
- Input tuning impacts ability to do linear correction of flatness
- Output tuning is staggered with lower and upper half of channel tuned for flatness and minimum saddle at overlap
- Tuning of channel skirts is very soft

Cooling Pumps

Pass Through Receiver

To move an off-Air DTV to a cable channel without demodulating, the receiver must be a double conversion type (2 Ifs) to avoid unwanted beats. It should have a filter capable of removing adjacent channels without distorting the passband or adding phase distortion.

The conversion from IF to cable channel must be linear and not add distortions to the signal.

The output must be filtered to avoid having the signal interfere with adjacent channels.

NTSC Vs 8VSB

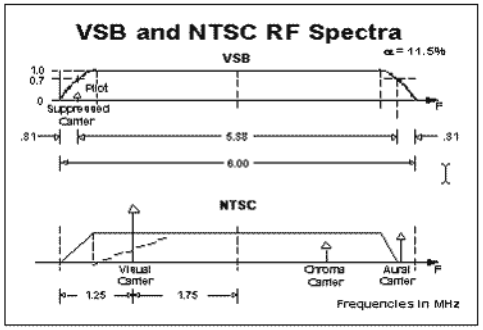


Figure 1

Factors Involved in 8VSB Design

Unfriendly Environment:

Received signal isn't constant - varies over time.
Multipath is a problem and may be dynamic in nature
Transmission path is subject to static, burst noise and to noise from intergalactic noise sources.

Transmission complexity must be confined to the transmit end so that a simple receiver with defined characteristics can be used

Data packets must be sent non sequentially and encoded with forward error correction so that the signal can be reconstructed if parts of it are missing.

The need to keep the over the air data robust limits the number of symbol levels to just 8 versus 32, 64, 128, and 256 for QAM via fiber.

S/N Budget

- Output to xmit antenna should be maintained at >27DB S/N using linear and non-linear correction
- Receiver needs >15.2 DB S/N to avoid cliff effect

NTSC Carriers

Three Carriers:

Visual – 1.25 MHz from channel bottom

(Bottom 1.25 MHz is a vestige of the lower sideband. From 1.25 MHz up is the upper sideband.)

Chroma – 3.58 MHz from Visual Carrier

-Roll off @ 4.2 MHz above Vis Carrier to allow for aural carrier

Aural – 4.5 MHz above Visual Carrier

NTSC Power

Visual Power:

Transmitter output power is measured into a water cooled dummy load with the transmitter modulated by a black signal with no burst on it.

TV uses negative modulation

Max power occurs when the video signal consists of sync only.

Calories of heat are measured by a calorimeter using water flow rate and temperature rise. Average power is computed.

Average power X 1.68 = peak power.

All FCC power values for NTSC TV stations are peak power.

Calorimeter

NTSC Power cont.

Visual power varies with average picture level

Aural Carrier is FM modulated so level never changes

Aural Power is the average power as measured by a calorimeter and is typically 10 – 20% of visual power.

8VSB Power

Spectrum is random without a repetitive signal like sync in NTSC

Power is measured on an average basis by connecting a thermocouple power meter to a transmission line sample port with a known loss (45 dB port loss + measured level = Av. power out)

Short duration peaks occur, 99.7% of the time they won't exceed the average power by more than 6.3 dB.

In power, every 3dB represents a doubling of power

If 10 kW average transmitter output is required, the transmitter must be linear enough to pass a 40 kW peak without distortion

Driver and IOT

- Ratings much be conservative to provide headroom and avoid non-linear operation
- Common problem is trying to get by without sufficient reserve in driver
- Running driver near edge requires changing corrections as driver distortion will vary with ambient temp

HP Power Meter

8VSB Spectrum

No signal carriers

Centered in channel

Rolloff slopes 618.881 kHz from channel bottom and channel top

.3dB Pilot Carrier 309.411 kHz above lower channel edge

3 dB Nyquist bandwidth of 5.381119 MHz

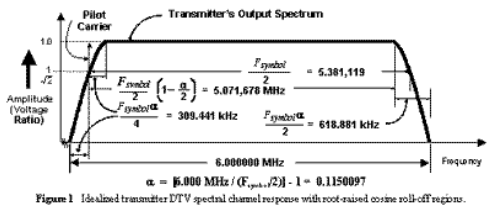


Figure 1 Idealized transmitter DTV spectral channel response with root-raised cosine roll-off regions.

Channel Spectrum

Channel spectrum looks like a haystack unless averaging is used on a spectrum analyzer

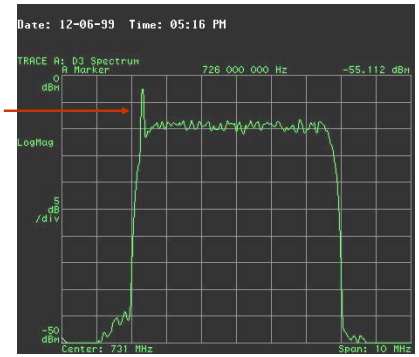
With averaging it looks similar to the diagram with skirts of 36 dB or greater at the channel edges (If there's no adjacent channel)

Due to gain bandwidth distortions when using short spans on a spectrum analyzer (such as 10 MHz) the pilot amplitude will be greatly exaggerated.

HP Vector Signal Analyzer

Spectrum using Analyzer averaging function

Pilot is actually much lower. It appears large because of resolution bandwidth of Spectrum Analyzer. Using a greater span causes it to appear smaller



Dirty Little Secrets

All digital TV (cable too) is actually analog.

Digital information is encoded as a vector with a certain magnitude and a certain angle.

Errors occur due to non-linear effects that produce magnitude and phase errors.

All digital TV transmissions must model the buffer in the receiver to avoid buffer underflow or overflow. Null packets are sent to avoid underflow

Binary Numbers & Symbols

- A bit is a 0 or 1
- Two adjacent bits result in 4 states: 00, 01, 10, 11 that can be represented by 4 analog voltage levels
- Adding an additional bit for error correction and concealment makes 8 levels 000, 001, 010, 011, 100, 101, 110, 111

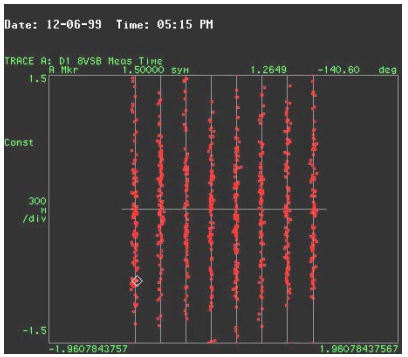
8 Voltages and their Binary Values

- 8 octal numbers are represented by the following voltages:

• 000	-7	100	+1
• 001	-5	101	+3
• 010	-3	110	+5
• 011	-1	111	+7

DTV Constellation

0 1 2 3 4 5 6 7



000 = 0
001 = 1
010 = 2
011 = 3
100 = 4
101 = 5
110 = 6
111 = 7

-7 -5 -3 -1 1 3 5 7

Q Values

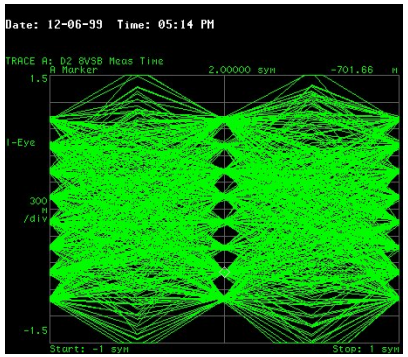
The I (in-phase) values are set at +/- 1, 3, 5, 7

Why do the Q (quadrature) values vary?

The Q values are used to shape the channel edges to make them drop off sharply.

Observed spectrum edges are at least 36 dB down and may be > 40 dB. The actual FCC spec is tighter but it is defined in such a way that it can't be measured using a practical instrument.

Eye Pattern



7
5
3
1
-1
-3
-5
-7

8VSB Symbols

Channel 3 dB bandwidth: 5.381119 MHz

A sine wave of that frequency would have double that many half cycles.

That's the limit of how many symbols can be sent

Symbol rate = 5.381119 X 2 = 10.762238 MSym/sec

Each symbol represents a 3 bit number

Bits/sec = 10.762238 X 3 = 32.286714 MBits/sec

Payload net of overhead = 28.9 MBits/sec

Payload, net of error correction = 2/3 X 28.9 = 19.267 MHz

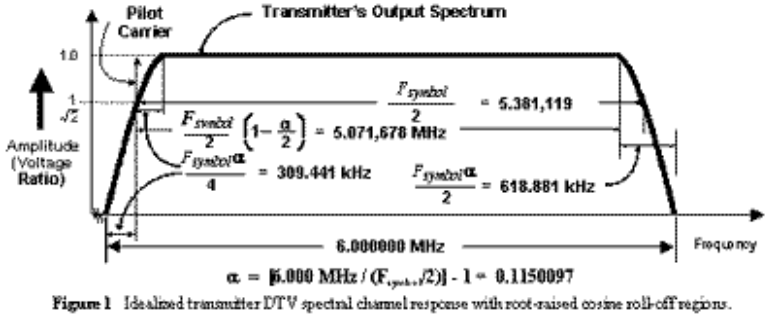


Figure 1 Idealized transmitter DTV spectral channel response with root-raised cosine roll-off regions.

8VSB Features

Data is randomized

Reed-Solomon coding added to protect from burst noise

Data is interleaved (spread out) to avoid errors from impulse noise

Trellis coding – randomizes data to produce a flat spectrum

Root raised cosine filtering (avoids having ringing from prior symbols interfere with the current symbol)

Equalizer training signal – 511 symbols of pseudo-random data

Types of Data Packets

Some data packets define what is contained in the transport stream, carry clock information, EAS messages, Closed Captioning, etc. PID, PCR, PAT, PMT

Video packets for HD or multiple SD channels

Associated Audio packets

PSIP – Program and System Information Protocol

- Defines relationship of DTV channel to ATV channel
- Program guide for all programs carried in signal
- Text and other data

DATA Broadcasting – replaces null packets with data such as news, internet pages, messaging etc.

Signal Transport

Uncompressed HD occupies 600 MHZ BW

Progressive scan is 2X

Mezzanine compressions fits HD into DS3 channel BW (45 MB/S)

Blown back up, it can be switched with local HD before ATSC encoding

Insert commercials, add ID bugs etc.

Mezz vs ATSC

- NHK provided free HD pool feed of 2000 political conventions
- We used mezz feed done for participating($) stations – looked OK
- PBS did ATSC encoding at site and uplinked – It was much better

Local Xport

- Analog SD video and audio flat rate of $1.5K/mo anywhere in local area
- DS3 – 4 miles to Sutro $6K/mo on contract
- PUC sets price based on number of POTS circuits 45 MHZ can carry

HD Channel Usage

1 HD broadcast channel using 19.39 MHz + datacasting using available null packets

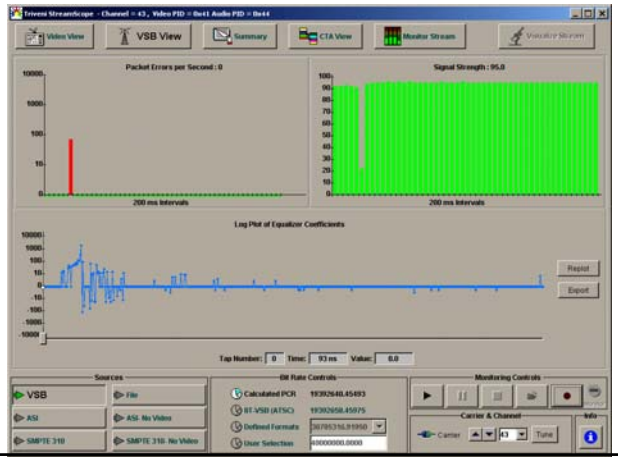
1 HD Broadcast channel with a bandwidth of 11 to 15 MHz + 1 SD channel => 3.5 MHz bandwidth + datacasting using available null packets

5 to 6 SD broadcast channels using a statmux to allocate bandwidth dynamically + datacasting using available null packets

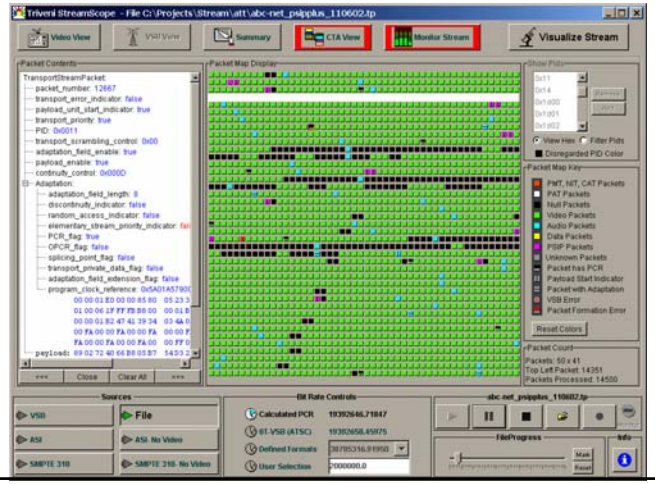
FCC requires that one channel be open but permits the others to be conditional access

See www.atsc.org Standard A70 for Conditional Access details

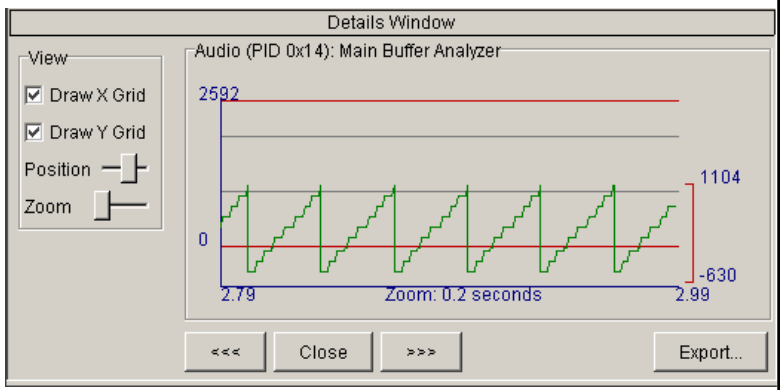
Off Air Signal Check using Triveni Streamscope (Courtesy Triveni Digital)



Packet Content – per Triveni



Audio Buffer per Triveni



Transmitter Block Diagram

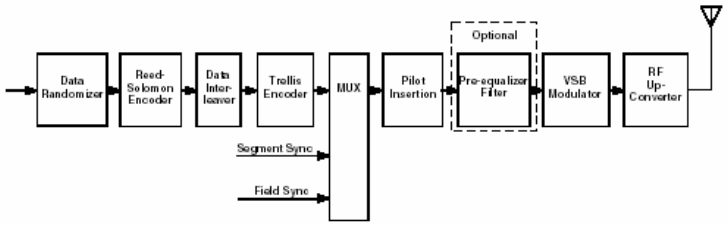


Figure D1 VSB transmitter.

Zenith 8VSB Exciter

MPEG Packets / Data Segments

Standard MPEG transport packet = 187 bytes

Add 20 bytes of Reed Solomon parity code = 207 bytes

207 bytes X 8 = 1656 bits

Trellis coding – For every 2 bits of data a third bit is added for error correction

1656 bits X 3/2 = 2484 bits

1 8VSB symbol = 3 bits

2484 bits / 3 = 828 symbols

1 8VSB data segment = 828 symbols + 4 symbols of segment sync = 832 symbols per segment

Segment Diagram

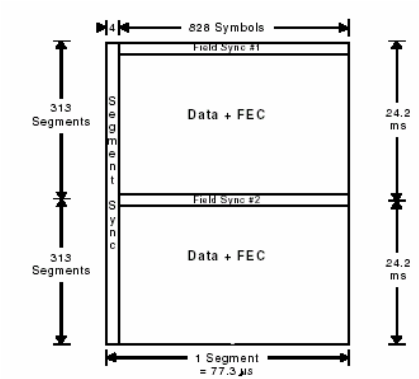


Figure D2 VSB data frame.

Data Frames

2 data fields = 1 data frame

313 segments = 1 data field

626 segments = 1 data frame

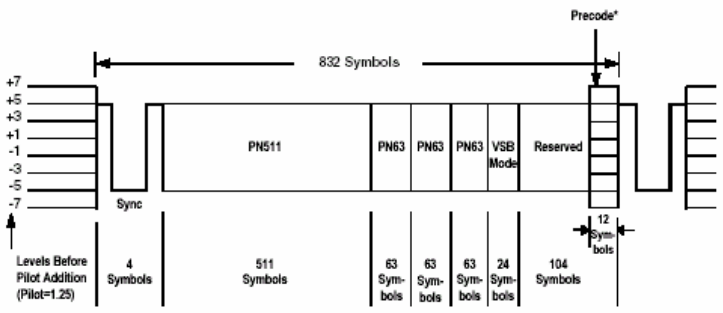
First segment in each data field carries field sync information and the 511 symbol training signal used by the receiver equalizer

10,766,080 symbols/ sec // 832 symbols/segment =

12940 segments/ sec

12940 segments/sec // 626 segments/frame = 20.67 frames / sec

Field Sync



* For trellis coded terrestrial 8 VSB the last 12 symbols of the previous segment are duplicated in the last 12 reserved symbols of the field sync.

Figure D10 VSB data field sync.

PSIP Problems

PSIP – Program and System Information Protocol

Channel on cable won't be the same as over the air channel

> Information re DTV and ATV channel #s will have to be corrected to conform to cable channel #s.

Cable system may convey PSIP information using an out of band channel for data (OOB). PSIP information will have to be decoded and muxed into that stream.

HD Pass-thru

Table A3 Compression Format Constraints

vertical_size_value	horizontal_size_value	aspect_ratio_information	frame_rate_code	progressive_sequence
1080[2]	1920	1,3	1,2,4,5	1
			4,5	0
720	1280	1,3	1,2,4,5,7,8	1
			1,2,4,5,7,8	1
480	704	2,3	4,5	0
	640	1,2	1,2,4,5,7,8	1
			4,5	0

Legend for MPEG-2 coded values:
aspect_ratio_information: 1 = square samples, 2 = 4:3 display aspect ratio, 3 = 16:9 display aspect ratio
frame_rate_code: 1 = 23.976 Hz, 2 = 24 Hz, 4 = 29.97 Hz, 5 = 30 Hz, 7 = 59.94 Hz, 8 = 60 Hz
progressive_sequence: 0 = interlaced scan, 1 = progressive scan

Interlace & Progressive Scan

Interlace – Every other line in the picture is scanned. TV Field 1 - (1,3,5,7…) then the lines in between are scanned for TV Field 2 (2,4,6,8…) Actually field 1 ends in the middle of a line and field 2 starts in the middle of a line

Progressive – All the lines are scanned in sequence

Interlace advantage – Less bandwidth is required to send half of the information and then the other half. Motion information is updated in each field.

Progressive advantage – Picture appears sharper because there are no interlace errors in the picture but the frame rate must be as high as the field rate in interlace (approx 60 frames/sec)

3:2 Pull down

Film runs at 24 frames/sec and video at 30 frames/sec

In conventional TV, a special projector called a telecine is used. It alternates between holding film frames for 3 TV fields or 2 TV fields. After 24 frames of film, 60 TV fields or 30 frames have been televised.

3 X 12 frames + 2 X 12 frames = 36 + 24 = 60 TV fields = 30 F

This creates a jerky motion distortion known as “judder”

In DTV, 24 frame film can be broadcast directly and displayed. No need to use a telecine projector. 24 frames is one of the normal DTV modes and 24 frame video cameras and recorders are being used to make TV shows and movies.

EAS

OC-SP-HOST-CFR-I11-021126

7.2.7 Digital Television (DTV) Emergency Alert Service (EAS)

The OpenCable Host Device processes emergency messages that utilize the EAS message syntax, which is compatible with MPEG-2 transport and is defined in [21]. For in-band transmission, it appears in the transport packet with the same PID as those used for Service/System Information (SI). The table ID for the EAS message is 0xD8 as defined in [21]. For out-of-band (OOB) transmission, the EAS message is transmitted according to [21].

Acquiring the Signal

Known reception problems:

Strong reflections may cause multiple notches and distortions in the signal that render it unusable

When a ghost is cleaner that the direct signal, the direct signal will appear as a leading ghost to the receiver. Early receivers had a limited window for accommodating leading ghosts.

Dynamic multipath distortion may prevent the receiver from locking to the signal. Training signal inadequate for short duration interference and interference with phase rotation.

Receivers near a transmitter site may need a 6 – 10 dB pad in the antenna lead to prevent overload. Overload can be from other nearby signals saturating the receiver front end.

Strategic Errors

- Broadcasters are the only ones required to use 8VSB
  - No impact on cable or DBS
  - After Feb 17, 2009 broadcast NTSC ceases only for over-the-air broadcasts
- No upgrade path to newer coding schemes
  - NTSC lasted > 50 years
  - MPEG 2 – 5 years, 10 years?

COFDM

Ideal for cell type scheme using many low powered repeaters as done in Europe

Not good for the US single central site scheme due to power required for comparable coverage

- Interference during transition phase would have been excessive.
- Would have worked if we had kissed off the single site transmitter scheme and paid some broadcasters to just go away

Channel BW

- In Europe 8 mhz broadcast channels permit enough COFDM carriers to make it advantageous.
- Number of carriers possible in a U.S. 6 mhz channel make COFDM a wash with 8VSB

A failed scheme goes on

- Broadcasting from one central point is a failed delivery scheme
- Cable + DBS penetration is 85% of households
- No requirement for cable to carry anything but "free" unconditional access channel
- Research and testing has been done on single frequency networks but I doubt many will be realized.

USDTV

- Cable that isn't cable
  - In markets with no significant terrain problems such as Las Vegas, Salt Lake City, Fresno, Albuquerque etc. multiple encoded SD channels are used to create a cable-like system
  - 4 or 5 stations provide 4 channels carrying popular cable programs plus 1 providing their main program to USDTV
  - DTV receiver with decoder is provided at a discount to local basic cable monthly fee

Future Trends

- A great deal of money is no longer on the table for broadcasters.
- Alternate forms of delivery including non-realtime will drain the best demographic segments as they give up on TV viewing
- As 20 years ago the studios realized more money selling movie tapes than they did from theatrical releases so it soon may be with popular TV programs.

Cable Off-Air HD Receivers

Scientific Atlanta SA 6237 Freq Agile 8VSB Receiver

Receives off-air 8VSB Ch 2 - 69

Outputs: SMPTE 310M

DVD-SPI LVDS

(Mpeg-2 synchronous parallel interface)

DVB-ASI (asynchronous serial interface)

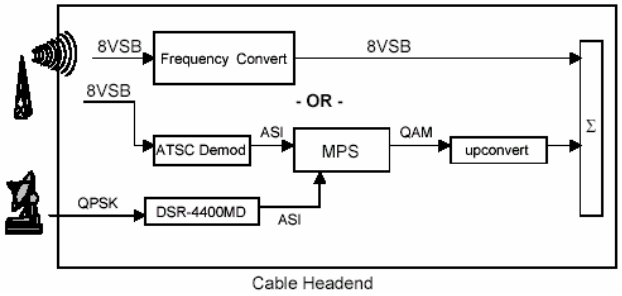
10 MHz reference for DVB-ASI

www.motorola.com

Click Cable Operators then white papers

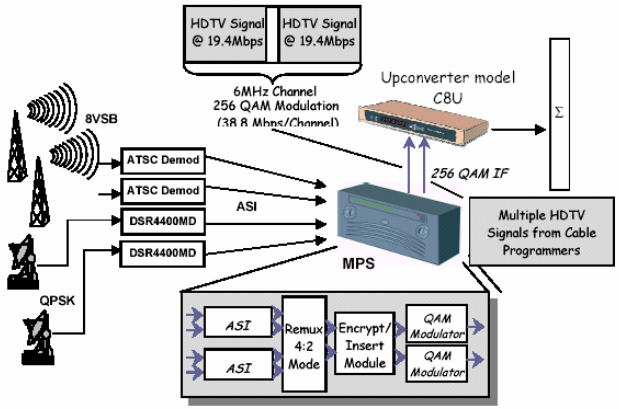
Download: "High-Definition Television Over Cable"

Download: "Acronyms"

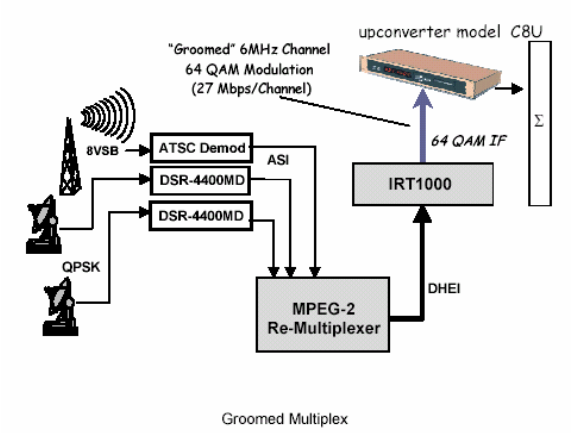


Cable Headend

Motorola cont.



Motorola cont. 2



Groomed Multiplex

Terayon Cherrypicker

Selects and modifies MPEG 2 transport streams

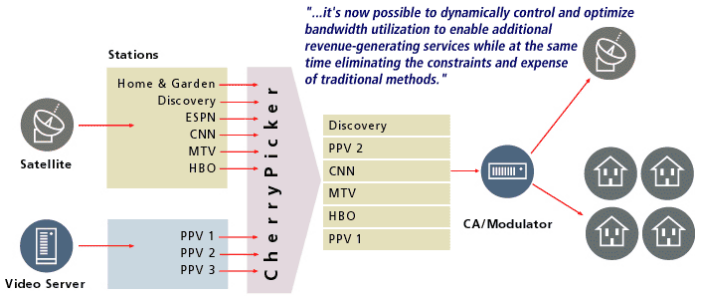
Terayon cont.

REMULTIPLEXING FUNCTIONS	
Static and Dynamic Grooming:	
PID filtering and re-mapping	•
PCR de-jittering and re-stamping	•
PAT and PMT computation and insertion	•
SI and PSI processing	•
ATSC (PSIP) Aggregation	License
Statistical Remultiplexing	
CBR to VBR conversion	•
VBR to CBR conversion	•
Bit rate conversion CBR to CBR, VBR to VBR	•
HD rate shaping	License

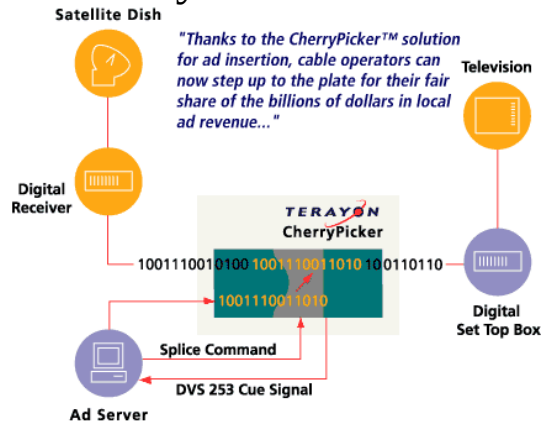
Terayon cont 2

INPUTS/OUTPUTS	
Number of inputs	16 max.
Number of outputs	4 max.
Number of video streams rate shaped	SD - 64 max.
(4:1 ratio SD:HD)	HD - 16 max.
Interface formats	DVB-ASI, DHEI
Data coding	MPEG-2 (DVB, DCII, ATSC) SPTS, MPTS, or A-MTS
Video formats	MP@ML, all resolutions (SDTV) MP@HL (HDTV)
Frame Rate	25, 29.97, 30, 59.94, 60 Hz 3:2 pulldown (FILM)
Aspect Ratio	4:3 and 16:9
Audio formats	AC-3 (Dolby Digital) and Musicam (MPEG-1 Layer 1 and 2)
Data rate	
Input	200 Mbps per ASI port
Aggregate Output	Up to 160 Mbps
Bitrates of individual programs	0.2 to 20 Mbps, CBR or VBR

Terayon Grooming



Terayon Ad Insertion



OpenCable Receiver

Consumer set contains set-top box digital functions in a Terminal Host Device. Will probably be bi-directional

DOCSIS Modem is built into the receiver

Conditional Access card from cable company defines what can be viewed from cable

HD signals are output on a IEEE-1394 connection to an HD recorder. (Firewire is Apple ™ ilink is Sony ™)

IEEE-1394 rate is 400 Mbits/sec with 1.2gigabits proposed

Consumer HD Receivers

$10 to $14 per pound for flat screen 34" CRT Sets. Sets lack IEEE 1394 interface and OpenCable electronics with conditional access card

Panasonic CT34WX52	172 lb
Toshiba 34HHX82	176 lb
Philips 34PW9818	176.5 lb
Sony KV34XBR800	201 lb

Anticipated Sea Change

Standard Definition Digital Cable and DBS are somewhat better than VHS tape in picture quality

Okay for small CRTs but really soft on a big screen. Portions of image breaking up into checkerboards will be more visible.

The difference between an HD broadcast and compressed SD will be pronounced.

Not a problem as long as there are few HD viewers

But, Consumer Electronics wants to make big bucks from HD whether or not Broadcasters, Cable, or DBS do anything

Merry Xmas - Blue-Ray Disc

Blue-violet laser DVD
27 gigabytes of payload in a single layer
2 hrs HD playing time & 13 hrs SD playing time
The Usual Suspects:
Hitachi, LG Electronics, Matsushita Electric Industrial Co., Pioneer, Royal Philips Electronics, Samsung Electronics, Sharp Corporation, Sony Corporation and Thomson Multimedia.
Coming to the stores by 2003 holiday season
Coming in the future: multilayer 1 terabyte discs

Thank You