There have been may suggestions as to how the Government can help: decisive standard setting; antitrust relief for joint efforts; matching grants; tax credits; etc. We think this Committee and the Congress should continue to examine these alternatives. But we can and should agree as soon as possible on what we should do: introduce by the year 2000 an American processed digital HDTV system which permits the transmission within a 6 MHz bandwidth.

END

I collect ... copy ... for

To: JULIUS BARNATHAN

From: FRANK J. HANEY

Date: APRIL 12, 1989

Subject: FAROUDJA CABLE-TV TEST

CAPITAL CITIES/ABC, INC.

RECEIVED

JULIUS BARNATHAN 1989

Summary: The writer attended a demonstration of Faroudja's super NTSC system yesterday at the Sunnyvale (Ca) City Hall. Simultaneous side by side presentation of regular NTSC and super NTSC were given on 19" monitors. Pictures arrived via the local cable system on adjacent channels. Later a large screen presentation (12' x 15') of super NTSC was given at the Faroudja Laboratory. In all cases the super NTSC pictures looked excellent.

Cable-TV Test: The cable TV test was a co-operative effort on the part of TCI (owner of Sunnyvale cable system) and Faroudja Labs. The city council chambers proved to be a good location for the viewing since it was near the end of the cable system (approx. 18 amplifiers deep) and provided a neutral ground for public viewing. No public officials were present for the test, however.

Channel 14 carried the super NTSC signal, while Channel 15 (next adjacent) carried regular NTSC. A common signal source fed both channel modulators at the cable system headend. The regular NTSC monitor utilized a Rhode & Schwartz demodulator (tuned to Ch. 14), while the super NTSC monitor utilized a techtronix demodulator (tuned to Ch. 15). Further this super NTSC monitor was equipped with Faroudja's line doubler (1050 lines) and the picture tube changed out to a high resolution computer type kinescope and deflection circuitry. Because of this difference in kinescopes, it was not possible to get perfect color matching on the two monitors. The difference, however, was minor.

Source material was a 35mm Dolby test film transferred to Betacam-SP via a Rank scanner. Scenes containing wide contrast ranges, rapid motion, dark passages, bright passages, and test patterns were all shown. Although the regular NTSC picture was quite good, the super NTSC picture exhibited the following improvements:

a. No line structure
b. Noticeably better resolution
c. Noise free
d. No ringing or white following around edges (printed matter was clean and sharp)
e. No color fringing (Sunday comics look)

In summation super NTSC looked more like film than TV.

Laboratory Test: A portion of "Indiana Jones", via super NTSC, was shown on a 12'x15' screen. Except for low screen brightness, which writer gradually became accustomed to, picture quality again approached that of film as noted in items a through e above.

Concluding Remarks: Super NTSC is definitely a viable product, and for screen sizes normally found in the home (i.e. up to 30" or so) yields a picture subjectively as good as 1125/60. Until large size high brightness display devices become economically available and even generally acceptable, there is no reason to go to a 1000+ line number new television system.

As for the economic/political future of super NTSC, time is of the essence. For super NTSC to become available to the typical consumer, some major financial committments must be made by one or more TV set manufacturers. A key element to this effort is the development of a very large scale integrated circuit containing most of the line doubling technology which must go into the TV set. Typically such VSLI's take about two years and ½ million dollars to develop. With the FCC embarking upon selection of a new terrestrial advanced television system, TV set manufacturers may be reluctant to expend major dollars on the development of a super NTSC receiver, in advance of an FCC decision which could adversely affect super NTSC.

FJH:ah

cc: Messrs. Meitlich, Uyttendaele

Attachment #1

REPORT

ON

THE POTENTIAL FOR EXTREME

BANDWIDTH COMPRESSION

OF DIGITALIZED HDTV SIGNALS

PREPARED BY

DALE N. HATFIELD

OF

HATFIELD ASSOCIATES, INC.

March 20,1989

DALE N. HATFIELD HATFIELD ASSOCIATES, INC.

I, Dale N. Hatfield, President of Hatfield Associates, Inc., located at 4840 Riverbend Road, Boulder, Colorado, 80301, declare that:

I received a Bachelor of Science degree in Electrical Engineering from Case Institute of Technology in 1960, and a Master of Science degree in Industrial Management from Purdue University in 1961. I have completed additional graduate work in engineering, mathematics, operations research, and business administration at Illinois Institute of Technology, Case-Western Reserve University, and the University of Chicago.

After graduation from Purdue, I joined Stewart-Warner Electronics as a production engineer. From 1963 until 1971 I was employed as a communications engineer with the Institute for Telecommunication Sciences of the U.S. Department of Commerce. Between 1971 and 1974, I held various communications policy analyst positions with the Office of Telecommunications in the Department of Commerce. In 1974, I was appointed Deputy Chief of the Office of Studies and Analysis, Office of Telecommunications Policy, Executive Office of the President. In 1975, I moved to the Federal Communications Commission where I became Chief of the Office of Plans and Policy. In 1977, I returned to the Department of Commerce where I became Associate Administrator for Policy Analysis and Development, National Telecommunications and Information Administration. In 1981, I was appointed Deputy Assistant Secretary of Commerce for Communications and Information.

In 1982, I left government and established my own consulting organization. Our firm specializes in engineering, economic, market, and policy studies in the telecommunications field. Our clients include firms in the terrestrial and satellite long-haul communications, cable television, local exchange, cellular mobile, broadcasting, specialized mobile radio, and international communications fields. I am also the Director of the Telecommunications Division of University College at the University of Denver where I teach courses in telecommunications policy and regulation and in telecommunications management. I am also an Adjunct Professor in the Graduate Program in Telecommunications at the University of Colorado at Boulder. In addition, I was recently appointed a Fellow of Northwestern University's Annenberg Washington Program on Communications Policy Studies.

I declare that the foregoing is true and correct, that the attached document entitled "The Potential for Extreme Bandwidth Compression of Digitized HDTV Signals," dated March 20, 1989, was prepared under my direction and supervision, and that I agree with the results and conclusions.

Executed on March 20, 1989 by

Dale N. Hatfield

The Potential for Extreme Bandwidth Compression of Digitized HDTV Signals

1.0 Introduction

Hatfield Associates, Inc. (HAI) has been retained by Tele-Communications, Inc. (TCI) to assess the likelihood that, over the next ten years or so, a digitally-encoded HDTV signal could be transmitted via terrestrial broadcasting and cable systems within the 6 MHz bandwidth occupied today by NTSC signals. This report reviews current progress and trends in the bandwidth compression of broadcast-quality television signals and in digital transmission technology in order to estimate whether the existing states of the various arts could, with suitable further development, lead to such a goal. The report does not address the transition to fully digital transmission or the different enhancements that might be applied to NTSC technology during the interim.

Video compression and transmission techniques are assumed to be independent in this analysis. The fundamental approach to the problem included estimating the maximum bit rate, using advanced high-level modulation and coding techniques, that could be supported by a 6 MHz channel under signal-to-noise ratio assumptions discussed in section 3 below. The other principal part of the study considered video compression developments that would minimize the bit rate required to transmit a "full-motion" HDTV signal. Accordingly, the investigation considered transmission technology and video compression technology separately; this report is correspondingly organized into sections that discuss each technology. The conclusions discuss the joint implications of the findings of the individual sections.

2.0 Summary of findings

Current digital modulation techniques used in telecommunications transmission systems exhibit bandwidth efficiencies of several bits per second per Hertz of bandwidth. Under our interference assumptions, a bit rate of about 18 Mbps can be supported in a 6 MHz channel using well-proven techniques. Assuming that an uncompressed digital HDTV signal would be transmitted at a rate of about 1.2 Gbps, an overall compression ratio of at least 67:1 is necessary to allow transmission in the same bandwidth allocated for NTSC signals using our carrier-to-noise ratio and modulation format assumptions.

There are currently intraframe compression techniques that allow 30:1 ratios with apparently little detectable degradation in quality. Interframe compression is available that allows bit rate reductions of greater than 3:1. Assuming that these techniques can be applied more or less independently of each other, the joint application of these techniques should result in a net compression ratio in the neighborhood of 90:1. This would allow the use of 6 MHz channels for transmission either over the air or via cable systems; sufficient spare bandwidth is available for forward error correction.

A successful reduced-bandwidth digital HDTV system clearly requires a well-coordinated enterprise involving participants from diverse fields. The fundamental components appear to be in place; an appropriate impetus could ensure the successful development in the next decade of bandwidth-efficient digital HDTV offering 35 mm image quality for consumer use.

3.0 Video compression

One generally assumes that HDTV systems will present images of 35 mm quality. The uncompressed bit rate for a digital HDTV signal is about 1.2 Gbps, according to several sources.[1] Various techniques exist to compress video signals to allow transmission in reduced bandwidths. Probably the most active area to date has been video teleconferencing, in which video signals are compressed for transmission at rates of 384 kbps and occasionally less. The compression techniques used for teleconferencing, however, do not generally offer good rendition of moving images.

Today, an NTSC signal requires a bit rate of about 90 Mbps without compression. Existing interframe coding techniques allow this rate to be reduced to 20 to 30 Mbps while still allowing "network quality."[2]

Intraframe coding can generally be applied independently of interframe coding, and compression ratios of 30:1 are currently available. Intel, for example, in its DVI (Digital Video Interactive) system that was developed by the Sarnoff Research Center[3] and acquired by Intel from General Electric,[4] achieves at least this degree of intraframe compression reportedly without noticeable degradation; Intel claims the reproduced signal is of the quality of one reproduced by VHS-format video tape.

---

[1]See, e.g., Cable TV Technology, September 20, 1988, p 5.

[2]K. Feher, Advanced Digital Communications -- Systems and Signal Processing Techniques, Prentice-Hall, Inc., Englewood Cliffs: 1987.

[3]"IBM-TV?", Forbes, February 20, 1989, p. 74.

[4]"DVI May Be Programmers' Next Gold Mine," Electronics, February, 1989.

If the interframe and intraframe compression techniques are independent, then currently-available technology should allow a net compression of 90:1, with a resulting required bit rate of between 13 and 14 Mbps. Others have suggested that such rates are achievable. Workers at the Massachusetts Institute of Technology, for example, have stated that

> "[t]he most complex receiver would depend on all of the techniques developed for highly sophisticated video conferencing systems. This implies a transmission rate of, perhaps, 10 Mbits/sec, which could readily be accomodated [sic] in an analog channel of a few MHz. This tradeoff between receiver complexity and channel efficiency shows that the former has a profound influence on TV system design. A system to be deployed in the 90's and to be used well into the next century should use technology appropriate to its era, and not to times past. This means, at the very least, a good deal of computational capacity, digital signal processing, programmability, and generous use of memory."[5]

The speed and computation power of microprocessors continue to grow at phenomenal rates. Microcomputers using Intel's 80386 processor have been favorably compared with the large IBM 360/50 mainframe machine of 20 years ago, and even more advanced devices have been announced by Intel and others. Furthermore, memory devices are decreasing in price per bit and are increasing in density, making it more and more economical to employ large quantities of memory in end-user devices, such as digital HDTV receivers.

Whether the compression techniques discussed in this section can be used together must be determined by competent investigators. However, it is reasonable to assume that sufficient knowledge exists in various areas to allow the 90:1 or so compression ratios that are required to reduce the raw digital HDTV bit rate to something under 20 Mbps. The information available to us suggests that these techniques can be applied to result in a highly-processed digital signal that will allow the reproduction of an HDTV image with little perceptible degradation. Progress in this area will continue to be made, and it seems quite safe to assume that, over the next decade or so, such compression ratios should be achievable without any perceptible degradation of static or moving images.

---

[5] W. F. Schreiber and A. B. Lippman, "Bandwidth-Efficient Advanced Television Systems," 1988 NAB Engineering Conference Proceedings, p. 410.

4.0 Digital transmission technology

Unlike cable distribution systems in which carrier-to-noise (C/N) ratios in the neighborhood of 50 dB can be sustained, the broadcast environment in the future may result in low carrier-to-interference levels (C/I) in fringe areas. In this study, HAI assumed that broadcast transmission will be interference-limited, and that C/N in such a system can be approximated by C/I. HAI further assumed that the worst-case C/I that must be handled will be about 12 dB and that 6 dB of antenna pattern interference rejection can be obtained for a net working value for minimum C/I (and hence C/N) of 18 dB.

Current digital transmission systems routinely exhibit bandwidth efficiencies of 4.5 bps/Hz. For example, digital long-haul microwave systems achieve this level using 64-level quadrature amplitude modulation (QAM). Systems using even higher-level (256 and 1024) QAM are either in service or are about to enter production; these offer bandwidth efficiencies of about 6 and 7.5 bps/Hz, respectively. The corresponding bit rates in a 6 MHz channel for these techniques range from 27 Mbps to 45 Mbps.

The penalty one pays for employing high-level modulation schemes is a reduction in the energy per transmitted bit and hence an increased bit error rate for a fixed carrier-to-noise ratio. For the problem at hand, either 16- or 64-level QAM is probably the most attractive of these techniques. For C/N = 18 dB, the Eb/No for 64-level QAM is about 11.5 dB and is about 13 dB for 16-level QAM. Corresponding bit-error rates are about 2×10^{-2} and 2×10^{-5}, respectively.[6]

Because there has been little widespread experimentation with digital HDTV, there are no subjective testing results that indicate the acceptability to viewers of images degraded by a range of bit error rates. According to conventional voice communications practice, however, these error rates are rather high, and some form of forward error correction should be used. Furthermore, the fact that compression is achieved by the removal of redundant information suggests that errors may have a pronounced effect on the displayed image. We will therefore assume that an appropriate error-correcting technique will be required for the transmission of the compressed digital signal. A 33% overhead for redundant information seems reasonable to assume in the transmitted bit stream, using, for example, a rate 3/4 convolutional technique.

For broadcast transmission, then, it is reasonable to assume, under the conditions outlined in this section, that a

---

[6] D. R. Smith, Digital Transmission Systems, Van Nostrand Reinhold Company, New York: 1985.

6 MHz channel can support a bit rate of 18 Mbps using 16-level QAM. Thus, the compressed signal plus error correction overhead must result in a bit rate of no more than this value to be accommodated in a broadcast system using our C/I assumptions.

For the case of cable transmission, carrier-to-noise ratios are typically in the vicinity of 50 dB, and high-level QAM or other techniques will be usable at very low bit-error rates. Using 1024-level QAM, for example, would allow transmission of at least a 45 Mbps bit stream in a 6 MHz channel.

The modulation techniques discussed in this section are well-proven in practice and, as section 4 will show, appear to be perfectly adequate for the purpose at hand under our stated assumptions. However, there is much ongoing activity directed toward further improvements in the spectral efficiency of digital modulation formats. For example, such combined modulation and coding techniques as trellis-coded modulation can improve the efficiencies of older techniques by a few decibels. These improved techniques are in somewhat limited use today and will be available in improved form for implementation over the next few years.

5.0 Discussion and conclusions

A principal benefit of using digital transmission of HDTV signals is that it allows the use of digital processing techniques and devices. The rapid advances in the processing capabilities of microprocessors over the past decade are well-documented, as are the increases in memory density per device and the decrease in the overall cost of memory. Cheaper and denser memory facilitates economic frame storage in receivers and thereby allows the application of advanced interframe compression and expansion techniques.

In section 2, we noted that existing intraframe compression techniques allow ratios of around 30:1, with little noticeable degradation, leading to a reduced bit rate of about 40 Mbps. Other techniques for interframe compression have resulted in ratios of greater than 3:1. Under the assumption that intraframe and interframe compression can be performed more or less independently of each other, then it seems reasonable to conclude that a net bit rate of less than 18 Mbps, including error correction, should be within reach. Even if a factor of two or three were missing, one could justifiably expect that advances in image processing and compression techniques over the next few years would improve by at least such an amount.

Certainly, this data stream can be transmitted within a 6 MHz bandwidth using well-established digital modulation formats, as the discussion in section 3 has shown. This fact suggests, then, that broadcast transmission of digitized HDTV signals is likely to be technically feasible within the existing states of the transmission and video compression arts. Obviously, suitable receiver circuitry must be developed that detects and corrects the received bit stream, expands the compressed information and converts it to analog form for display. One can expect, given the quantities one associates with consumer electronic products, that suitable digital processing and memory devices will be available at affordable prices over the next decade and very likely sooner.

The Potential for Extreme Bandwidth Compression of Digitized HDTV Signal

Addendum

March 28, 1989

Countermeasures for Multipath-Induced Errors on Highly-Compressed Digital HDTV Broadcast Transmissions

Compression of a video signal is achieved principally through the removal of redundant information both within frames and between successive frames. The consequences of compressed HDTV digital transmission errors therefore can be expected to be proportionately greater than those of corresponding errors in a bit stream carrying a similar, but uncompressed, signal.

A great deal of work has been done in recent years in developing coding techniques known collectively as FEC, or forward error correction, to protect the integrity of digital signals against errors. Each of the various techniques requires adding redundant information in a prescribed way to the original data stream; some techniques are more efficient than others in that they achieve a greater degree of protection for the same quantity of redundant symbols.

Other techniques are available as well: Channel equalization can compensate for undesirable features in channel frequency response and for time spread caused by multipath signals. The most direct way of reducing the effects of multipath transmission is through forward error correction, however. As an example, consider a Reed-Solomon code of rate 7/8, specifically the RS(256,224) code with eight bits per symbol. One bit out of eight is redundant; *i.e.*, the FEC overhead is about 14%. With this small amount of redundant information, this code can correct a raw error rate of 10^{-3} to 10^{-12}. Its performance improves as the input error rate decreases: For an input rate of 10^{-4}, the corrected error rate is less than 10^{-25}.[1]

In an earlier paper written by Hatfield Associates, Inc., for Tele-Communications, Inc., the authors assumed a 33% overhead for error correction in a 6 MHz channel operating at a carrier-to-noise ratio of 18 dB. A 16-level QAM modulation format (four bits per symbol) was also assumed. The corresponding Reed-Solomon code RS(64,48) gives the following performance:[2]

---

[1] Berlekamp, E.R., R. E. Pelle and S.P. Pope, "The application of error control to communications," *IEEE Communications Magazine*, April, 1987, pp. 54-55.

[2] *Id.*, p. 47.

Input bit error rate	Output bit error rate
10^{-3}	$<10^{-8}$
10^{-4}	$<10^{-15}$

The uncorrected error rate in the example given in the earlier paper was about 2×10^{-5}. Using the rate 3/4 Reed-Solomon code from above would result in a corrected error rate of much less than 10^{-20}. For purposes of comparison, an error rate of 10^{-20} in a 10 Mbps bit stream corresponds to an average of one bit error every 300,000 years or so!

Extremely powerful error-correction schemes presently exist that can render a transmission exhibiting a moderate error rate practically error-free at the expense of a small degree of redundancy. The example given in this paper would allow essentially errorless transmission of a compressed HDTV signal in what would normally be considered a very poor broadcast environment.

THE SETBACKS OF JAPAN'S HDTV MASTER PLAN

The MITI/NHK's grand master plan, as conceived in the mid 70's, is to propel Japan to be the dominant provider of the new information-age television system in the world. This plan has encountered many setbacks both internationally and domestically. Its flaws are fundamental. Let us review some of the key elements of the master plan.

A. The Master HDTV Plan

- Create a world HDTV production standard that is compatible to NHK's MUSE transmission standard. The 1125 lines were designed to be easily down-converted to the U.S.'s 525 and Europe's 625 lines and the 60 frames per second was designed to satisfy Hollywood's desires. (U.S.' broadcast studio engineering community generally welcome the NHK production HDTV system in the early 80's.)

- Introduce the non-compatible HDTV system in Japan (Hi-vision) using Ku-band satellite DBS with the MUSE transmission system (9MHz RF bandwidth). The DBS deployment will be a relatively slow ramp up in domestic Japan to replace terrestrial broadcast systems.

- Introduce MUSE as the most cost-effective HDTV family of transmission systems in the U.S. and Europe for broadcasters, cable, DBS, etc., assuming the adoption of the world production standard.

- Introduce Hi-vision VCR, video disc players, and MUSE TV sets worldwide.

- Use the global HDTV revenue base to accelerate cost reduction based on volume production in order to become the most competitive system globally.

B. International Problems

- Europe has rejected the NHK production standard and the MUSE transmission standards.

- The U.S. has withdrawn its initial support for NHK's productions standards.

- The FCC has made a tentative decision to ban any transmission standard that is not NTSC compatible and that requires more than 6 MHz bandwidth (MUSE needs 9 MHZ).

- Modified 6 MHZ and 9 MHZ NTSC compatible systems are technically inferior to U.S. proponent of NTSC compatible HDTV systems. (The NTSC compatible versions are hurried patch development after FCC's ruling.)

C. Domestic Setbacks

- Japan's privately owned and powerful (most are owned by large newspaper publishers) terrestrial broadcasters are aggressively rolling out EDTV systems this fall in competition with NHK's proposed DBS HDTV system, which will not be available until 1992. Improved EDTV-2 with wide screen, digital sound, and that is NTSC compatible (6 MHz), will also be available by 1992.

- The 500,000 early adapters in Japan who purchased $2,500 worth of DBS satellite dishes and receivers (TVRO) to watch 2 channels of programming using NTSC standard will be first asked to pay for programming when the 2 DBS channels are scrambled next year. Worst yet, by 1992, these consumers will be forced to buy completely new and non-compatible TVRO receivers and very expensive HDTV sets ($4,000). A consumers' revolt may accompany such actions.

- The three channel DBS/HDTV service to be launched in 1992 is woefully inadequate in today's multi-channel environment.

- MPT's about face in authorizing the residential reception of Ku-band communications satellites programming this fall (Mitsubishi's Superbird and C. Itoh, Mitsui, Hughe's JC-SAT) will offer 32 channel capacity in competing with NHK's 3 channel BSB-3 DBS service with HDTV. These 32 channels can use standard NTSC TV sets.

D. Reverse "Smokestack Syndrome"

NHK's MUSE transmission system is analog based, which means that the reception quality is subject to transmission degradations, such as noise and reflections. The design is based on at least 10 year old concepts and technological assumptions. NHK and MITI, together with the support of all major vertically integrated electronics companies in Japan, have committed enormous amounts of manufacturing facilities towards a DBS/HDTV launch in 1992 and volume production perhaps by 1995.

If the U.S. can develop and deploy a superior digitally based transmission system within the next decade while deploying quickly an interim cost competitive ATV/EDTV system that will thwart the worldwide success of the non-compatible MUSE system, then the NHK's HDTV strategy will be boxed by its own momentum.

In fact, a cost competitive ATV/EDTV such as the SuperNTSC system will have great technological export potential to all NTSC based countries including Japan, Korea, Taiwan and many others.