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Advanced Digital Television

Project Overview for TCE

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David Sarnoff Research Center
High-Definition Imaging and Computing
Princeton, N.J.

Outline

- Strategy and Technical Introduction
- Digital RF Transmission
- Data Compression
- System Considerations
- Summary and Discussion

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Strategy

Political Situation in the U.S.

- The FCC has advocated a simulcast approach for HDTV, in a single 6 MHz channel
- The FCC will make no decision on EDTV until it has a decision on HDTV
- It is highly desirable for every broadcaster to be able to obtain a simulcast HDTV channel
- There are now three proponents of all-digital HDTV
  - ATRC
  - Zenith/AT&T
  - General Instruments

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Why Should HDTV Be Digital?

- **The HDTV standard should last for *50 years!***
  - preserve consumer investment
  - new adoption curves are costly to the industry

- **In the long term, digital compression will achieve higher picture quality than analog systems of the same bandwidth**
  - digital encoding has the flexibility of computing
  - encoding will ride the computing technology curve)

- **Reduced transmission impairments**
  - low noise is just as important as resolution

- **Natural use of encryption (i.e., pay-per-view)**

Why Should HDTV Be Digital? (cont'd)

- Overall technology infrastructure will be digital
  - recording (VCRs and discs)
  - communications (teleconferencing)
  - IC's (TV receivers etc.)

- Non-entertainment applications of "High-Resolution Video" will accelerate technology development and lower costs
  - Computing ("Convergence of Video and Computing")
  - Defense
  - Space
  - Medical

- Broadcasting and Consumer Electronics may be best served by leveraging the digital infrastructure

Technical Challenges

- Design a digital transmission system for terrestrial broadcast that can co-exist with existing NTSC
- Design a digital transmission system with adequate capacity, robustness, and coverage area for HDTV
- Design a digital transmission system that can send nearly 30 Mbps in a 6 MHz terrestrial broadcast channel (in order to achieve outstanding picture quality)
- Design a data compression system that achieves outstanding quality at less than 0.5 bits/pixel
- And, of course, we must meet the FCC timetable with an "acceptable" demonstration

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Digital RF Transmission

Terrestrial Broadcast Problems

- Terrestrial channel is *very* challenging one
  - 20-30 db signal variation (FEC gains 4-5 db)
  - Noise is not stationary (impulse, etc.)
  - Co-channel interference
  - Need to minimize interference with NTSC channels

- Limited coverage and image "drop outs"

- Additional considerations
  - Combined source/channel coding (5-15 db)
  - Cellular approaches
  - VBI

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Allocation Problems

- In order for every broadcaster to obtain a simulcast channel, co-channel spacing must be greatly reduced
  - this may not be feasible, but...
  - FCC has been advised that it will work

- Digital simulcast signals must not degrade reception of NTSC stations, therefore they must be lower power

- This means that the existing NTSC is a high-power interference to the digital simulcast channel

- There are complex tradeoffs to be made among:
  - Power
  - Coverage area
  - Modulation technique
  - Interference characteristics
  - Data rate
  - Bit error rate and characteristics
  - Receiver complexity and cost

Techno-Political Issues

- **Will the FCC change their "mode of operation"?**
  - will they relax the current blanket rules and allow local solutions?
  - will they consider cellular approaches?

- **Is it *really* necessary to provide every current broadcaster with an HDTV channel?**
  - the biggest problem is the few top markets
  - e.g., Los Angeles currently has 25 channels

- **It appears possible to double the number of channels received by half of the U.S. population**
  - they receive less than 10 of the 68 channels

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Some Possible Solutions

- By relaxing one taboo rule, every household in the U.S. could theoretically receive 28 channels
- Is reduced HDTV broadcast coverage supplemented by cable a solution for the top markets?
- Directional antennas and fill-in slave stations are tools to achieve local solutions for broadcast

RF Transmission Options

- Quadrature Amplitude Modulation
(16 QAM for 20 Mbps and 64 QAM for 30 Mbps
  - inexpensive hardware
  - susceptible to multipath distortion
  - multipath can be corrected by ghost-cancellation
  - current Sarnoff effort

- Multiple carrier techniques (OFDM)
  - sophisticated technique
  - more expensive hardware
  - current LER-Rennes effort

- Continuous Phase Modulation
  - robust
  - low channel efficiency (data rate)
  - current Briarcliff/RPI effort

ATRC RF Transmission Effort

- Both Twin-QAM (Sarnoff) and OFDM (LER) were undergoing active hardware development

- Both modems were tested on Sarnoff's RF transmission test-bed in 12/90, and their characteristics compared
  - interference with co-channel NTSC
  - BER under NTSC interference conditions
  - BER under impulse noise interference conditions
  - BER under sine-wave interference conditions
  - BER under multipath conditions

RF Transmission Results

- Twin-QAM concept of avoiding the co-channel picture carrier buys about 18 db of signal level for simulcast
  - this practice was adopted by OFDM just prior to tests
- The wideband component of twin QAM had a 4db advantage compared to OFDM
- The narrowband component of Twin-QAM had a 6db advantage compared to OFDM
- The Twin-QAM concept of using of higher power in the lower sideband of the NTSC co-channel (where the receiver has its Nyquist filter) is important
- Twin-QAM seems to be a good tradeoff having good performance and low cost

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Data Compression

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The Data Compression Problem

- **Digital HDTV has a high data rate:**
  - 1 Mpix/frame x 30 fps = 30 Mpix/sec (just for Y)

- **Transmission in a 6 MHz channel (20-30 Mbps) requires compression to less than 0.5 bits/pixel**

- **Several compression techniques produce good quality at 1 bit/pixel, but below that is hard**

- **What is the competitition doing?**

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ATRC Data Compression Effort

- During the last half of 1990, there was an intensive effort to select a data compression approach

- The finalists were:
  - MPEG-HD (TCE-LA)
  - Block-match DCT with frame skip (LEP/DTB)
  - Motion-compensated QMF (Sarnoff)
  - Hybrid SBC/VQ (Briarcliff)

- Systems were compared at 13.8 and 20 Mbps

- Systems were to demonstrate performance with simulated bit errors in transmission

Data Compression Results

- MPEG-HD demonstrated the best picture quality (particularly at 13.8 Mbps)

- Frame-skip DCT and MC-QMF were also very good

- Only MC-QMF demonstrated extremely robust performance even at poor BERs

- Decision to develop "MPEG++"
  - based on MPEG algorithm
  - apply robustness concepts from MC-QMF
  - apply other good ideas (frame skip, fixed length codes) where appropriate

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Current Status

- "MPEG++" meetings at Sarnoff
- Hardware architecture meetings at Briarcliff
- Plan tasks and staffing
- Start hardware construction ASAP

System Considerations

Digital Hierarchy

- Mimic the "analog continuum" of performance
  - Broadcast Grade A and Grade B contours
  - Effectively use the high power narrowband component of Twin-QAM for "high-priority" information
- Provide cost/performance tradeoffs
  - Enable HDTV receivers at different costs
  - VCR Slow Play and Extended Play modes
- Provide features
  - VCR "trick modes"
- The widely-known concept of "augmentation" ensures that *some* Hierarchy will be invented
- Be compatible with future technology developments in computing, displays, etc.

Other Elements of Simulcast

- Much system-level work remains to be completed
- Periodic restart of information flow
  - Channel tuning
  - VCR
  - Robustness
- Error management
  - Correctable errors
  - Uncorrectable errors
  - Undetected errors
- Matching the encoder to the channel

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Summary and Discussion

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Summary

... an exciting opportunity to create the television system standard for the next 50 years ...

- **Technical elements of a solution are progressing:**
  - **Advanced data compression**
  - **Excellent modulation techniques that minimize co-channel interference, etc.**
  - **System engineering that includes the Digital Hierarchy concept for Broadcast, VCR's, etc.**

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ACTV and ADTV

... a two-phase strategy for the introduction of advanced television...

- **In addition to its own appeal, ACTV paves the way**
  - Compatible widescreen production is a precedent to simulcast
  - Establishing widescreen displays in high-volume manufacturing is a precedent to low-cost HDTV receivers
  - A profitable way to address the existing market is a precedent to investment during the adoption time of a new HDTV standard

- **Advanced Digital Television is the wave of the future**
  - Advanced data compression enables HDTV in 6 MHz, and puts broadcasters on an equal footing with competitive media
  - Low-power digital signal minimizes NTSC interference, and thus allows more simulcast stations to be approved
  - Robust encoding enables a larger coverage area for simulcast, thus improving the economics of the new HDTV service
  - Digital flexibility assures a useful standard well into 21st century

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ADTV Program Plan

Rev. 1.0
$7,120k

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RF Transmission Tasks

<u>Twin-QAM Modem</u>
Continue development of QAM modem. Modify for 64 QAM operation. Improve performance and extend range of adaptive equalizer. Develop synchronization/training approach and circuitry.
$75k DPC

*Hugh White (1.0)
Steve Evans (.75)
Bavesh Bhatt (1.0)
Sal Noto (.75)
Adolph DeSouza (TCE-Indy)

-Clock and Carrier Recovery
Develop techniques and circuitry for reliable clock and carrier recovery, solely from the random data QAM signal
*Carlo Basile (1.0) (NAP)
Other (Philips)

-Pilot Tone Based Clock and Carrier Recovery
Develop techniques and circuitry to insert a pilot tone into the QAM signal, and then to extract it for reliable clock and carrier recovery.
*Jim Walter (.5)
Jeremy Pollack (.5)

-Modem Simulation
Develop a software simulation model for QAM that can verify measured performance and predict performance under a variety of channel conditions
*Dave Bryan (.25) (NAP)

RF Transmission Tasks, cont'd

Packet/Transport Processor

Develop a processor to merge the many MPEG compression data types (e.g. motion vectors, DCT DC coefficients, DCT AC coefficients, inter/intraframe switches, etc.) into high- and low-priority serial bit streams. Headers must be added to identify data types, and variable length codes must be assembled into fixed-length packets. Packet-to-packet continuation must be accounted for. Information must be dynamically routed between HP and LP streams as a function of their relative buffer fullness. The inverse processing to unpack and distribute received data must also be developed for the receiver/decoder.

$75k DPC

*Al Acampora (1.0)
Jim Arbeiter (1.0)
D. Raychaudhuri (.5)
Bob Siracusa (.5)
Rick Bunting (1.0)
Dave Harris (.5)
Ken Bahrs (.5)
J. Turkenich (.75) (NAP)

RF Transmission Tasks, cont'd

FEC
Develop circuitry to compute and stuff Reed-Soloman error correcting codes into data packets, and then provide a serial bit stream to the modem. In the receiver/decoder, packet synchronization must be achieved, followed by serial-to-parallel conversion, error correction, and detection of uncorrectable errors.

$50k DPC

*Liston Abbott (1.0)
Krish Jonnallagadda (.5)
Bob Petri (.5)
Dave Harris (.5)
Ken Bahrs (.5)

RF Front End
Develop a tuner/IF system with appropriate linearity and performance for a digital HDTV receiver.

*Maier (TCE-Villingen)

Rack/System Assembly
Packaging, power, assembly, etc.

$30k DPC

*Jeremy Pollack (.25)

RF Testing
Test and characterize RF modem and entire communications subsystem in a simulated cochannel environment, using Sarnoff RF test bed facility.

*Lou Stetz (.5)
Jim Gibson (.25)
Dick Klensch (.25)

Transmission System Simulation
Extend QAM modem simulation to include FEC and protocol elements and performance. Use simulation to predict performance under different scenarios.

$30k DPC

*Dave Bryan (.75) (NAP)
Newman Wilson (.5)

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Data Compression Hardware Tasks

Front End/Rear End

Develop a complete subsystem containing matrix, prefilters, A/D, and programmable filtering and downsampling. Also develop upconversion, D/A, postfilter and inverse matrix.

$50k DPC

*Roger Bessler (.125)
Jeremy Pollack (.5)

-Chroma Downsample/Upsample

*Roger Bessler (.125)

-A/D, D/A, and Matrix

*Fred Vannozzi (.5)

Frame Memory Module

Modify the DARPA frame store to be a useful subsystem for ADTV. Transition the design to other tasks.

$25k DPC

*Roger Bessler (.25)
Steve Evans (.25)

Motion Estimation

Develop a complete subsystem for motion estimation. This will require a large amount of parallel computation.

*LEP

DCT/Quantizer

Develop a subsystem containing DCT, coefficient quantization, and intra/interframe decisions. Develop the inverse decoder.

*NAP

VLC/VLD

Develop circuitry to implement modified Huffman coding, which generate a variable-length code based on a table of symbol probabilities. Develop a state-machine to decoder the variable-length stream. Develop control interface to reset decoder with packet synchronization.

*NAP
Jim Arbeiter (1.0)
J. Cooper (TCE-Indy)

Communication System Interface

Make sure that coding and communications subsystems will work together.

*NAP

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Al Acampora

Control Microcode

Distributed contol of computing elements in the compression system will have to be accomodated. The most straightforward exaple is modifying coding based on buffer fullness feedback. This will require substantial effort.

*NAP
Barbara Connelly (1.0)
Bob Siracusa (.5)

Error Concealment

Implement error concealment approaches such as "repeat a block from the previous frame" in the decoder. The design of other decoder functions will also be impacted to insure that error flags are correctly generated and propogated.

*NAP
Terry Smith (1.0)

Rack/System Assembly

This will be a large system, with many boards and significant power and cooling requirements.

*NAP

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Data Compression Software Tasks

ADTV System and Algorithm Development

Develop and simulate system concepts. Provide for ongoing performance improvements in hardware through continued algorithm development, particularly where software changes can be made to the FCC hardware system.

*D. Raychaudhuri (.5)

-System Specification and Refinement

*Joel Zdepski (.5)
Sheau Ng (.25)
Faramarz Azadegan (.75) NAP

-Encoder Algorithm

*Regis St. Girons TCE-LA
Tristan Savatier TCE-LA

-Decoder/Concealment Algorithm

*Joel Zdepski (.5)
Kuriacose Joseph (.5)
Huifang Sun (.25)
Charlie Wine (.5)

-Transport Protocols and software

*Bob Siracusa (.5)
Kuriacose Joseph (.5)

SubBand Compression Research

Continue advanced algorithm development to insure that ATRC is in a position to counter new developments by competitors and newly emerging proponents.

*Jerry Shapiro (1.0)
Huifang Sun (.25)

VQ Compression Research

Continue advanced algorithm development to insure that ATRC is in a position to counter new developments by competitors and newly emerging proponents.

*Yo-sung Ho (0.5) NAP
K. Challapali (0.5) NAP

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ADTV System Tasks

RF Issues and Frequency Allocation
Study frequency allocation and channel spacing issues as they apply to the FCC process and broadcasters.
*Jim Gibson (.5)
John Henderson (.125)
Krish Jonnallagadda (.125)
Aldo Cugnini (.25) (NAP)

FCC Documents and Meetings
Support the FCC process with documents and meeting attendance.
Sheau Ng (.5)
John Henderson (.25)
Krish Jonnallagadda (.125)
CAAJ Greebe (.125) NAP
Alan Cavalerano (.25) NAP
Brian McFarlane (.5) NAP

NAB and Other Demos $300k DPC
Support ADTV with appropriate industry demonstrations and publicity.
Sheau Ng (.25)
Kuriacose Joseph (.125)
Bob Plummer (.5)
D. Malloy (.75) NAP
Jose Alvarez (.5) NAP

Misc. Support
VAX and Sun support.
Rod Borchardt (.5)
Howard Edinger (.25)
Paul Hohman (.25)

Program Management
Glenn Reitmeier (.75)
Mike Tsinberg (.75) NAP
Frank Kot (.75) NAP
Secretary (1.5)