

UNITED STATES PATENT AND TRADEMARK OFFICE

BEFORE THE PATENT TRIAL AND APPEAL BOARD

LG Electronics, Inc.

Petitioner

v.

Broadcom Corporation

Patent Owner

Patent No. 7,342,967

Case No. IPR2017-01544

**DECLARATION OF DR. EDWARD J. DELP IN SUPPORT
OF PETITION FOR *INTER PARTES* REVIEW OF
UNITED STATES PATENT NO. 7,342,967**

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I, Dr. Edward J. Delp, declare as follows:

I. Introduction

1. I have been asked to submit this declaration on behalf of LG Electronics, Inc. (“LGE”) in connection with a petition for *inter partes* review of U.S. Patent No. 7,342,967 (“the ’967 patent”),¹ which I have been told is being submitted to the Patent Trial and Appeal Board of the United States Patent and Trademark Office by LGE.

2. Specifically, I have been retained as a technical expert by LGE to study and provide my opinions on the technology claimed in, and the patentability or unpatentability of, claims 1 through 5 of the ’967 patent (“the Challenged Claims”). For purposes of this declaration, I was not asked to provide any opinions that are not expressed herein.

II. Summary of Opinions

3. This declaration is directed to the Challenged Claims of the ’967 patent, and sets forth the opinions I have formed, the conclusions I have reached, and the bases for each.

¹ I understand that the ’967 patent is Exhibit 1001 to the petition for *Inter Partes* Review of the ’967 patent.

4. Based on my experience, knowledge of the art as of the effective filing date of the '967 patent, analysis of what I have been told are prior art references, and the understanding a person of ordinary skill in the art would have had of the claim terms in light of the specification as of the effective filing date, it is my opinion that the Challenged Claims of the '967 patent are unpatentable as being anticipated and/or obvious over the prior-art references discussed below.

III. Background and Qualifications

A. Background

5. I am currently employed as the Charles William Harrison Distinguished Professor of Electrical and Computer Engineering at Purdue University ("Purdue University") in West Lafayette, Indiana. My professorship is sponsored by the Charles William Harrison endowment. I have worked within the areas of digital signal processing, embedded computing systems, and wireless communications for over twenty-five years, and have authored, co-authored, or edited several books and numerous peer-reviewed technical papers in these areas.

6. I received my Bachelor of Science in Electrical Engineering from the University of Cincinnati in 1973 and my Master of Science from the University of Cincinnati in 1975. I obtained my Ph.D. in Electrical Engineering from Purdue University in 1979. I received an Honorary Doctor of Technology Award from the Tampere University of Technology in Tampere, Finland in 2002.

7. I have been active in the areas of signal and video signal processing, computer vision, computer systems, embedded systems, multimedia (audio, video, speech, wireless), wireless communications, system-level design methodologies and tools, and software systems.

8. I have been studying subject matter relating to these areas in connection with grants provided by the National Science Foundation, the National Institutes of Health, the Department of Defense, the Department of Homeland Security and the Department of Energy.

9. I have been elected a Fellow of the Institute of Electrical and Electronics Engineers (IEEE). The Fellow is the highest grade of membership of the IEEE, a world professional body consisting of over 300,000 electrical and electronics engineers, with only one-tenth of one percent (0.1%) of the IEEE membership being elected to the Fellow grade each year. Election to Fellow is based upon votes cast by existing Fellows in IEEE. I have also been elected a Fellow of the Society for Imaging Science and Technology (IS&T), the International Society for Optical Engineering (SPIE), and the American Institute of Medical and Biological Engineering.

10. In 2004, I received the Technical Achievement Award from the IEEE Signal Processing Society for my work in image and video compression and multimedia security. In 2008, I received the Society Award from IEEE Signal

Processing Society (SPS). In 2009, I received the Purdue College of Engineering Faculty Excellence Award for Research. In 2014, I received the Morrill Award from Purdue. In 2015, I was named Scientist of the Year by the IS&T and SPIE. In 2017, I received the SPIE Technology Achievement Award. The SPIE Technology Achievement award is awarded annually to recognize outstanding technical accomplishment in optics, electro-optics, photonic engineering, or imaging. The SPIE Awards Committee made this recommendation in recognition of my pioneering work in multimedia security including watermarking and device forensics and for my contributions to image and video compression.

11. I have developed and taught undergraduate and graduate courses in signal processing systems at Purdue University for the past 35 years. I taught thousands of undergraduate students in these fields. In 1990, I received the Honeywell Award and in 1992 the D. D. Ewing Award, both for excellence in teaching. In 2001, I received the Raymond C. Bowman Award for fostering education in imaging science from the Society for Imaging Science and Technology (IS&T). In 2004, I received the Wilfred Hesselberth Award for Teaching Excellence. In 2000, I was selected a Distinguished Lecturer of the IEEE Signal Processing Society, and I gave lectures in France, Spain, and Australia on signal, image, and video processing. In 2016, I received the Purdue College of

Engineering Mentoring Award for my work in mentoring junior faculty and women graduate students.

12. I have been active in the area of extensive research relating to signal, image, and video processing techniques. Over the last ten years, I have supervised the research and preparation of more than 48 Ph.D. theses relating to topics in signal, image, and video processing. These former graduate students now work as professors or in technical positions around the world. As part of my continuing research in the field of signal, image, and video processing, I have studied new developments in the field of signal, image, and video processing and embedded systems, analyzed the publications of other leaders in this field, and participated in industry organizations chartered to study the processing of images, video, and audio signals. My experience in the field of signal processing includes more than 35 years of directed research.

13. I am knowledgeable and familiar with standards related to the video processing and decoding field, and as shown in Appendix A (my curriculum vitae), some of my papers describe the application of these standards and technology similar to the patent. For example, I am an author on papers entitled “Wavelet Based Rate Scalable Video Compression,” “Error Concealment in Encoded Video Streams,” “Real-Time Error Concealment In Digital Video Streams Using Digital Signal Processors,” and “Future of Video Coding and Transmission.” I am also

knowledgeable and familiar with parallel processing systems for image and video compression, among other technologies. I am very familiar with the MPEG-2 standard that is referenced in the '967 patent and the prior art, in that I have taught it in my graduate level course on video systems for more than 10 years.

14. I also received the Technical Achievement Award from the IEEE Signal Processing Society in 2004 for my work in image and video compression and multimedia security. In 2008, I received the Society Award from the IEEE Signal Processing Society, the highest award they grant, for my work in multimedia security and image and video compression.

15. Additional details about my employment history, fields of expertise, and publications are included in my Curriculum Vitae (attached as Appendix A to this Report).

B. Compensation

16. I am being compensated for services provided in this matter at my usual and customary rate of \$650 per hour plus travel expenses. My compensation is not conditioned on the conclusions I reach as a result of my analysis or on the outcome of this matter, and in no way affects the substance of my statements in this declaration.

17. I have no financial interest in Petitioner LG Electronics, Inc. or any of its subsidiaries. I also have no financial interest in Patent Owner Broadcom

Corporation or any of its subsidiaries. I do not have any financial interest in the '967 patent and have not had any contact with the named inventors of the '967 patent, Gaurav Aggarwal, Arun Gopalakrishna Rao, Marcus Kellerman, David Erickson, Jason Demas, Sandeep Bhatia, or Girish Hulmani.

IV. Materials Reviewed

18. In forming my opinions, I have reviewed the prosecution history of the '967 patent and the following exhibits:

- Exhibit 1001. U.S. Patent No. 7,342,967 (“the '967 patent”).
- Exhibit 1003. U.S. Patent Application Publication No. 2002/0061183 to MacInnis (“*MacInnis*”).
- Exhibit 1004. U.S. Patent Application Publication No. 2001/0026677 to Chen et al. (“*Chen '677*”).
- Exhibit 1005. U.S. Provisional Patent Application 60/239,425 to MacInnis.
- Exhibit 1006. U.S. Patent Application 09/951,693 to Demas et al (“CIP parent application”).
- Exhibit 1007. U.S. Patent No. 6,940,904 to Chen et al. (“*Chen '904*”).
- Exhibit 1008. Exhibit 69 from Complaint in *Certain Semiconductor Devices and Consumer Audiovisual Products Containing the Same*, ITC-337-TA-1047.
- Exhibit 1009. ISO/IEC Standard 13818-2:2000: “Information technology- Generic coding of moving pictures and associated audio information: Video.” (“ISO 13818-2”)
- Exhibit 1010. Excerpts from IEEE 100 The Authoritative Dictionary of IEEE Standards Terms, 7th Edition (2000).
- Exhibit 1011. Excerpts from Newton’s Telecom Dictionary 16th Edition (2000).

Exhibit 1012. Excerpts from Digital Video: An Introduction to MPEG-2, Barry G. Haskell, et al. (1997).

19. I have been asked to assume that each of Exhibits 1003-1005, 1007, and 1009-1012 qualifies as prior art to the Challenged Claims of the '967 patent.

V. Legal Standards

20. I have been told the following legal principles apply to analysis of patentability based on 35 U.S.C. §§ 102 and 103. I also have been told that, in an *inter partes* review proceeding, a patent claim may be deemed unpatentable if it is shown by a preponderance of the evidence that the claim was anticipated by a prior art patent or publication under § 102 and/or rendered obvious by one or more prior art patents or publications under § 103.

A. Anticipation

21. I have been told that for a claim to be anticipated under § 102, every limitation of the claimed invention must be found in a single prior art reference.

B. Obviousness

22. I have been told that under 35 U.S.C. § 103(a), “[a] patent may not be obtained though the invention is not identically disclosed or described as set forth in section 102, if the differences between the subject matter sought to be patented and the prior art are such that the subject matter as a whole would have been obvious at the time the invention was made to a person having ordinary skill in the art to which said subject matter pertains.”

23. When considering the issues of obviousness, I have been told that I am to do the following:

- a. Determine the scope and content of the prior art;
- b. Ascertain the differences between the prior art and the claims at issue;
- c. Resolve the level of ordinary skill in the pertinent art; and
- d. Consider evidence of secondary indicia of non-obviousness (if available).

24. I have been told that the relevant time for considering whether a claim would have been obvious to a person of ordinary skill in the art is the time of alleged invention. Counsel for LGE instructed me to assume that the alleged invention date for the Challenged Claims is the effective filing date.

25. I have been told that a reference may be modified or combined with other references or with the person of ordinary skill's own knowledge if the person would have found the modification or combination obvious. I have also been told that a person of ordinary skill in the art is presumed to know all of the relevant prior art, and the obviousness analysis may take into account the inferences and creative steps that a person of ordinary skill in the art would employ.

26. In determining whether a prior-art reference could have been combined with another prior-art reference or other information known to a person

having ordinary skill in the art, I have been told that the following principles may be considered:

- a. A combination of familiar elements according to known methods is likely to be obvious if it yields predictable results;
- b. The substitution of one known element for another is likely to be obvious if it yields predictable results;
- c. The use of a known technique to improve similar items or methods in the same way is likely to be obvious if it yields predictable results;
- d. The application of a known technique to a prior art reference that is ready for improvement is likely obvious if it yields predictable results;
- e. Any need or problem known in the field and addressed by the reference can provide a reason for combining the elements in the manner claimed;
- f. A person of ordinary skill often will be able to fit the teachings of multiple references together like a puzzle; and
- g. The proper analysis of obviousness requires a determination of whether a person of ordinary skill in the art would have a “reasonable expectation of success”—not “absolute predictability” of success—in achieving the claimed invention by combining prior art references.

27. I have been told that whether a prior art reference renders a patent claim unpatentable as obvious is determined from the perspective of a person of ordinary skill in the art. I have also been told that, while there is no requirement that the prior art contain an express suggestion to combine known elements to achieve the claimed invention, a suggestion to combine known elements to achieve the claimed invention may come from the prior art as a whole or individually, as filtered through the knowledge of one skilled in the art. In addition, I have been told that the inferences and creative steps a person of ordinary skill in the art would employ are also relevant to the determination of obviousness.

28. I have been told that, when a work is available in one field, design alternatives and other market forces can prompt variations of it, either in the same field or in another. I have also been told that if a person of ordinary skill in the art can implement a predictable variation and would see the benefit of doing so, that variation is likely to be obvious. I have been told that in many fields, there may be little discussion of obvious combinations, and in these fields market demand—not scientific literature—may drive design trends. I have been told that, when there is a design need or market pressure and there are a finite number of predictable solutions, a person of ordinary skill in the art has good reason to pursue those known options.

29. I have been told that there is no rigid rule that a reference or combination of references must contain a “teaching, suggestion, or motivation” to combine references. But I also have been told that the “teaching, suggestion, or motivation” test can be a useful guide in establishing a rationale for combining elements of the prior art. I have been told that this test poses the question as to whether there is an express or implied teaching, suggestion, or motivation to combine prior art elements in a way that realizes the claimed invention, and that it seeks to counter impermissible hindsight analysis.

VI. The '967 Patent

A. Background

30. At the time the application that matured into the '967 patent was filed, “distribution of digital video content for TV display [was] dominated by use of the MPEG-2 video compression standard (ISO/IEC 13818-2).” EX-1001 1:31-33. “An MPEG-encoded stream may have three types of pictures, Intracoded (I), Predicted (P) and Bi-directionally predicted (B).” *Id.* 1:35-37. Both the patent and *Chen '677* explain how these different types of pictures (or “frames”) differ from each other:

- 1) An intracoded picture (“I-picture”) is not compressed using any temporal predictions and can be decoded without the use of any other pictures,

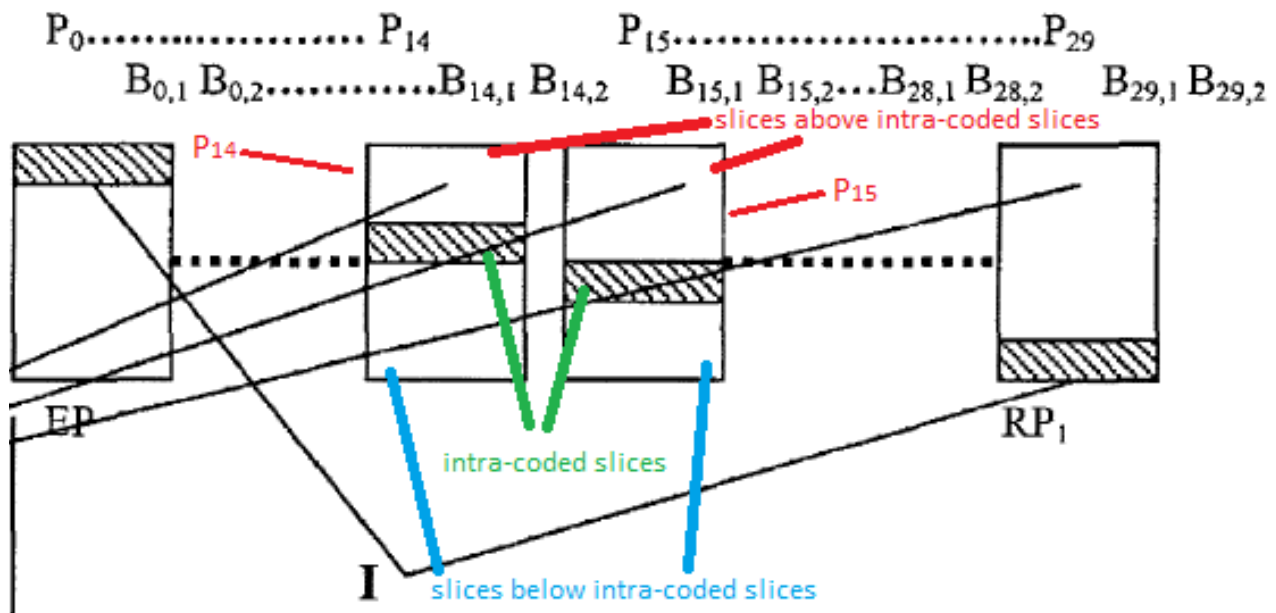
- 2) A predicted picture (“P-picture”) uses temporal predictions from a picture that comes before it in the display order, so it can only be decoded with a picture that comes before it in the display order, either an I-picture or another P-picture, and
- 3) A bi-directionally predicted picture (“B-picture”) uses bi-directional motion predictions, so it can only be decoded with a picture that comes before it in the display order *and* a picture that comes after it in the display order.

EX-1001 1:35-47; EX-1004 ¶¶[0003], [0008]. I agree with this assessment.

31. “During a Rewind operation, the pictures have to be displayed in the reverse order.” EX-1001 1:52-53. This “can be accomplished by decoding pictures in the forward picture order starting from the last I-picture before the B-picture in the forward decoding order. The I-picture is used as a reference picture since I-pictures do not require any other picture to be decoded.” *Id.* 1:61-65. As recognized by the background section of the ’967 patent, it was known that “the intervening pictures between the reference picture and the current picture only need to be decoded but not displayed.” *Id.* 1:65-67.

32. The background section of the ’967 patent criticizes how existing decoders rewound “a special class of MPEG-2 streams, known as Headend In The Sky (HITS) streams.” EX-1001 2:1-37. Referring to Figure 4, reproduced below

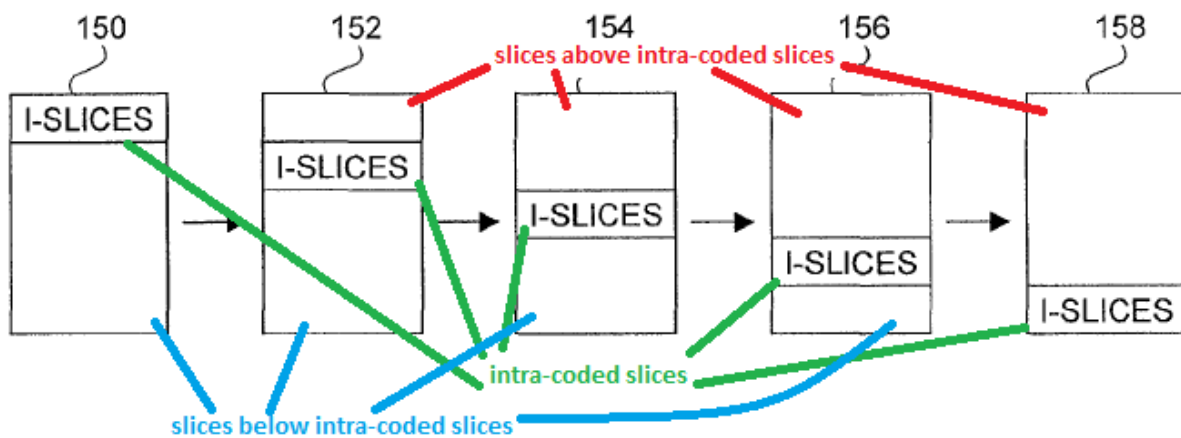
with colored annotations added, the patent explains HITS streams include “P-pictures, P, and B-pictures, B, but do not include I-pictures . . . because I-pictures require the most memory and bandwidth. Instead, HITS streams use a progressive refresh mechanism to build reference pictures,” with each P-picture having at least one intra-coded slice, I, where a slice comprises 16 horizontal lines of pixels. *Id.* 5:37-48.



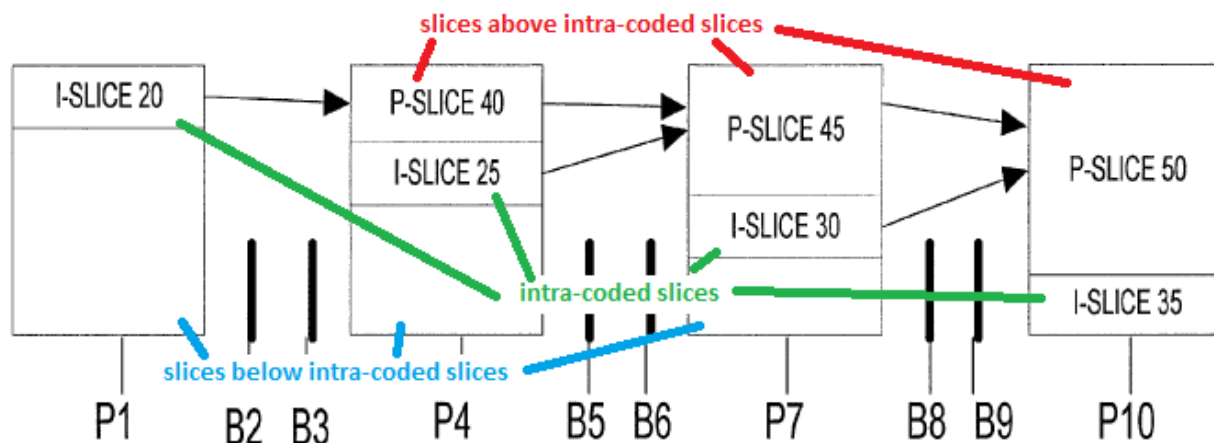
33. In Figure 4, each of a first P-picture P_{14} and a second P-picture P_{15} includes slices above the intra-coded slice, an intra-coded slice (shaded), and slices below the intra-coded slice. *Id.* 5:37-45. The HITS stream is configured such that the intra-coded slice in a first picture, such as P_{15} , is vertically just below the intra-coded slice in a previous P-picture, such as P_{14} . *Id.* 5:48-50. This downward progression of intra-coded slices from picture to picture enables predicting slices

above an intra-coded slice in a later picture (e.g., P_{15}) based on only the slices of the previous P-picture (e.g., P_{14}) that are above the current intra-coded slice. *Id.* 5:51-56. This “ensures that if a series of pictures is decoded starting from a P-picture whose first-slice is intra-coded, then a ‘clean’ refreshed picture will be built after all slices have been progressively refreshed.” *Id.* 5:56-59.

34. Both *MacInnis* and *Chen* describe progressive refresh mechanisms using figures similar to Figure 4 in the '967 patent. EX-1003 ¶¶[0049]-[0058] and Fig. 4A:



35. EX-1004 ¶¶[0022]-[0023], Fig. 1:



36. The '967 patent summarizes its invention as a “system and method for enhancing performance of personal video recording (PVR) functions on HITS digital video streams.” EX-1001 2:60-65. According to the patent, “[d]uring rewind of a HITS stream, the video decoder builds a clean reference picture,” but “because the P-pictures are not displayed, the decoder does not decode the portion of the P-picture below the last intracoded slice.” *Id.* 2:65-3:3. This “advantageously reduces the processing required to build a clean reference picture,” and is possible “because the subsequent pictures do not use the said portions for prediction.” *Id.* 3:3-10.

B. Effective Filing Date

37. I understand that the application that matured into the '967 patent is a continuation-in-part (CIP) of U.S. Application No. 09/651,693, filed on September 12, 2001. EX-1006 (copy of originally filed application from USPTO File

Wrapper). I have been told that the effective filing date may be impacted by whether or not the CIP parent application discloses all of the features of the claims in the '967 patent. In my opinion, the CIP parent application does not disclose all of the features of the claims in the '967 patent. I have been told that this means the claims are not entitled to the filing date of the CIP parent application and the effective filing date of all of the claims is thus December 11, 2002, the filing date listed on the face of the '967 patent.

38. For example, the CIP parent application lacks any discussion of “decoding at least a portion of another picture after decoding the at least one slice above the intracode slice and the intracode slice *without having decoding the at least one slice below the intracoded slice*,” as required by claim 1. The slices in the CIP parent application are used to determine whether a frame is an Entry Point Picture (EP), a portion of a stream “that would efficiently allow a complete picture to be decoded.” EX-1006 25:14-22; *see also* 26:15-28:8. But I note that there is no discussion of decoding only particular slices in one picture and then decoding an additional portion of another picture.

39. In addition to considering the CIP parent application as a whole, I was specifically asked to consider whether the CIP parent application’s “Appendix” discloses the claims in the '967 patent. It does not. The “Appendix” describes a progressive refresh mode in which “I-pictures are not mandated in the bit stream”

and points out a limitation of this mode is that “motion vectors for the macro-blocks located above the refreshed slices in the current P-picture can only point to the region above refreshed slices in the previous P-picture.” *See* EX-1006 46:2-19.

40. But this limitation has nothing to do with whether any of the slices in the previous P-picture are decoded. One of skill would appreciate that this merely prevents macro-blocks located above refreshed slices in a P-picture from being decoded based on certain P-slices in a previous P-picture. In my opinion, the CIP parent application’s appendix, like the rest of the CIP parent application, thus does not support claim 1’s “decoding at least a portion of another picture . . . *without having decoding* the at least one slice below the intracoded slice.”

41. Although counsel for LGE told me to assume the effective filing date of the ’967 patent is December 11, 2002, based on my conclusion that the CIP parent application does not disclose all of the features of the claims in the ’967 patent, I note that even if any of the claims had an effective filing date of September 12, 2001, the filing date of the CIP parent application listed on the face of the ’967 patent, my opinions in this declaration would remain the same.

C. Claims of ’967 patent

42. Of the Challenged Claims, only claim 1 is independent. For simplicity, I will refer to elements of the claims using separate reference numbers

for each claim element. For example, I will refer to the elements of claims 1-5 as follows:

Claim 1

1. [1.0] A system for displaying pictures, said system comprising:

[1.1] a host processor for transmitting transport packets, said transport packets providing a plurality of instructions;

[1.2] a video decoder for executing the plurality of instructions; and

[1.3] wherein execution of the instructions by the video decoder comprises causing:

[1.4] selecting a picture, said picture comprising

[1.4.a] an intracoded slice and at least one slice above the intracoded slice, and

[1.4.b] at least one slice below the intracoded slice;

[1.5] decoding the at least one slice above the intracoded slice;

[1.6] decoding the intracoded slice; and

[1.7] decoding at least a portion of another picture after decoding the at least one slice above the intracode slice and the intracode slice without having decoding the at least one slice below the intracoded slice.

Claim 2

2. [2.0] The system of claim 1,

[2.1] wherein the another picture comprises an intracoded slice and at least one slice above the intracoded slice, and

[2.2] wherein decoding at least a portion of the another picture further comprises:

[2.2a] decoding the at least one slice above the intracoded slice in the second picture; and

[2.2b] decoding the intracoded slice of the second picture.

Claim 3

3. The system of claim 2, wherein causing decoding the at least one slice above the intracoded slice in the another picture comprises causing: predicting the slices above the intracoded slice in the another picture from the intracoded slice and the slices above the intracoded slice in the picture.

Claim 4

4. The system of claim 1, wherein decoding the at least one slice above the intracoded slice further comprises causing: decoding the at least one slice in raster order.

Claim 5

5. The system of claim 1, wherein the picture comprises a P-picture from a HITS stream.

VII. Level of Ordinary Skill

43. I understand a person of ordinary skill in the art is determined by looking at (A) type of problems encountered in the art; (B) prior art solutions to those problems; (C) rapidity with which innovations are made; (D) sophistication of the technology; and (E) educational level of active workers in the field. Based on my experience in this art in the 1980s, 1990s, and 2000s, and accounting for these factors, I believe a person of ordinary skill in the art would have had as of the effective filing date at least a Bachelor's degree in Electrical Engineering, Computer Engineering, or Computer Science, and three to four years of experience in image/video processing or graphics systems, or an equivalent degree and/or experience, where more education could substitute for experience.

44. I was at least a person of ordinary skill in the art as of the effective filing date.

VIII. Claim Construction

45. I have been told by counsel that the claims in the '967 patent should be understood based on their broadest reasonable construction in light of the patent specification for purposes of this *inter partes* review proceeding. Unless otherwise noted, my opinions in this declaration are consistent with the broadest reasonable construction of the claims to a person of ordinary skill in the art at the effective filing date.

46. I have been told that the '967 patent has been asserted in at least the following litigations:

- Certain Semiconductor Devices and Consumer Audiovisual Products Containing the Same, Inv. No. 337-TA-1047, filed Mar. 7, 2017;
- *Broadcom Corporation v. LG Electronics Inc., et al*, 8-17-cv-00404 (Central District of California, filed Mar. 7, 2017);
- *Broadcom Corporation v. MediaTek Inc., et al*, 8-17-cv-00405 (Central District of California, filed Mar. 7, 2017); and
- *Broadcom Corporation v. VIZIO, Inc.*, 8-17-cv-00408 (Central District of California, filed Mar. 7, 2017).

47. I understand that there has been no claim construction briefing or proceeding yet in these litigations.

48. Below I provide what I understand to be the broadest reasonable constructions in light of the patent specification of some terms.

A. “instructions” (claim 1)

49. Based on the '967 patent and the parent application, which is incorporated by reference into the '967 patent, it is my opinion that the broadest reasonable construction of “instructions” should be “commands, separate from video or audio data, that specify trick play functions to be performed.”

50. The '967 patent differentiates the parts of a transport stream (TS) including video or audio data from the parts of the TS including instructions. According to the patent, a data transport processor 335 “passes the audio TS to an audio decoder 360 and the video TS to a video transport processor 340, and then to a MPEG video decoder 345 that is operable to decode and extract embedded, TS formatted command packets, that may include instructions to perform trick play functionality.” EX-1001 5:6-13. In addition to these TS formatted command packets, the “video TS comprises pictures that are compressed representations of individual images forming a video.” *Id.* 5:25-26.

51. The CIP parent application of the '967 patent, which is incorporated by reference into the '967 patent, EX-1001 1:8-12, 7:37-43, also makes clear that

the claimed “instructions” are separate from any audio or video data. The CIP parent explains that

The MPEG TS content 400 includes an MPEG TS 410. The MPEG TS 410 includes *data 420* and *TS formatted trick play commands 430*. The data 410 may include any one or combination of *video data 422*, *audio data 424*, . . . , and *any other data type 429* as understood by those persons having skill in the art. The *TS formatted trick play commands 430* may include any one or combination of commands that direct functions of pause/still 431, fast forward 432, rewind 433, slow forward 434, slow rewind 436, skip 436, . . . , and any other *commands 439* as understood by those persons having skill in the art.²

52. EX-1006 ¶[0051]. I understand that Broadcom has asserted that “instructions” means “the contents of the coded or compressed audio or video syntax itself, which instructs or causes the decoder to perform various tasks.”

EX-1008 3. But the patent makes clear that the broadest reasonable construction *does not* require that the “instructions” be contents. Rather, as explained in both the ’967 patent and its CIP parent application, “instructions” are separate and different

² All emphasis is added unless otherwise indicated.

from “data” that makes up the audio/video stream. EX-1001 5:9-14, 25-28; EX-1006 ¶[0051].

B. “without having decoding the at least one slice below the intracoded slice” (claim 1)

53. Based on the ’967 patent and the parent application, which is incorporated by reference into the ’967 patent, it is my opinion that the broadest reasonable construction of “without having decoding the at least one slice below the intracoded slice” should be “omitting decoding the at least one slice below the intracoded slice.”

54. The ’967 patent explains that “[d]uring rewind of a HITS stream, the video decoder builds a clean reference picture.” EX-1001 2:65-67. The reference pictures are built by decoding each P-picture between two Entry Pictures (EPs). *Id.* 1:67-2:1.

55. However, the ’967 patent explains that the P-pictures are not displayed, so “the decoder does not decode the portion of the P-picture below the last intracoded slice.” *Id.* 3:1-3. The patent explains that “[o]mitting decoding the portion of the P-pictures below the intracoded slice advantageously reduces the processing required to build a clean reference picture.” EX-1001 3:8-10.

C. “transport packet” (claim 1)

56. Based on the ’967 patent and the parent application, which is incorporated by reference into the ’967 patent, it is my opinion that the broadest

reasonable construction of “transport packet” should be “a packet containing either data or instructions.”

57. According to the CIP parent application of the '967 patent, which is incorporated by reference into the '967 patent, EX-1001 1:8-12, 7:37-43, a “transport stream” can contain “both data packets and command packets.” EX-1006 ¶[0011]. “Transport packet” in this context thus refers to a portion of a stream that contains one of data or commands.

IX. Analysis

58. Based on my understanding of one of ordinary skill in the art at the relevant time and my review of the prior art, it is my opinion that *MacInnis* anticipates claims 1-5, that *MacInnis* in view of *ISO 13818-2* renders obvious claim 4, that *Chen '677* anticipates claims 1-4, that *Chen '677* renders obvious claim 5, and that *Chen '677* in view of *ISO 13818-2* renders obvious claims 1-5.

A. Overview of the Prior Art

1. *MacInnis* (U.S. Patent App. Pub. 2002/0061183)

59. I understand that *MacInnis*, EX-1003, a U.S. Patent Application Publication No. 2002/0061183 to MacInnis (“*MacInnis*”), is prior art and claims priority to provisional application no. 60/239,425, EX-1005.

60. I understand that whether or not *MacInnis*' provisional application, EX-1005, discloses all of the features of claim 1 of *MacInnis* may impact how it qualifies as prior art. I have been asked to consider whether *MacInnis*' provisional

application discloses all of the features of claim 1 of *MacInnis*. In my opinion, it does, as shown in the following chart.

| <i>MacInnis</i> , claim 1 | Provisional Application No. 60/239,425 |
|--|--|
| 1. A method for enabling trick modes for a digitally encoded stream, the method comprising the steps of: | 26:4-5 (“1. A <i>method for enabling trick modes</i> in a personal video recording system, <i>the method comprising the steps of:</i> ”); 2:19-21 (“present invention provides a system and method for PVR to record <i>digitally encoded data streams</i> , and to <i>playback and decode the recorded streams</i> ”) |
| storing the digitally encoded stream, wherein the digitally encoded stream comprises video pictures; | 19:30-31 (“In another embodiment, transport streams (TS) <i>are stored on disk and played from disk.</i> ”); 26:6-7 (claim 1) (“receiving a <i>digitally encoded stream including video pictures</i> for display at a display rate”) |
| decoding the video pictures, starting from an entry picture, to generate one or more fully decoded pictures, wherein | 26:8-9 (claim 1) (“ <i>decoding the video pictures</i> at a rate faster than the display rate”), 3:6-9 (“Reverse decode and |

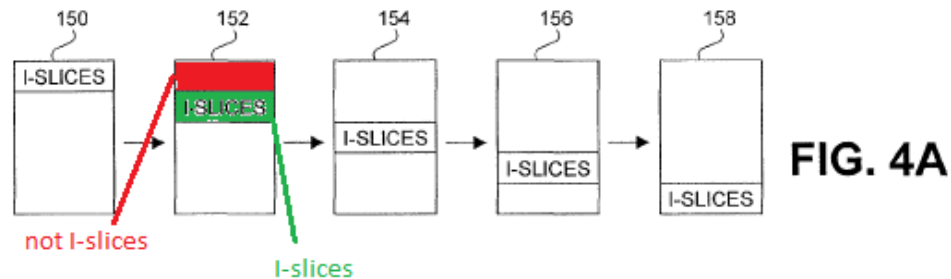
| | |
|---|---|
| <p>the entry picture is a non-intra-coded picture; and</p> | <p>display may be implemented by <i>starting at a suitable entry point, decoding quickly up to the point of the desired picture, and displaying the result, and repeating the process.</i>"); 2:24-27 ("The invention . . . may be used with streams that <i>have no I pictures and that have a 'progressive refresh' pattern of using intra-slices (I-slices)</i>"); 5:30-34 ("if the decoding starts with a picture whose first row is an I-slice, then successive P pictures can be decoded until a picture is decoded where the bottom row is an I-slice, and from that picture on, the <i>resulting pictures are fully decoded</i> and capable of being presented.")</p> |
| <p>displaying at least one of the fully decoded pictures.</p> | <p>26:11-12 (claim 1) ("<i>display video pictures</i> that are aligned with available display times") ; 5:30-34 ("if the decoding starts with a picture whose</p> |

| | |
|--|--|
| | <p>first row is an I-slice, then successive P pictures can be decoded until a picture is decoded where the bottom row is an I-slice, and from that picture on, the <i>resulting pictures are fully decoded</i> and capable of being presented.”)</p> |
|--|--|

61. *MacInnis* teaches systems for recording and playback of digitally encoded audio/video streams. EX-1003 ¶[0002]. Like the '967 patent, *MacInnis* talks about digital streams without I-pictures, such as progressive refresh or HITS (“Headend In The Sky”) streams. EX-1003 ¶[0008], [0050]; *see also* EX-1001 2:1-6. These streams are known in the field as a type of progressive refresh I-slice-based streams. EX-1003 ¶[0046]. These streams include P-pictures and B-pictures, but no I-pictures. *Id.* ¶[0052]-[0053].

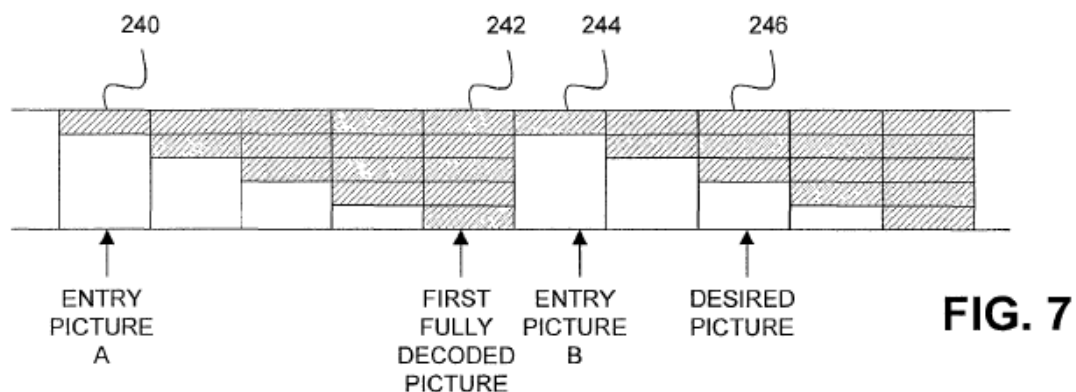
62. For example, Fig. 4A, which I have marked up below, depicts pictures 150, 152, 154, 157, and 158. A “refresh depth” that defines the number of rows of I-slices in each P-picture may be used to define how many rows of each picture are I-slices. For example, *MacInnis* explains that the “first D rows” of picture 150 are intra-coded, i.e., I-slices, where D is an integer (a number) representing refresh depth. EX-1003 ¶[0056]. The “remaining rows typically are predictively coded,

i.e., P-slices.” *Id.* In picture 152, “the first D rows are *not* I-slices and the second D rows are [I-slices].” *Id.* ¶[0057].



63. The decodable (or refreshable) portion of each picture, the I-slices, moves down “until all rows in the consecutive sequence of pictures [] [have] been represented in I-slices.” *See id.* ¶¶[0056]-[0057] (discussing pictures 150, 152, 154, 156, 158), Fig. 3 (note that I-slices move down from picture to picture).

64. Figure 7 depicts a “timing diagram” for decoding pictures having I-slices in progressive bitstreams. ¶[0021]. This figure illustrates the “reverse play” or “rewind” trick play process. ¶¶[0108]-[0109].



65. During a trick play rewind process, where the pictures in Fig. 7 must be displayed quickly from right to left (i.e., in reverse), pictures must be decoded from left to right, from EP (Entry Picture) to EP. *See, e.g., id.* ¶[0107]:

reverse display involves *starting at entry pictures, decoding forward until the desired fully decoded picture is reached, and displaying the resulting picture* while again decoding a portion of the stream, stopping the decode process at an earlier picture, and possibly starting the decode process from an earlier coded picture if necessary to achieve a fully decoded picture.

66. The decoding process may begin by decoding Entry Picture A 240 to eventually obtain a desired picture 246. ¶[0110]. After decoding EP A 240, the decoder continues decoding the pictures to the right of EP A 240 (including pictures 242 and 244), until reaching and decoding desired picture 246. *Id.* ¶[0111]. The decoding process starts with picture (or frame) EP A 240, and not with picture EP B 244, because the lowest two slices in desired picture 246 may be non-intracoded and thus cannot be decoded if the decoding process starts at picture EP 244. *See id.* ¶¶[0021], [0056], [0111]. Thus, starting the decoding process at picture EP A 240 enables decoding of slices below the last I-slice in desired picture 246. *Id.* ¶[0110].

67. *MacInnis* teaches that because the I-slices are encoded in a progressive pattern, *see* ¶¶[0021], [0056], “not all slices [in every picture] must be

decoded.” *Id.* ¶[0111]. Instead, *only* “necessary slices” are decoded, which can double the average decoding rate. *Id.*

68. Fig. 3 depicts playback system 100 which enables playback of decoded MPEG video data:

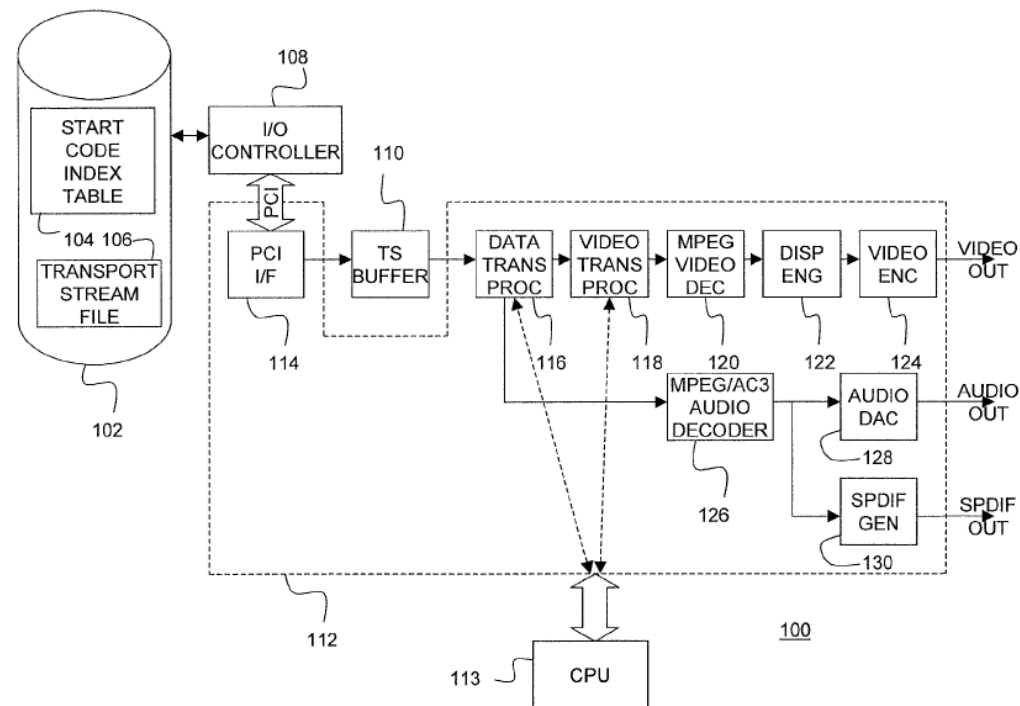


FIG. 3

69. CPU 113 reads a transport stream (“TS”) from storage device 102 into a TS buffer 110. *Id.* ¶[0036]. Similar to the host processor in the ’967 patent, CPU 113 may control a data transport processor 116 and/or a video transport processor 118 to implement trick play such as rewinding. *Id.* ¶[0037]. I note that EX-1003 ¶[0037]:

CPU 113 may control the data transport processor 116 and/or the video transport processor 118 to implement

trick modes (e.g., pause, fast forward, slow forward, rewind, fast reverse, slow reverse, skip).

is similar to EX-1001 3:45-50:

The TS 115 may be received by the decoder 120 from a host processor 110, or any other source 105 without departing from the scope and spirit of the invention. The *host processor 110* or the any other source 105 is the *device controlling the playback* (including *trick play* playback) of the data.

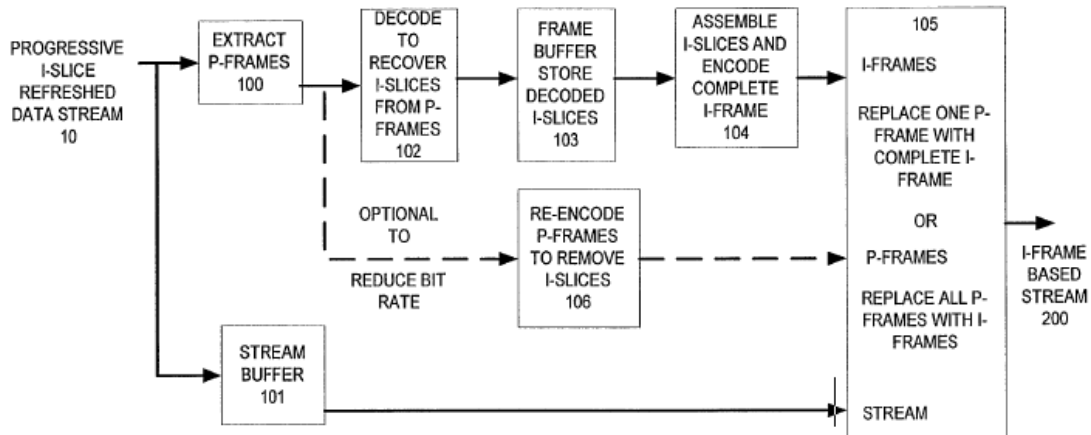
70. In my opinion, data transport processor 116 in *MacInnis* operates similarly to data transport processor 335 described in the '967 patent, by demultiplexing a transport stream TS and passing the constituent parts to respective decoders. Again, I note that the disclosure in EX-1003 ¶[0037] (“data transport processor 116 preferably de-multiplexes the TS into its constituents and *passes...MPEG video (video Transport Stream) to a video transport processor 118 and then to an MPEG video decoder 120*”) is similar to the disclosure in EX-1001 5:7-15 (“data transport processor [335] then de-multiplexes the TS into its PES constituents and *passes...the video TS to a video transport processor 340, and then to a MPEG video decoder 345* that is operable to decode and extract embedded, TS formatted command packets”).

2. Chen '677 (U.S. Patent App. Pub. 2001/0026677)

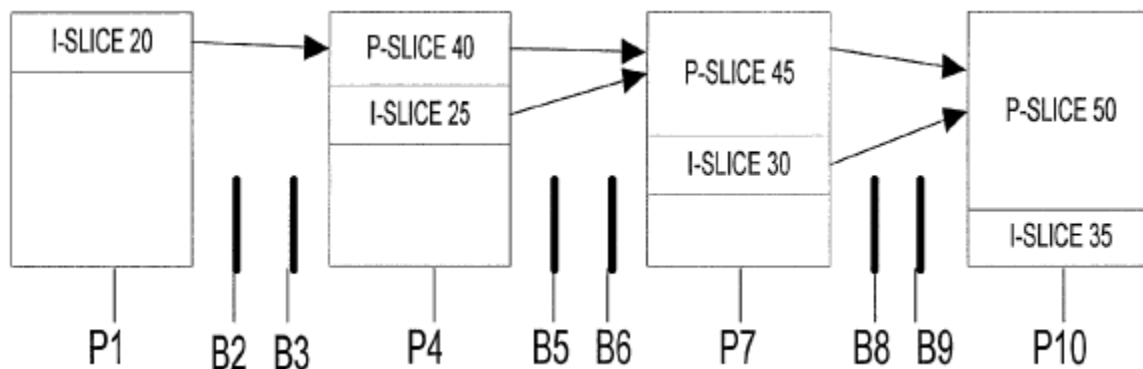
71. I understand that *Chen* '677, EX-1004, is a U.S. Patent Application Publication No. 2001/0026677 to Chen et al.

72. Like the '967 patent, *Chen* '677 relates to decoding “progressive I-slice refreshed MPEG data streams.” EX-1004 ¶[0003]; *see also* EX-1001 2:6-16. The phrase “progressive refresh” (as used in *Chen* '677) refers to the manner of decoding a picture. *See* EX-1004 ¶¶[0005], [0009]. For example, in a progressive refresh scheme, a decodable portion (such as an I-slice) in each picture in a set of pictures moves from the top of one picture to the bottom of the next. EX-1004 Fig. 1, ¶¶[0022]-[0025]. A P-picture can only be decoded (“refreshed”) once a set of P-pictures has been decoded such that each portion of that original P-Picture has been decoded. EX-1004 ¶¶[0022], [0031]; *see* EX-1007 1:22-25 (explaining refreshing of P-pictures).

73. *Chen* '677 recognizes the difficulty in implementing “trick play modes in a progressive I-slice refreshed MPEG data stream.” EX-1004 ¶[0005]. *Chen* '677 notes that “the lack of I-frames requires either extremely large buffers for several pictures worth of data or the stream must be fully decoded and then re-encoded as an I-frame based stream.” ¶[0005]. The process in *Chen* '677 solves this problem by “transcoding progressive I-slice refreshed MPEG data streams to I-frame based MPEG data streams to enable trick play modes on a television appliance.” *Id.* ¶[0021]. Figure 2 represents this transcoding process:



74. Television appliance 300 receives a progressive I-slice refreshed stream (10) in step 100 and extracts the P-frames. EX-1004 ¶[0025]. The stream is buffered in step 101, and the P-frames are decoded “to recover the I-slices” which are distributed over multiple P-frames and “make up a complete I-frame.” *Id.* ¶[0012], [0025]. Fig. 1 shows an example of such a stream, where the I-frame is divided into slices and spread across P-frames:



75. Rather than requiring decoding of every slice in each frame, *Chen* ‘677 explains that “[t]hose skilled in the art will appreciate that the P-frames need only be *partially decoded* in order to recover the I-slices.” *Id.* ¶[0025].

76. Reconstructing a P-frame requires decoding at least the previous frame. *Id.* ¶[0022]. For example, I-slice 25 and P-slice 40 in P-frame P4 provide “reference macroblocks that can be used to predict” the contents of P-slice 45 in P-frame P7. *Id.* ¶[0023]. Macroblocks are square-shaped blocks representing picture data. EX-1009 5 (definition 3.89).

3. ISO/IEC 13818-2 (“*ISO 13818-2*”)

77. ISO/IEC 13818-2 (which I will refer to as “*ISO 13818-2*”) is a standard for coding of “moving pictures and associated audio information.” EX-1009 1. *ISO 13818-2* is also referred to as the “H.262” and “MPEG-2 Part 2” standard. EX-1009 v (“the identical text is published as ITU-T Rec. *H.262*”), 154 (discussing the complexity of the “MPEG-2 Standard” embodied in the document); *see also* EX-1003 ¶[0054] (referring to “*the MPEG-2 video standard [as] ISO/IEC 13818-2*”). ISO 13818-2 makes up one portion of a larger standard that includes ten separate parts. *See* EX-1009 v (listing Parts 1-10). According to the ’967 patent, the *ISO 13818-2* dominated distribution of digital video content for TV display at the time the application that matured into the ’967 patent was filed, EX-1001 1:31-33.

78. *ISO 13818-2* is a part of the ISO 13818 standard that enables motion video to be “manipulated as a form of computer data” for storage and transmission over various networks. EX-1009 vi. The standard defines how video data may be

encoded for computers to render it as well. For example, the standard discusses sending MPEG bitstreams “within transport packets.” EX-1009 160 (§ D.13.2.2). Encoders that produces bitstreams with “adaptive slice sizes” may “keep[] track of the data contents within transport packets” and place the start of each slice “at the first opportunity in every transport packet.” *Id.* ISO 13818-2 makes other references to storing and transmitting the stream in a PES or “Packetized Elementary Stream.” *See, e.g.*, EX-1009 154 (referring to storing information for decoding the bitstream in the “PES packet”), 155 (same); *see also* EX-1011, 647, defining “PES” as

Packetized Elementary Stream: In MPEG-2, after the media stream has been digitized and compressed, it is formatted into packets before it is multiplexed into either a Program Stream or Transport Stream.

79. ISO 13818-2 explains that using adaptive slice sizes and placing the start of each slice in every transport packet “gives an advantage in cell or packet based transmission,” such as transmission over the Internet, “or where error detection occurs over a large block of data.” EX-1009 160 (§ D.13.2.2).

80. ISO 13818-2 also explains that a “slice” is a “series of an arbitrary number of consecutive macroblocks.” EX-1009 18 (§ 6.1.2). Each slice in a frame “shall occur in the bitstream in the order in which they are encountered, starting at the upper-left of the picture and *proceeding by raster-scan order* from left to right

and top to bottom (illustrated in Figures 6-8 and 6-9 as alphabetical order).” *Id.*

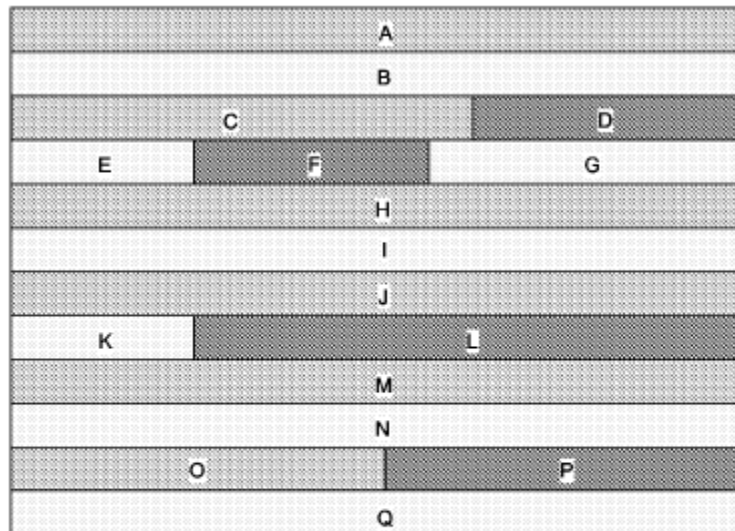


Figure 6-9 – Restricted slice structure

81. In my opinion, MacInnis anticipates claims 1-5 under the broadest reasonable constructions consistent with the '967 patent or those offered by Broadcom in the related ITC Investigation. EX-1008.

a. [1.0] MacInnis discloses “A system for displaying pictures”

However, to the extent the preamble is argued or found to be limiting, it is my opinion that *MacInnis* discloses a system and method for recording and playback

of digitally encoded audio/video streams. EX-1003 ¶[0002]. For example,

MacInnis depicts playback system 100 in Fig. 3:

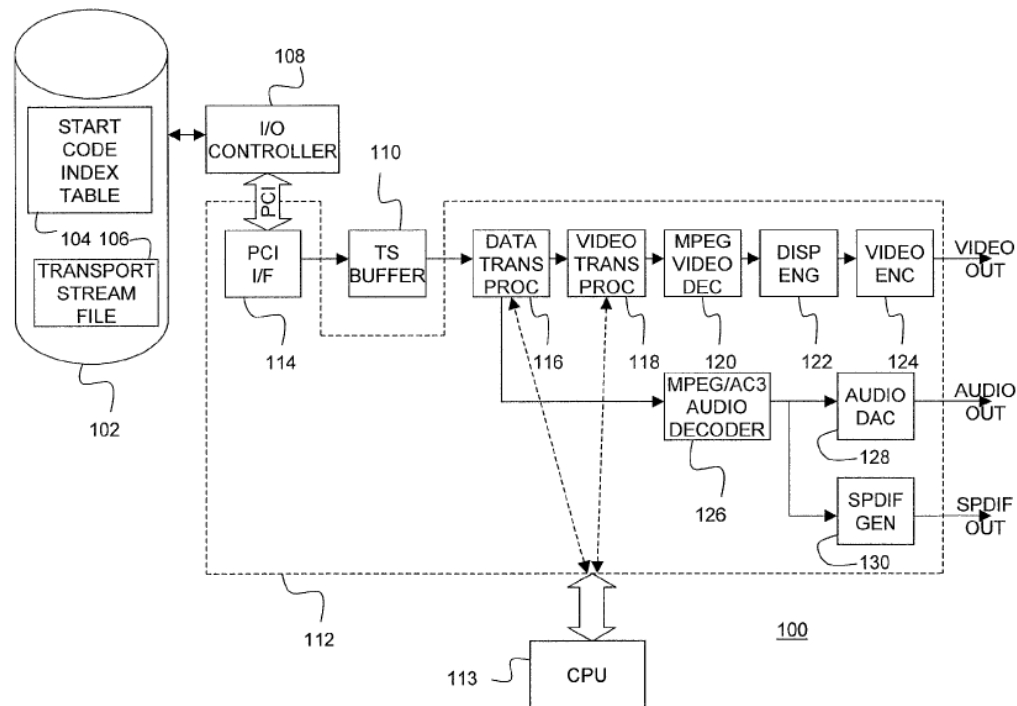


FIG. 3

83. Playback system 100 includes CPU 113. CPU 113 reads a transport stream (TS) from a storage device 102 and a data transport driver in CPU 113 is “responsible for data flow of the stream to be played back through the data transport processor 116 and/or the video transport processor 118.” *Id.* ¶[0040]. CPU 113 “may control the data transport processor 116 and/or the video transport processor 118 to implement trick modes” such as “rewind.” *Id.* ¶[0037].

84. The “data transport processor 116 de-multiplexes the TS into its constituents.” *Id.* ¶¶[0036]-[0037]. Data transport processor 116 transmits the MPEG video TS to a video transport processor 118 and an MPEG video decoder

120. ¶[0037]. The MPEG video decoder may decode the MPEG video and send it to a display engine 122. ¶[0045]. Display engine 122 may scale the video, render graphics, and construct a complete display based on the decoded video. *Id.* Once the video is “ready to be presented,” display engine 122 may pass the video to a video encoder 124 for output in analog format or in digital format. *Id.*

85. Thus, because playback system 100 may read and pass a stream to a video encoder for output, *MacInnis*’ playback system 100 discloses the claimed “system for displaying pictures.”

b. [1.1] MacInnis discloses “a host processor for transmitting transport packets, said transport packets providing a plurality of instructions”

86. As I explained above, in my opinion, the broadest reasonable construction of “transport packet” is “a packet containing either data or instructions.” Moreover, in my opinion, the broadest reasonable construction of “instructions” is “commands, separate from video or audio data, that specify trick play functions to be performed,” *id.*, while Broadcom’s construction of this term is “the contents of the coded or compressed audio or video syntax itself, which instructs or causes the decoder to perform various tasks.” *Id. see also* EX-1008 3.

87. Because the construction of “transport packet” includes the construed term “instructions,” I note that incorporating the constructions of “instructions” into the construction for “transport packet” yields two different constructions:

- I. a packet containing either data or commands, separate from video or audio data, that specify trick play functions to be performed; and
- II. a packet containing either data or the contents of the coded or compressed audio or video syntax itself, which instructs or causes the decoder to perform various tasks.

88. Under either of these constructions, it is my opinion that *MacInnis* teaches element [1.1].

i. Construction I

89. CPU 113 in *MacInnis* discloses the claimed host processor for transmitting transport packets providing a plurality of instructions under the first construction of “transport packet.” I understand that Broadcom has asserted in related litigation that the phrase “host processor” means

any device or element that processes an incoming transport stream (i.e., a stream of packets), extracts the packets from the stream, and passes the packets on to a decoder device (such as any audio or visual decoding device or functionality),

citing 3:45-52 of the '967 patent. EX-1008. Under at least this construction, it is my opinion that CPU 113 in *MacInnis* teaches the claimed “host processor.” CPU 113 “reads the TS [(transport stream)] data from storage device 102 based on the user selected playback mode.” ¶[0036]. Reading this transport stream comprises

extracting the packets from it. *See* ¶[0027] (explaining that the TS comprises “packets”). CPU 113 may comprise a data transport driver, or “DTD.” ¶[0040]. DTD may be responsible for playing back the stream “through the data transport processor 116 and/or the video transport processor 118.” *Id.* ¶[0037].

90. The DTD may control the playback of the stream by “*insert[ing] a command transport packet* containing various commands to the video transport processor 118 and video decoder 120.” *Id.* ¶[0040]. Inserting command transport packets comprises inserting them into the transport stream and transmitting them to decoder 120. *Id.*

91. Because the DTD inside of CPU 113 inserts into the stream transport packets that contain “commands, separate from video or audio data, that specify trick play functions to be performed” (LGE’s construction of “instructions”) into a stream for transmission to video transport processor 118 and video decoder 120, CPU 113 teaches element [1.1] under the first construction.

ii. Construction II

92. CPU 113 in *MacInnis* meets this limitation under the second construction (i.e., “the contents of the coded or compressed audio or video syntax itself, which instructs or causes the decoder to perform various tasks”) as well.

93. DTD in CPU 113 is “responsible for data flow of the stream to be played back through the data transport processor 116 and/or the video transport

processor 118.” EX-1003 ¶[0040]. CPU 113 “[feeds]” the video stream to the decoder. *Id.* ¶[0099]. The video stream itself constitutes the “contents of the coded or compressed audio or video syntax itself, which instructs or causes the decoder to perform various tasks” under Broadcom’s construction.

94. Because CPU 113 transmits the video stream to the decoder, it is my opinion that *MacInnis* teaches element [1.1] under this construction as well.

c. [1.2] MacInnis discloses “a video decoder for executing the plurality of instructions”

95. *MacInnis* discloses, as I explained above, an MPEG video decoder 120. EX-1003 Fig. 3, ¶[0037]. The DTD in CPU 113 may control the playback of the stream by “insert[ing] a command transport packet *containing various commands* to the video transport processor 118 and *video decoder 120.*” ¶[0040].

96. Video decoder 120 may use these commands to control the data flow of the MPEG video stream, for example, by implementing and controlling trick modes. ¶[0043]. Trick modes include, for example, pausing the stream, fast forwarding the stream, rewinding the stream, or skipping portions of the stream. ¶[0037].

97. Video decoder 120 supports these trick modes during playback by “randomly access[ing] the recorded Transport Stream (e.g., TS file 106) stored in storage device 102 to retrieve the correct TS data.” ¶[0038]. Video decoder 120

interprets the command fields in the transport packet inserted into the stream to control the MPEG video stream. ¶¶[0040], [0043].

98. Because video decoder 120 receives command transport packets that contain various commands, and uses those commands to operate on the MPEG stream, for example, to effect trick play, it is my opinion that *MacInnis*' video decoder 120 constitutes the claimed "video decoder for executing the plurality of instructions."

d. [1.3] MacInnis discloses "wherein execution of the instructions by the video decoder comprises causing"

99. As discussed above with respect to element [1.2], video decoder 120 interprets command fields in transport packets inserted into the MPEG stream to control the MPEG video stream. ¶[0040]. Video decoder 120 can execute these commands to perform trick modes during playback. ¶[0038].

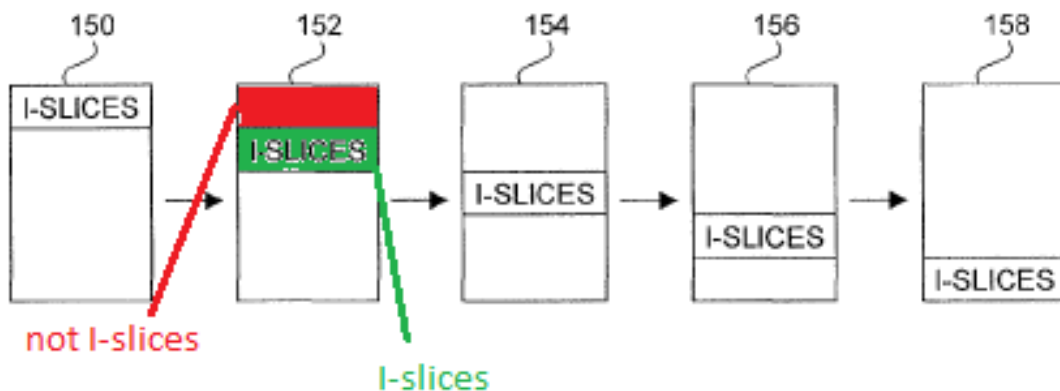
100. Because video decoder 120 receives command transport packets that contain various commands, and executes those commands to operate on the MPEG stream, it is my opinion that *MacInnis*' video decoder 120 teaches executing "the instructions by the video decoder."

- e. **[1.4] MacInnis discloses “selecting a picture, said picture comprising an intracoded slice and at least one slice above the intracoded slice, and at least one slice below the intracoded slice.”**

101. *MacInnis* discloses element [1.4], which I have broken out into subparts below.

- i. **[1.4.a] MacInnis discloses “selecting a picture, said picture comprising an intracoded slice and at least one slice above the intracoded slice.”**

102. Figure 4A of *MacInnis* depicts pictures 150-158 in a stream lacking I-pictures. EX-1003 ¶¶[0047]-[0050], [0056]. For example, in picture 152, the “first D rows are not I-slices, and the second D rows are [I-slices].” ¶[0057]. Here, “D” is an integer (a number).



103. Picture 152 constitutes the claimed “picture.” *MacInnis* explains that decoding a stream for trick play functionality comprises “starting at entry pictures” and “decoding forward until the desired fully decoded picture is reached.”

EX-1003 ¶[0107]. Thus, in my opinion, *MacInnis* teaches “selecting” each picture as part of a decoding process.

104. *MacInnis* explains that within P-pictures (such as P-pictures 150-158) “there are some rows that are coded as intra-slices (I-slices).” ¶[0054]. The remaining rows of each picture “typically are predictively coded, i.e., P-slices, even though it is possible for the remaining rows to include I-slices.” *See* EX-1003 ¶[0056].

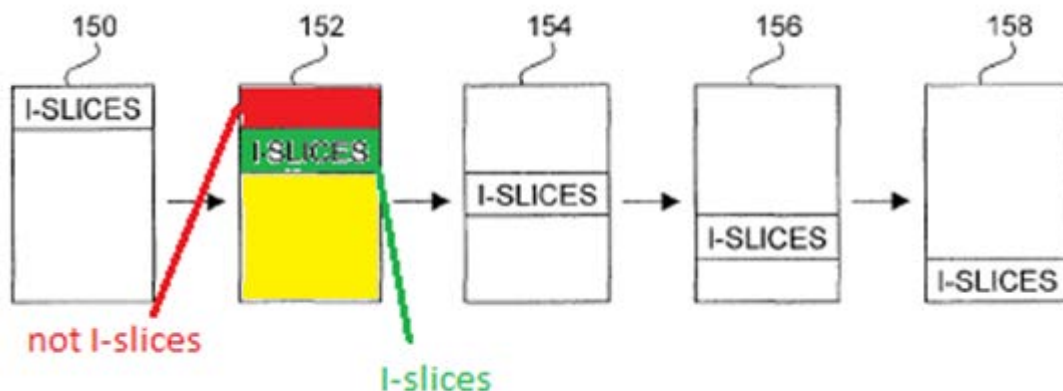
105. *MacInnis* makes clear that the variable “D” represents an integer that represents the number of rows that “are encoded as I-slices in each P-picture,” which it refers to as the “refresh depth.” ¶[0055]. The “I-slices” portion highlighted in green may contain “[a]nywhere from 1 to 9 rows [] encoded as I-slices.” *Id.* For example, the “I-slices” in *MacInnis* may be a single row encoded as an I-slice (e.g., D=1). *Id.*

106. In my opinion, the “I-slices” highlighted in green (above) constitutes the claimed “intracoded slice,” and the rows in red above the intracoded slice constitute the claimed “at least one slice above the intracoded slice.”

- ii. **[1.4.b]: *MacInnis* discloses “said picture comprising...at least one slice below the intracoded slice.”**

107. As I explained above with respect to element [1.4.a], picture 152 contains rows that are not coded as intracoded slices (in red) and rows that are coded as intracoded slices (in green). ¶¶[0054], [0057].

108. *MacInnis* makes references to the rows that follow the intracoded slices, explaining that the “remaining rows” that follow rows coded as intracoded slices “typically are predictively coded, i.e., P-slices, even though it is possible for the remaining rows to include I-slices.” ¶[0056]. These “remaining rows” are highlighted in yellow in picture 152 below:



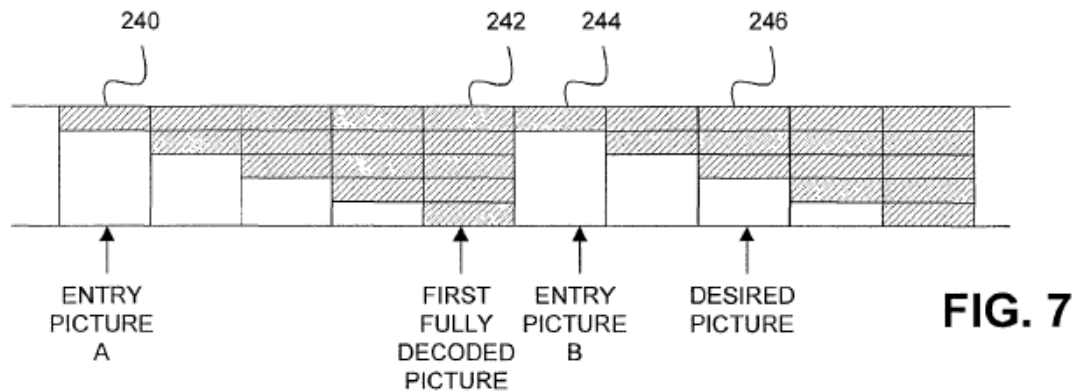
109. In my opinion, the rows that follow the I-slices in *MacInnis* constitute the claimed “at least one slice below the intracoded slice.”

f. [1.5]: *MacInnis* discloses “decoding the at least one slice above the intracoded slice.”

110. *MacInnis* explains that decoding starts with a picture whose first row is an I-slice, and may continue successively “until a picture is decoded where the bottom row is an I-slice.” ¶[0060]. For example, decoding may start at picture 150

(where “the first D rows...are I-slices”) and continue until picture 158 (“where the bottom row is an I-slice”). *See, e.g., id.*, ¶¶[0056]-[0060].

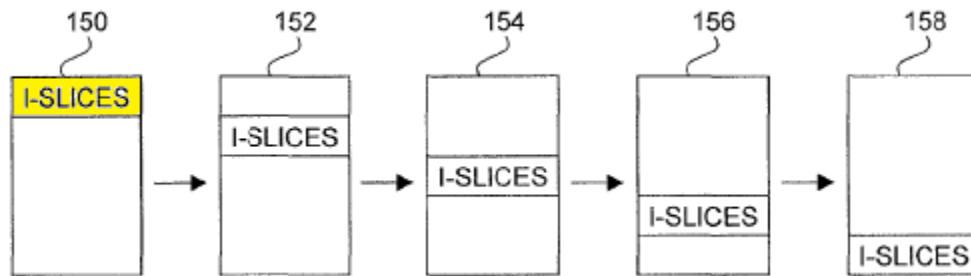
111. Fig. 7 illustrates a process of implementing “reverse display” such as trick play rewind. EX-1003 ¶[0107]:



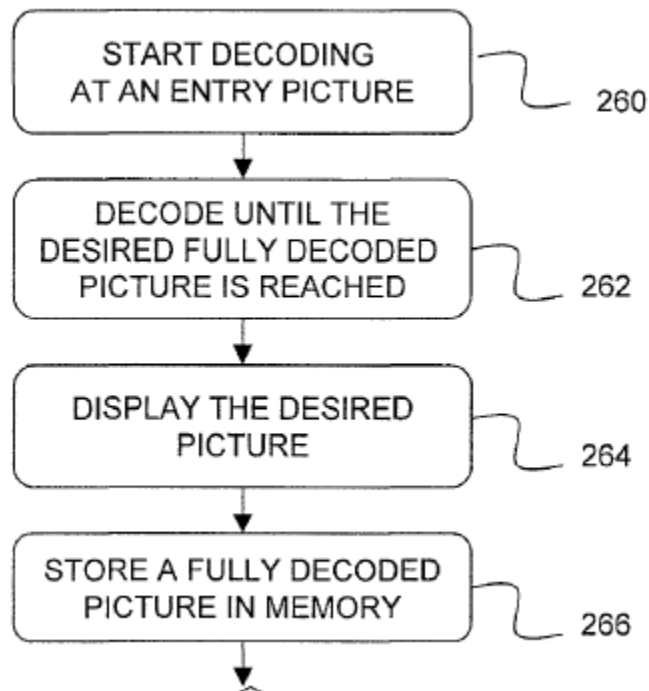
112. Decoding a stream for trick play rewind, where pictures are displayed from right to left, starts by decoding pictures in forward order, e.g., from left to right, starting at picture EP 240 (Entry Picture). *See, e.g., id.*, ¶[0107]:

In an embodiment according to the present invention, a method of implementing *reverse display* involves starting at entry pictures, *decoding forward until the desired fully decoded picture is reached*, and displaying the resulting picture while again decoding a portion of the stream, stopping the decode process at an earlier picture, and possibly starting the decode process from an earlier coded picture if necessary to achieve a fully decoded picture.

113. Entry Pictures (EP) are pictures whose first row is an I-slice. *Id.*, ¶[0061]. Because picture 150 in Fig. 4A has I-slices for its topmost D rows, picture 150 is an EP:

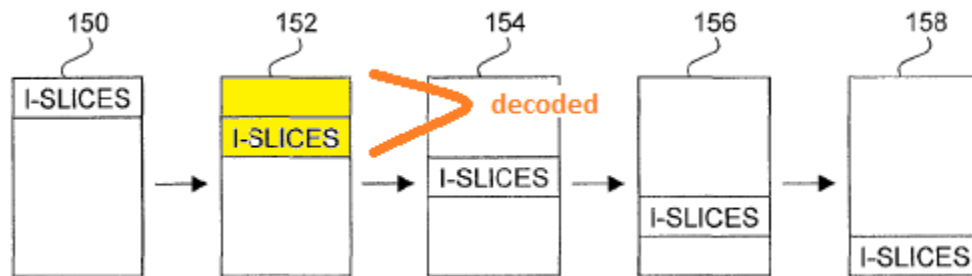


114. After decoding the EP, “the process proceeds with decoding forwards from the entry picture until the desired picture has been decoded in step 262, and [] the result [is displayed] in step 264.” *Id.*, ¶[0111]; see also Fig. 8:



115. This means that pictures are decoded from left to right (in Fig. 7, this is represented by starting at picture EP A 240 and ending at desired picture 246).
See, e.g., id., ¶[0107], Fig. 7.

116. Thus, after decoding picture 150 where the topmost D rows are I-slices, ¶[0056], MPEG video decoder 120 in playback system 100 may begin decoding picture 152, where the topmost D rows are not I-slices, but the second set of D rows are I-slices. ¶[0057], Fig. 4A:

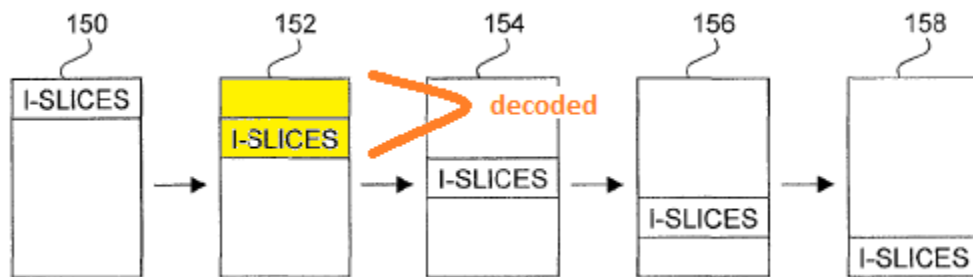


117. Paragraph [0095] of *MacInnis* explains that “for the entry picture [(picture 150)], only the I-slices (rows) at the top of the picture preferably are decoded” and for the “second picture [(picture 152)] the (2xrefresh depth) [(2*D)] rows at the top [of the picture] preferably are decoded.”

118. Because the first D rows of the claimed “picture” (e.g., picture 152) are decoded, and the first D rows include slices above the I-slices, it is my opinion *MacInnis* discloses the claimed “decoding the at least one slice above the intracoded slice.”

g. [1.6]: *MacInnis* discloses “decoding the intracoded slice.”

119. *MacInnis* discloses element [1.6]. As I explained above with respect to element [1.5], MPEG video decoder 120 may decode picture 152, where the topmost D rows are not I-slices, but the second set of D rows are I-slices. ¶[0057]. ¶[0095] explains that for this second picture, the first D *and* second D rows “at the top [of the picture] preferably are decoded.” *See again* Fig. 4A:



120. Because the second D rows of the claimed “picture” 152 are decoded, and the second D rows include I-slices, it is my opinion that *MacInnis* discloses the claimed “decoding the intracoded slice.”

h. [1.7]: *MacInnis* discloses “decoding at least a portion of another picture after decoding the at least one slice above the intracode slice and the intracode slice without having decoding the at least one slice below the intracoded slice.”

121. As I explained above with respect to elements [1.4]-[1.6], *MacInnis* explains that decoding starts with a picture whose first row is an I-slice, and may continue successively “until a picture is decoded where the bottom row is an I-slice.” ¶[0060]. For example, decoding may start at picture 150 (where “the first D

rows...are I-slices”), continue to picture 152 (for which “the first D rows are not I-slices, and the second D rows are”), and then continue to picture 154 (for which the “first 2*D rows are not I-slices, and the 3rd D rows are”). *See, e.g., id.* ¶¶[0056]-[0060]. Thus, picture 154 constitutes the claimed “another picture.” Moreover, for the reasons discussed above with respect to elements [1.5] and [1.6], *MacInnis* teaches “decoding the at least one slice above the intracode slice and the intracode slice” as also recited in element [1.7].

122. MPEG video decoder 120 may decode picture 154. *See, e.g.,* ¶[0107] (discussing left-to-right decoding of stream). Thus, it is my opinion that *MacInnis* discloses “decoding at least a portion of another picture after decoding the at least one slice above the intracode slice and the intracode slice.”

123. Not all slices of each picture in *MacInnis* have to be decoded. To save on processing time, *MacInnis* makes clear that in some embodiments, only the rows above the I-slices and the I-slices must be decoded:

in a progressively refreshed bitstream where the location of the I-slices moves from top to bottom, for the entry picture, *only the I-slices (rows) at the top* of the picture preferably are decoded. For the second picture, *the (2 x refresh depth) rows at the top* preferably are decoded, and so on until I-slices have been decoded at the bottom of the last picture of the BOP.

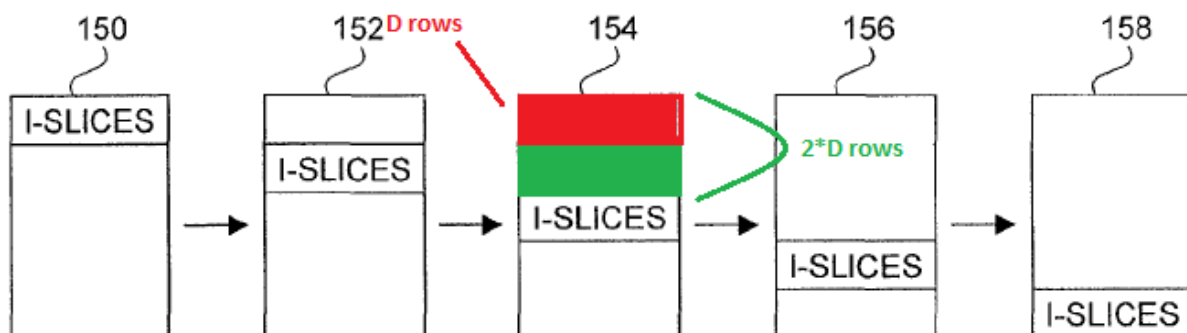
124. That discussion is in ¶[0095]. This means that each picture is decoded from the top of the picture until the end of the I-slice. The decoder thus may omit

the slices that come below the I-slices and “only” decode the I-slices (rows) at the top of the picture.” EX-1003 ¶[0095]. This process of decoding only particular slices applies equally to the reverse process, as *MacInnis* explains that

it should be noted that not all slices need to be decoded, *just as in the case of fast forward at high rates while skipping data*. Decoding *only the necessary slices* may approximately double the average decode rate.

See ¶[0111].

125. Because the first D (refresh depth) rows in the second picture (e.g., picture 152) are above the I-slice, and the second D rows in the second picture are the I-slices, decoding the “(2 x refresh depth) rows” decodes the rows above the I-slices and the I-slices themselves, but the rows below the I-slices need not be decoded. See EX-1003 ¶¶[0095], [0068], [0111]. Similarly, because in picture 154 “the first 2*D rows are not I-slices, and the 3rd D rows are [I-slices],” the rows above the I-slices and the I-slices are decoded, but the rows below the I-slices need not be decoded. *Id.* ¶¶[0095], [0111], Fig. 4A:



126. Thus, because the rows above the I-slices and the I-slices in each picture may be decoded, and because *MacInnis* also discloses omitting decoding the slices below the I-slices, it is my opinion that *MacInnis* discloses “decoding at least a portion of another picture...without having decoding the at least one slice below the intracoded slice” as required by element [1.7].

2. Claim 2

a. [2.1] *MacInnis* discloses “wherein the another picture comprises an intracoded slice and at least one slice above the intracoded slice.”

127. As I discussed above with respect to elements [1.4]-[1.7], *MacInnis* explains that decoding starts with a picture whose first row is an I-slice, and may continue successively “until a picture is decoded where the bottom row is an I-slice.” ¶[0060].

128. For example, after decoding pictures 150 and 152, decoder 120 may decode picture 154 (the claimed “another picture”), which is described as having the “first 2*D rows” that “are not I-slices, and the 3rd D rows are.” *See, e.g., id.* ¶¶[0056]-[0060].

129. Picture 154 (the claimed “another picture”) comprises at least one I-slice (the claimed “an intracoded slice”) and 2*D rows that are not I-slices (the claimed “at least one slice above the intracoded slice”). Thus, in my opinion, *MacInnis* teaches element [2.1].

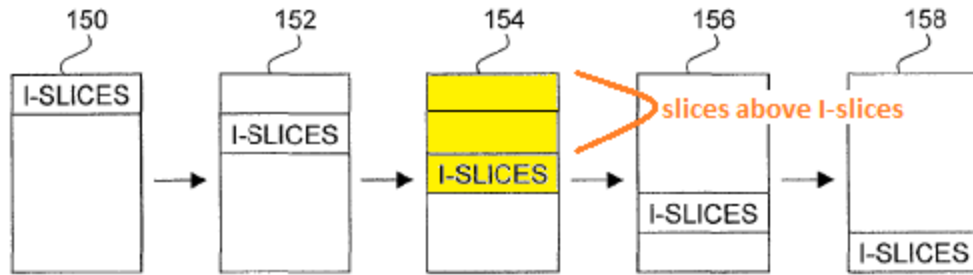
- b. **Element [2.2]: *MacInnis* discloses “wherein decoding at least a portion of the another picture further comprises: decoding the at least one slice above the intracoded slice in the second picture; and decoding the intracoded slice of the second picture.”**

130. *MacInnis* discloses element [2.2], which is broken into subparts below due to its length.

- i. **Element [2.2.a]: *MacInnis* discloses “wherein decoding at least a portion of the another picture further comprises: decoding the at least one slice above the intracoded slice in the second picture.”³**

131. See my discussion of elements [1.5] and [2.1] above. *MacInnis* explains that decoding starts with a picture whose first row is an I-slice, and may continue successively “until a picture is decoded where the bottom row is an I-slice.” *Id.* ¶¶[0060], [0058]. For picture 154, the first D, second D, and third D rows “at the top [of the picture] preferably are decoded.” *See, e.g., id.* ¶[0095] (explaining that rows at the top of each picture, including the I-slices, are decoded) and Fig. 4A:

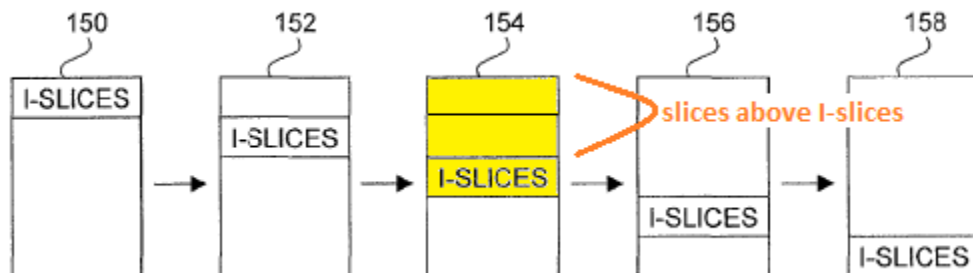
³ Claim 2 switches between discussing the “another picture” and the “second picture.”



132. Because the first D and second D rows of picture 154 are decoded, and the first D and second D rows include slices above the I-slices, *MacInnis* discloses the claimed “decoding the at least one slice above the intracoded slice in the second picture.”

- ii. **Element [2.2.b]:** *MacInnis* discloses “wherein decoding at least a portion of the another picture further comprises: . . . decoding the intracoded slice of the second picture.”

133. See my discussion of elements [1.6], [2.1], and [2.2.a], above. MPEG video decoder 120 may decode the first D, second D, and third D rows of picture 154, where the first D and second D rows are not I-slices, but the 3rd D rows *are* I-slices. See EX-1003 ¶[0057]. See again ¶[0095] and Fig. 4A:



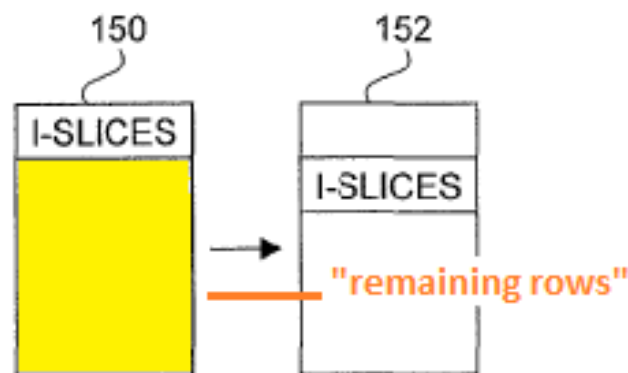
134. Because the third D rows of picture 154 are decoded, and the third D rows include I-slices, *MacInnis* discloses the claimed “decoding the intracoded slice of the second picture.”

3. **Claim 3: *MacInnis* discloses “wherein causing decoding the at least one slice above the intracoded slice in the another picture comprises causing: predicting the slices above the intracoded slice in the another picture from the intracoded slice and the slices above the intracoded slice in the picture.”**

135. *MacInnis* discloses claim 3. Each of the pictures in the stream is one of a P-picture (predicted picture) or a B-picture (bi-directionally predicted picture). See EX-1003 ¶[0053]. For example, in picture 150, other than the I-slices at the top of the picture,

[t]he *remaining rows* typically are predictively coded, i.e. P-slices, even though it is possible for *the remaining rows* to include I-slices in case all macroblocks happen to be intra coded.

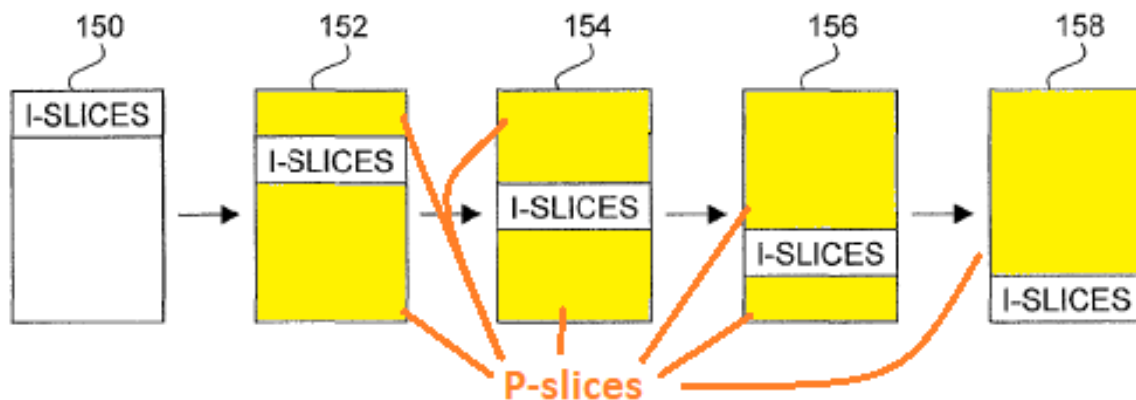
136. See also Fig. 4A:



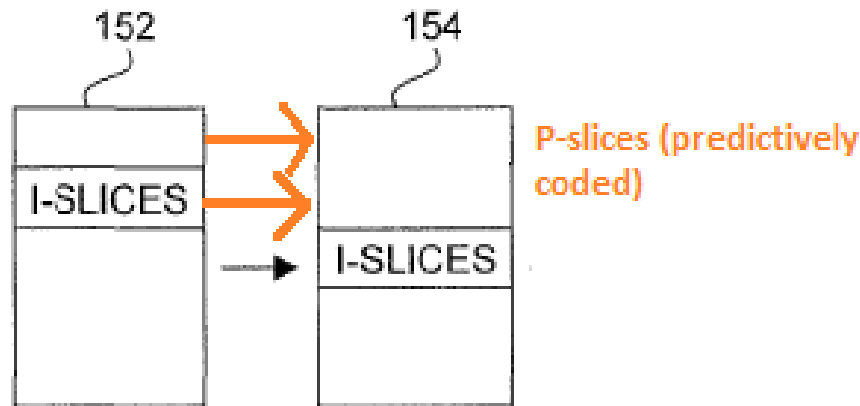
See also ¶[0058] (explaining that motion vectors in pictures where the I-slices are “not at the top of the picture” are limited to pointing at rows at or above their I-slices).

137. The rows above the I-slices in each picture may also be P-slices. In picture 152, “the first D rows are not I-slices.” EX-1003 ¶[0057]. In fact, a POSITA would understand from this disclosure that the slices in all “remaining rows” in pictures 152, 154, 156, and 158 may also be predictively coded (P-slices).

See again Fig. 4A:



138. Because the slices above the I-slices in picture 154 are predictively coded, those slices are predicted using the I-slices and P-slices above the I-slices in picture 152. See again Fig. 4A:



See also ¶[0058].

139. Thus, because *MacInnis* teaches predicting the slices above the intracoded slice in picture 154 (claimed “predicting the slices above the intracoded slice in the another picture”) using the I-slices and slices above the I-slices in picture 152 (“predicting...from the intracoded slice and the slices above the intracoded slice in the picture”), *MacInnis* discloses claim 3.

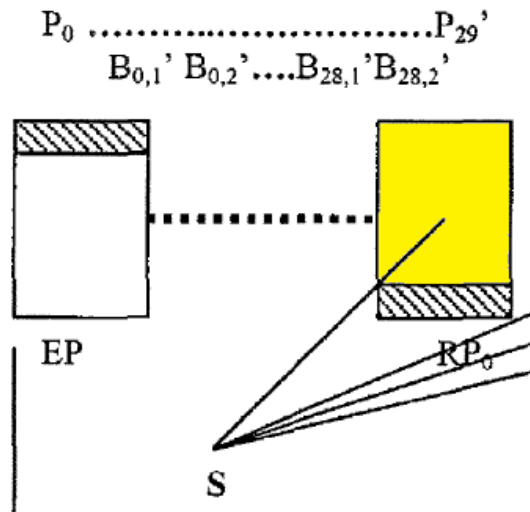
4. Claim 4: *MacInnis* discloses “wherein decoding the at least one slice above the intracoded slice further comprises causing: decoding the at least one slice in raster order.”

140. The ’967 patent discloses a top-to-bottom order of decoding for “raster order.” See EX-1001 6:46-52:

Accordingly, aspects of the present invention involve decoding the slices, S, of the HITS stream P-pictures, e.g., $P_0' \dots P_{28}'$ which are above the last intracoded slice I in the picture. If the slices, S, I of the P-pictures, $P_0' \dots P_{28}'$, are decoded in raster order, the video decoder 345

decodes *each slice of the P-picture, $P_0' \dots P_{28}'$, until the last intracoded slice, I* is decoded.

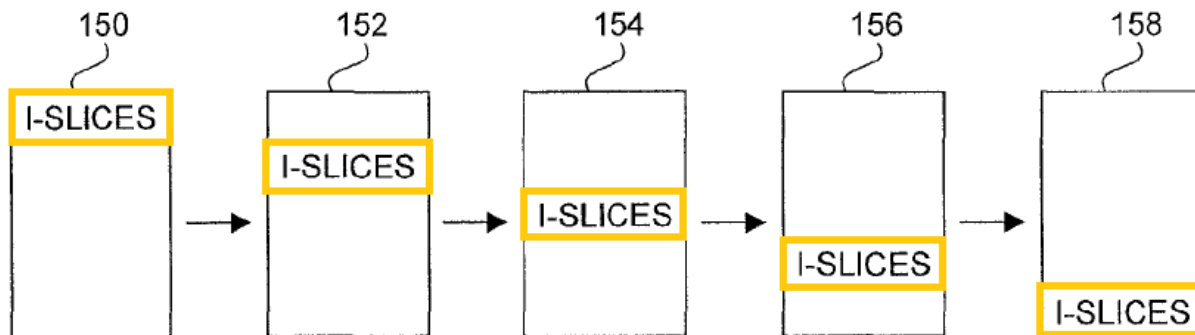
141. Fig. 4 depicts this top-to-bottom decoding order which decodes the slices (“S”) “which are above the last intracoded slice I in the picture” from top to bottom (highlighted in yellow):



Id. 6:48-49.

142. *MacInnis* similarly teaches this top-to-bottom decoding process. For example, decoding may start at picture 150, where “the first D rows...are I-slices.”

Id. ¶[0056]. Decoding may continue to picture 152, where “the first D rows are not I-slices, and the second D rows are” I-slices. *Id.* ¶[0057]. Decoding may then continue to picture 154 (the claimed “another picture”), similarly described as having the “first 2*D rows” that “are not I-slices, and the 3rd D rows are.” *See, e.g., id.* ¶¶[0056]-[0060], Fig. 4A:



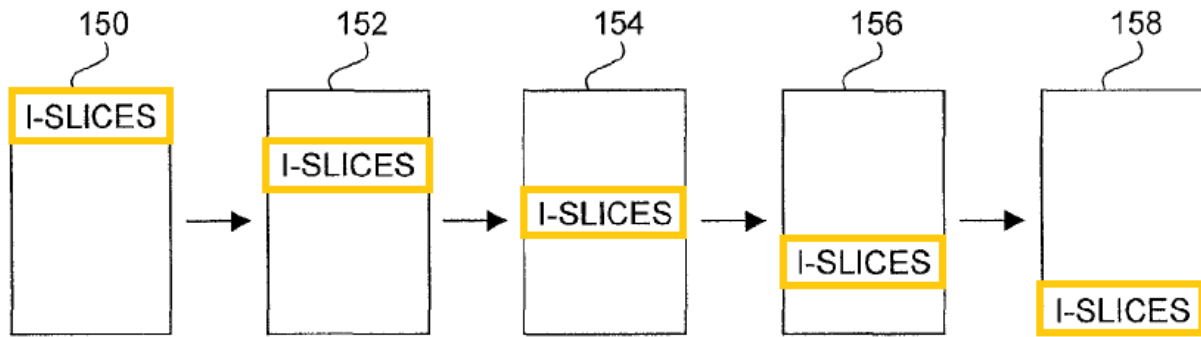
143. *MacInnis* thus teaches decoding a top-most slice (in picture 150), followed by slices that progressively move from top-to-bottom, until decoding a bottom-most slice (in picture 158).

144. Accordingly, because *MacInnis* teaches decoding the first D rows in a first picture, followed by the first D and second D rows in a second picture, followed by the first D, second D, and third D rows in a third picture, etc., it is my opinion that *MacInnis* teaches “decoding the at least one slice in raster order” as required by claim 4.

5. Claim 5: *MacInnis* discloses “wherein the picture comprises a P-picture from a HITS stream.”

145. *MacInnis* discloses claim 5. *MacInnis* relates to decoding digital streams, such as HITS streams, that do not include I-pictures but do include P-pictures (predicted picture) or B-pictures (bi-directionally predicted picture). EX-1003 ¶[0008], [0050], [0053].

146. The stream depicted in Figure 4A includes I-slices that “follow a consistent pattern” in that they “appear sequentially from top to bottom” from start to finish in the stream. EX-1003 ¶[0056]; Fig. 4A:



147. *MacInnis* explains that this pattern of I-slices only applies to P pictures. ¶[0056]. Thus, because picture 152 (the claimed “picture”) is a P-picture from a HITS stream, *MacInnis* teaches claim 5.

C. Obviousness of claim 4 based on *MacInnis* and *ISO 13818-2*.

148. In my opinion, *MacInnis* in view of *ISO 13818-2* renders claim 4 obvious under the broadest reasonable constructions consistent with the ’967 patent or those offered by Broadcom in the related ITC Investigation. EX-1008.

1. **Claim 4: *MacInnis* in view of *ISO 13818-2* renders obvious “wherein decoding the at least one slice above the intracoded slice further comprises causing: decoding the at least one slice in raster order.”**

149. As I mentioned above, *MacInnis* teaches a top-to-bottom decoding order for the slices in a bitstream. *See, e.g.*, EX-1003 Fig. 4A, ¶¶[0056]-[0060]. Decoder 120 decodes the slices in the bitstream from top-to-bottom. Therefore, the

claimed “at least one slice,” that is, the slice(s) across the bitstream, is decoded “in raster order.” Should the argument arise that *MacInnis* does not expressly disclose “decoding the at least one slice in raster order,” POSITA would understand that *ISO 13818-2* also expressly discloses this step.

150. *MacInnis* specifically refers to and builds upon the MPEG-2 standard in *ISO 13818-2*. ¶[0054] (“Rows and slices [in *MacInnis*] are defined in the MPEG-2 video standard, ISO/IEC 13818-2”); see also, e.g., ¶¶[0026], [0033], [0037], and [0050] (referring to “MPEG-2 video streams”). In my opinion, a POSITA would have started with *ISO 13818-2* when implementing *MacInnis*.

151. As I mentioned above, according to the ’967 patent, the ISO 13818 standard dominated distribution of digital video content for TV display at the time the application that matured into the ’967 patent was filed. EX-1001 1:31-33. This standard explains that a “slice” is a “series of an arbitrary number of consecutive macroblocks.” EX-1009 18 (§ 6.1.2). Each slice in a frame “shall occur in the bitstream in the order in which they are encountered, starting at the upper-left of the picture and *proceeding by raster-scan order* from left to right and top to bottom (illustrated in Figures 6-8 and 6-9 as alphabetical order).” *Id.* Figure 6-9 on page 19 depicts this top to bottom order of encoding and decoding video data as being in alphabetical order:

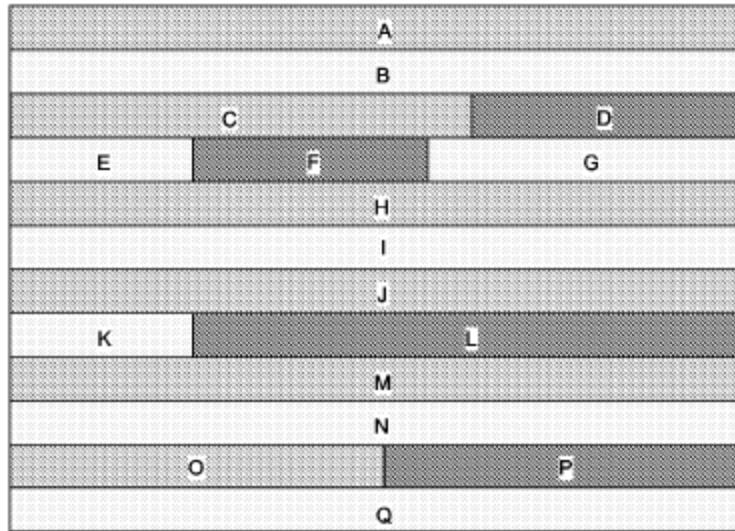


Figure 6-9 – Restricted slice structure

152. Having started with *ISO 13818-2* when implementing the teachings of *MacInnis*, based on these disclosures of *ISO 13818-2*, it is my opinion that a POSITA would have found it obvious to implement *MacInnis* to decode at least one slice in raster order. This implementation would have been straightforward – because *ISO 13818-2* explains that MPEG data (such as in *MacInnis*) is encoded in raster order, decoding in raster order would be the most straightforward method of decoding to POSITA. Raster ordering (from top to bottom) is also a natural method of decoding data because it is a straightforward application of “first-in, first-out” (FIFO) principles. EX-1010 919 (defining raster order as “the order in which pixels are scanned in a raster display device; usually left-to-right; top-to-bottom”).

153. A POSITA would have considered decoding slices in raster order obvious in view of the combined disclosures of *MacInnis* and *ISO 13818-2*.

Applying the known techniques of *ISO 13838-2* in *MacInnis* would have yielded predictable results and known advantages. Accordingly, a POSITA would have found it obvious to implement decoder 120 in *MacInnis* so as to “decod[e] the at least one slice in raster order,” as required by claim 4.

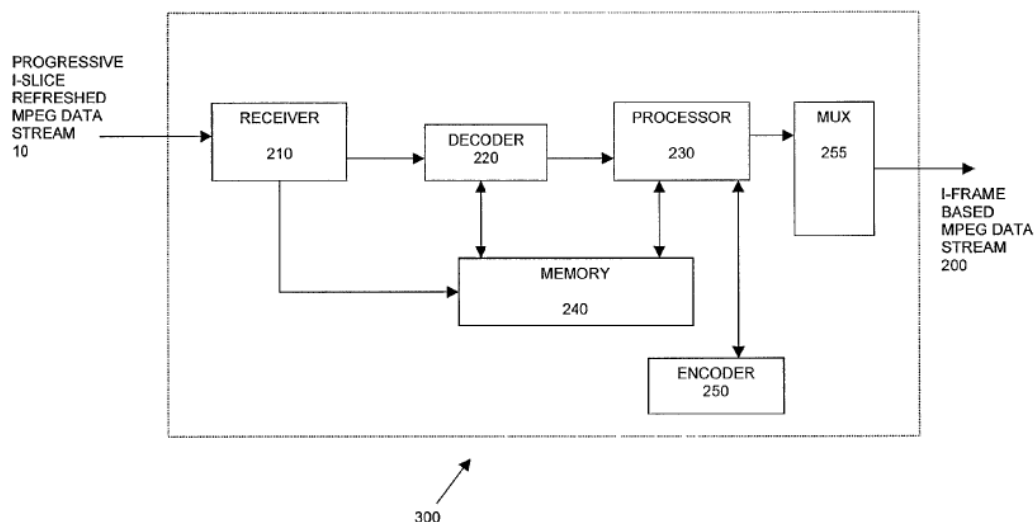
D. Anticipation of claims 1-4 by *Chen* ‘677.

In my opinion, *Chen* ‘677 anticipates claims 1-4 under the constructions offered by Broadcom in the related ITC Investigation. EX-1008.

1. Claim 1

a. [1.0]: *Chen* ‘677 discloses “[a] system for displaying pictures.”

154. I have been told that this claim element, the preamble, may not limit claim 1. *Chen* ‘677 teaches this element anyway. For example, *Chen* ‘677 discloses a television appliance 300, depicted in Fig. 3:



155. See also EX-1004 ¶¶[0027] and [0035]. Television appliance 300 includes a receiver 210 that receives an MPEG data stream 10. *Id.* ¶[0027], Fig. 3. The receiver 210 sends the stream to decoder 220 which decodes P-frames in the stream to recover I-slices (intra-coded slices) “which make up a complete I-frame.” *Id.* ¶[0027], Fig. 3. Memory 240 may additionally or alternatively buffer I-slices while decoding the P-frames and may buffer the MPEG data stream 10. ¶[0028], Fig. 3. Processor 230 reassembles the slices into a complete I-frame and encoder 250 encodes the complete I-frame. ¶[0027], Fig. 3. Multiplexer 255 replaces P-frames in stream 10 with an encoded I-frame in order to provide an encoded I-frame based stream 200. ¶[0027], Fig. 3. This stream can be stored for “trick play mode use.” ¶[0029].

156. It is my opinion that because *Chen* ‘677 discloses a system that receives a stream with P-frames, extracts I-slices from the stream, reassembles the stream using I-frames, and stores the stream for playback, *Chen* ‘677 discloses element [1.0].

b. [1.1]: *Chen* ‘677 discloses “a host processor for transmitting transport packets, said transport packets providing a plurality of instructions.”

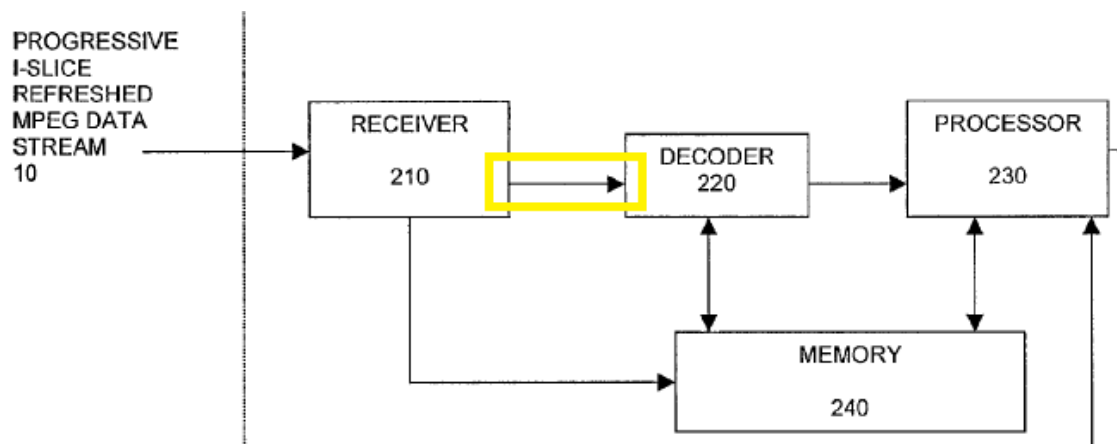
157. As I explained discussed above, I understand that Broadcom has taken the position that the phrase “host processor” means

any device or element that processes an incoming
transport stream (i.e., a stream of packets), extracts the

packets from the stream, and passes the packets on to a decoder device (such as any audio or visual decoding device or functionality),

citing 3:45-52 of the '967 patent. EX-1008. Under at least this construction, *Chen* '677 teaches the claimed “host processor.”

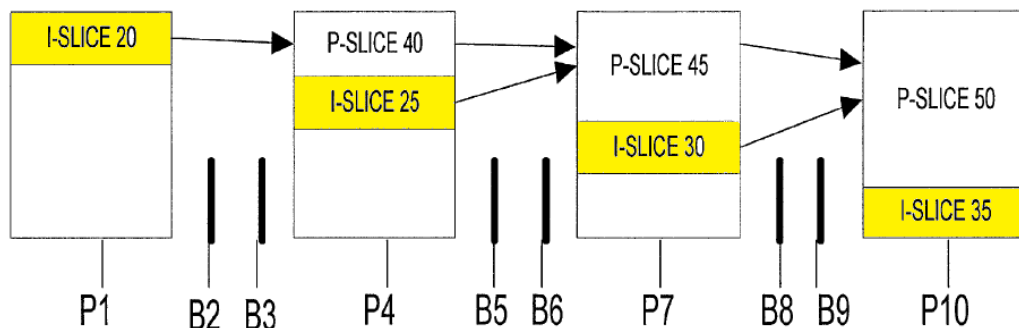
158. For example, *Chen* '677 depicts receiver 210 receiving a progressive I-slice refreshed data stream 10. EX-1004 Fig. 2, ¶¶[0025]-[0027] (“progressive I-slice refreshed MPEG data stream 10 having I-slices distributed over multiple P-frames is *received by a television appliance 300 (e.g., by receiver 210)*”). The stream is transmitted from the receiver 210 to the decoder 220, where the P-frames of the stream are decoded. ¶[0027]. The arrow between receiver 210 and decoder 220 in Fig. 3 indicates that the stream is transmitted from receiver 210 to decoder 220 for decoding:



159. In my opinion *Chen* '677 therefore teaches the claimed “host processor.”

160. Broadcom also asserts that the claimed “plurality of instructions” is “the contents of the coded or compressed audio or video syntax itself, which instruct or cause the decoder to perform various tasks.” EX-1008 3. If it is argued that Broadcom’s construction of “plurality of instructions” from the ITC proceeding is the broadest reasonable construction, *Chen* ‘677 teaches this element.

161. For example, as discussed above, *Chen* ‘677 depicts receiver 210 receiving a progressive I-slice refreshed data stream 10. EX-1004 Fig. 2, ¶¶[0025]-[0027] (“stream 10 . . . is received by a television appliance 300 (e.g., by receiver 210)”). The stream comprises a series of I-slices distributed over multiple P-frames. *Id.* ¶[0025], Fig. 1:



162. *Chen* ‘677 explains that this “progressive I-slice refreshed MPEG data stream” is a type of “compressed MPEG data stream.” *Id.* ¶[0009]. The stream is transmitted from the receiver 210 to the decoder 220. ¶[0027]. The stream causes the decoder to decode it to recover the I-slices. ¶[0027], *see also* Fig. 2, step 102.

163. *Chen '677* discloses receiver 210 transmitting a compressed data stream to a decoder 220, and further teaches that the stream causes decoder 220 to decode it. Because of this, in my opinion, *Chen '677* discloses the claimed “plurality of instructions” under at least Broadcom’s construction of “instructions” (“the contents of the coded or compressed audio or video syntax itself, which instruct or cause the decoder to perform various tasks”). EX-1008 3.

164. As I explained before, the broadest reasonable construction of “transport packet” is “a packet containing either data or instructions.” Because the construction of “transport packet” includes the construed term “instructions,” incorporating Broadcom’s construction of that term comes up with the following construction for “transport packet:” “a packet containing either data or the contents of the coded or compressed audio or video syntax itself, which instructs or causes the decoder to perform various tasks.”

165. While *Chen '677* does not explicitly explain that the MPEG data stream 10 comprises “transport packets,” a POSITA would understand that it discloses MPEG streams, which comprise transport packets. *Chen '677* explains that the stream is an MPEG stream. See EX-1004 ¶¶[0002]-[0012] (referring to stream 10 as being an “MPEG” stream), Fig. 3 (“Progressive I-slice Refreshed MPEG Data Stream 10”). Such MPEG streams comprised a Packetized Elementary Stream (“PES”) that was multiplexed into a Transport Stream (TS) at the time of

filing of *Chen '677*. The ISO 13818-2 standard, which the '967 patent recognized as dominating distribution of digital video content for TV display, 1:30-33, published in 2000. EX-1009 2. It explains that MPEG video may be stored and sent in the form of a PES multiplexed into a TS. *See, e.g., id.* 154 (referring to storing information for decoding the bitstream in the “PES packet”), 155 (same); *see also* EX-1011 647, defining “PES” as

Packetized Elementary Stream: In MPEG-2, after the media stream has been digitized and compressed, it is *formatted into packets* before it is multiplexed into either a Program Stream or *Transport Stream*.

166. Such packets must be extracted from the received MPEG data stream 10 (e.g., a Transport Stream) before they can be decoded. *See, e.g.,* EX-1012 18 (“Transport Streams are . . . unpackitized by a DePacketizer;” see Fig. 2.1); Because the packets were multiplexed into stream 10, they are also demultiplexed for retrieval and forwarding to decoder 220. *See, e.g.,* EX-1012 18 (“Transport Streams are decoded by a Transport Demultiplexer;” see Fig. 2.1)

167. Because MPEG streams are stored and sent in the form of packetized streams, and because *Chen '677* teaches a receiver 210 that receives an MPEG stream 10 and extracts data in the form of packets from the MPEG stream, and, *Chen '677* teaches that the “plurality of instructions” transmitted by a “host processor” is stored and sent in a series of “transport packets.”

168. Therefore, in my opinion, *Chen* '677 discloses element [1.1].

c. [1.2]: *Chen* '677 discloses “a video decoder for executing the plurality of instructions.”

169. I incorporate my discussion of element [1.1]. For example, as discussed above with respect to element [1.1], *Chen* '677 depicts receiver 210 receiving a progressive I-slice refreshed data stream 10. EX-1004 Fig. 2, ¶¶[0025]-[0027]. Starting in step 100, a progressive I-slice refreshed stream (10) is received and the P-frames are extracted. ¶[0025]. Step 102 represents decoder 220 decoding the P-frames in the stream “to recover the I-slices” which are distributed over multiple P-frames and “which make up a complete I-frame.” *See id.* ¶¶[0025], [0027] (discussing decoder 220).

170. Thus, because *Chen* '677 discloses a decoder 220 that decodes stream 10 to recover I-slices, *Chen* '677 discloses element [1.2].

d. [1.3]: *Chen* '677 discloses “wherein execution of the instructions by the video decoder comprises causing”

171. I incorporate my discussion above of elements [1.1] and [1.2]. Decoder 220 decodes the P-frames in the stream “to recover the I-slices” distributed over multiple P-frames and “which make up a complete I-frame.” *See id.*, ¶¶[0025], [0027] (discussing decoder 220). Decoder 220 “executes” the stream in that the stream causes decoder 220 to extract the I-slices.

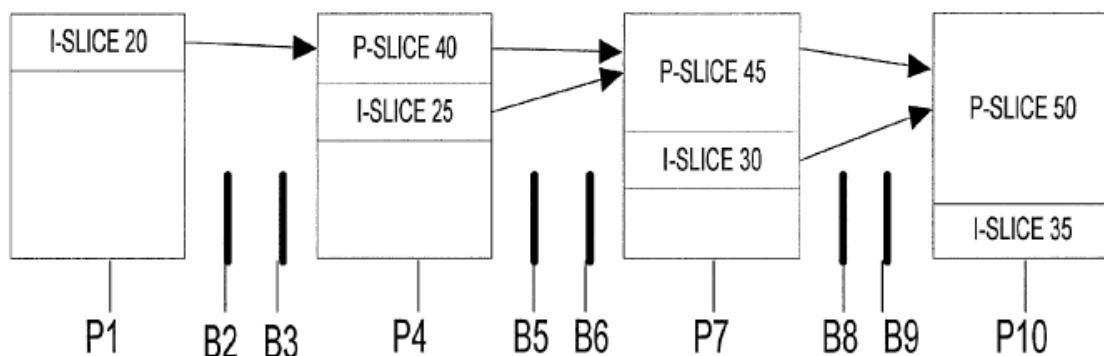
172. Because decoder 220 receives an MPEG stream, and executes the data in the stream to operate on the stream (e.g., to extract I-slices), decoder 220 in *Chen* '677 teaches executing “the instructions by the video decoder.”

- e. **[1.4]: *Chen* '677 discloses “selecting a picture, said picture comprising an intracoded slice and at least one slice above the intracoded slice, and at least one slice below the intracoded slice.”**

173. In my opinion, *Chen* '677 discloses element [1.4], which I have broken into parts below.

- i. **[1.4.a]: *Chen* '677 discloses “selecting a picture, said picture comprising an intracoded slice and at least one slice above the intracoded slice.”**

174. Decoder 220 in *Chen* '677 decodes “P-frames to recover the I-slices which make up [a] complete I-frame.” ¶[0030], *see also* Fig. 1. For example, in Figure 1, ten frames are depicted – P-frames P1, P4, P7, and P10, and B-frames B2, B3, B5, B6, B8, and B9.



175. *See also* ¶[0023]. Decoding all 10 frames is “required before a picture is completely refreshed,” that is, decoded, “using all four I-slices 20, 25, 30, and 35.” *Id.*

176. For example, decoder 220 may decode I-slice 20 in frame P1. EX-1004 ¶[0023]. I-slice 20 “provides reference macroblocks used to create motion vectors that predict the contents of P-slice 40 in P-frame P4.” *Id. see also* Fig. 1. After decoding P-frame P1, decoder 220 may decode P-frame P4. *See id.* ¶[0023], Fig. 1. P-frame P4 may include I-slice 25 and P-slice 40. *See, e.g.,* ¶[0023], Fig. 1. Decoder 220 may select each frame in the stream and determine its type (e.g., I picture, B picture, P picture). *See id.* ¶[0037], Fig. 4 (steps 300-325). P-frames are decoded to recover I-slices, frame by frame, “until a complete refresh cycle has passed.” *See id.* ¶[0040], Fig. 4 (steps 355-370). In my opinion, *Chen* ‘677 thus teaches “selecting a picture.”

177. Because P-frame P4 contains an intracoded slice, I-slice 25, and at least one slice above the intracoded slice, P-slice 40, P-frame 4 constitutes the claimed “picture comprising an intracoded slice and at least one slice above the intracoded slice.”

- ii. **[1.4.b]: *Chen* ‘677 discloses “said picture comprising...at least one slice below the intracoded slice.”**

178. Figure 1 of *Chen* '677 depicts P-frame P4 (claimed “said picture”), and depicts that P4 contains an I-slice 25 and a predictively coded P-slice 40 above I-slice 25. *See, e.g.*, EX-1004, ¶[0023], Fig. 1. *Chen* '677 also explains that “typically,” each frame, such as P-frame P4, “will be a ‘full’ video frame.” ¶[0020]. Because P-frame P4 is described as a “full” frame, P-frame P4 comprises additional slices below depicted I-slice 25.

179. As discussed above with respect to element [1.1], stream 10 in *Chen* '677 is an MPEG stream. *See* EX-1004 ¶¶[0002]-[0012], Fig. 3 (“Progressive I-slice Refreshed *MPEG* Data Stream 10”); Ex-1009 154, 155 (same); *see also* EX-1011 647.

180. The MPEG standard (ISO 13818-2) shows that slices in MPEG streams may encompass a “full” frame. EX-1009 19, Figure 6-9:

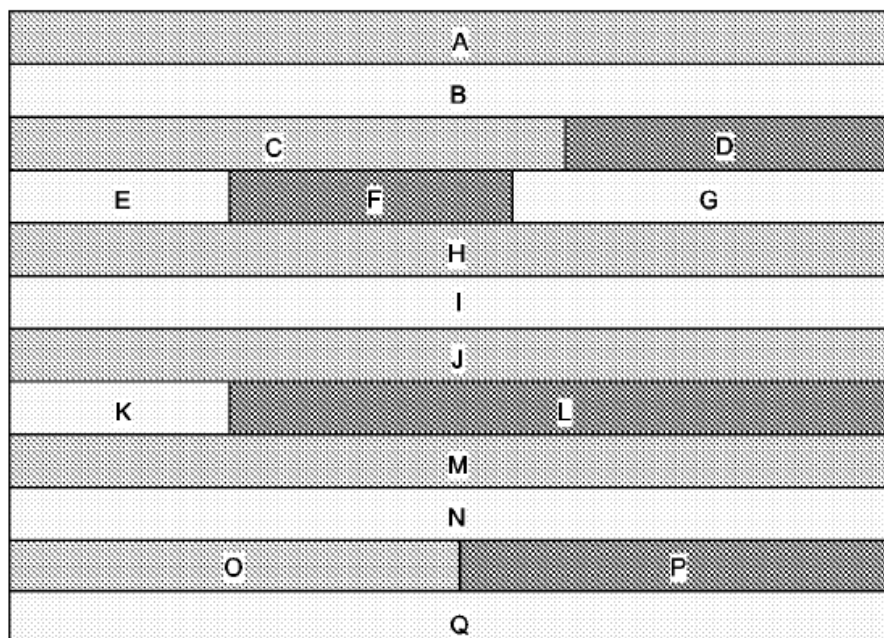


Figure 6-9 – Restricted slice structure

181. Because *Chen '677* teaches that frames may be “full” and MPEG pictures may comprise slices that encompass an entire picture, *Chen '677* teaches element [1.4.b].

f. [1.5]: *Chen '677* discloses “decoding the at least one slice above the intracoded slice.”

182. *Chen '677* discloses element [1.5]. “I-slice 25 and P-slice 40 contained in P-frame P4 provide reference macroblocks that can be used to predict the contents of P-slice 45 contained in P-frame P7.” EX-1004 ¶[0023]. This means that in order to eventually decode P7, P-slice 40 and I-slice 25 in P-frame P4 must also be decoded. *See id.* ¶[0023]. ¶[0040] also explains that recovering I-slices

requires the decoding of P-frames, which includes P-slices (such as P-slice 40).

EX-1004 ¶[0040].

183. As discussed above, decoder 220 may decode part of P-frame P4 (the claimed “picture”). *See* EX-1004 ¶[0023], Fig. 1. Decoding P-frame P4 includes decoding P-slice 40 above I-slice 25. *See, e.g., id.* ¶[0023], Fig. 1. Because P-frame P4 contains an intracoded slice, I-slice 25, and at least one slice above the intracoded slice, P-slice 40, and decoder 220 decodes P-slice 40, it is my opinion that *Chen* ‘677 discloses “decoding the at least one slice above the intracoded slice.”

g. [1.6]: *Chen* ‘677 discloses “decoding the intracoded slice.”

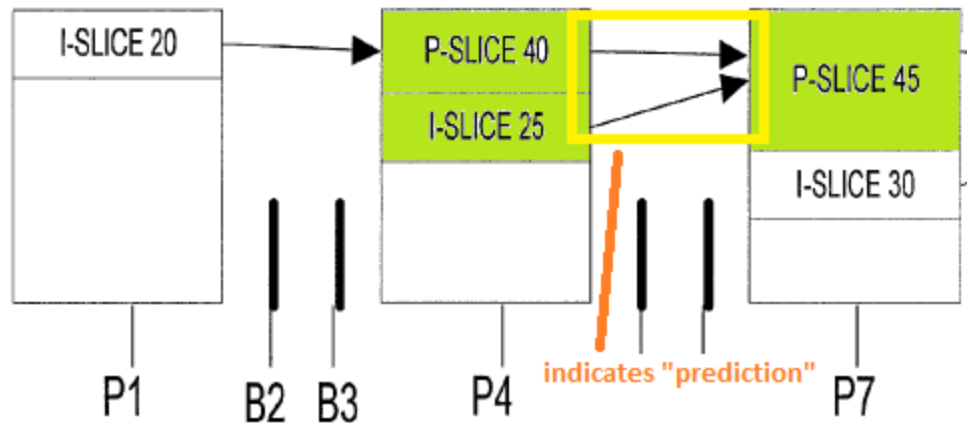
184. “I-slice 25 and P-slice 40 contained in P-frame P4 provide reference macroblocks that can be used to predict the contents of P-slice 45 contained in P-frame P7.” EX-1004 ¶[0023].

185. As discussed above, decoder 220 may decode part of P-frame P4, which includes decoding I-slice 25. *See, e.g., id.* ¶[0023], Fig. 1. Because decoding P-frame P4 decodes intracoded slice I-slice 25, it is my opinion that *Chen* ‘677 discloses “decoding the intracoded slice.”

- h. [1.7]: *Chen* ‘677 discloses “decoding at least a portion of another picture after decoding the at least one slice above the intracode slice and the intracode slice without having decoding the at least one slice below the intracoded slice.”⁴**

186. *Chen* ‘677 discloses element [1.7]. *Chen* ‘677 explains that each P-frame “contains an abridged set of data used by the decoder to predict a full frame from a previous ‘P’ frame or from a previous complete frame...in the video stream.” EX-1004 ¶[0003]. As discussed above, decoder 220 may decode part of P-frame P4, such as P-slice 40 and I-slice 25. *See* EX-1004 ¶[0023], Fig. 1. After decoding P-frame P4, decoder 220 may decode part of P-frame P7, such as P-slice 45 and I-slice 30. ¶[0023], Fig. 1. For example, decoder 220 may utilize the information decoded from P-frame P4, such as “reference macroblocks” from P-slice 40 and I-slice 25 to “predict the contents” of P-slice 45 in P-frame P7. *See id.*, ¶[0023], Fig. 1:

⁴ I understand the term “*intracode* slice” to be a reference to the claimed “intracoded slice.”



187. Decoding at least part of P-frame P7 after decoding P-slice 40 and I-slice 25 in P-frame P4, thus discloses “decoding at least a portion of another picture after decoding the at least one slice above the intracode slice and the intracode slice” as required by element [1.7].

188. *Chen* ‘677 extracts the P-frames from MPEG stream 10 by copying the P-frames and/or buffering the stream. *Id.* ¶[0025]. *Chen* ‘677 explains that “[t]hose skilled in the art will appreciate that the *P*-frames need only be partially decoded in order to recover the I-slices, although the entire P-frame may be decoded to recover the I-slices if desired.” *Id.* As depicted in Figure 1, the I-slices in each frame are stored in descending order. ¶[0023] explains that each of the I-slices in P-frames P1, P4, P7, and P10 are required to refresh a full picture.

189. Because the I-slices required to decode and reconstruct a complete picture are obtained by decoding P-frames P1, P4, P7, and P10 to obtain the I-slices, and because *Chen* ‘677 explains that an I-slice in a P-frame may be

decoded without decoding the rest of the respective P-frame, it is my opinion that *Chen '677* discloses the claimed “decoding at least a portion of another picture...without having decoding the at least one slice below the intracoded slice.”

2. Claim 2

- a. **Element [2.1]: *Chen '677* discloses “wherein the another picture comprises an intracoded slice and at least one slice above the intracoded slice.”**

190. *Chen '677* discloses element [2.1]. As discussed above with respect to elements [1.4]-[1.7], and as depicted in Figure 1, P-frame P7 comprises an intracoded slice (I-slice 30) and a slice above I-slice 30 (P-slice 45).

191. Because P-frame P7 contains an intracoded slice and at least one slice above the intracoded slice, it is my opinion that P-frame P7 in *Chen '677* discloses “the another picture comprises an intracoded slice and at least one slice above the intracoded slice,” as required by element [2.1].

- a. **Element [2.2]: *Chen '677* discloses “wherein decoding at least a portion of the another picture further comprises: decoding the at least one slice above the intracoded slice in the second picture; and decoding the intracoded slice of the second picture.”**

192. *Chen '677* discloses element [2.2], which I have broken into subparts below.

- i. **Element [2.2.a]: *Chen '677* discloses “wherein decoding at least a portion of the another picture further comprises: decoding the at least**

one slice above the intracoded slice in the second picture.”⁵

193. Decoder 220 may decode part of P-frame P7. *See* EX-1004 ¶¶[0023], [0040], Fig. 1. Decoding P-frame P7 requires decoding P-slice 45, which is above I-slice 30. *See, e.g.*, ¶[0023], Fig. 1. Because P-frame P7 contains an intracoded slice, I-slice 30, and at least one slice above the intracoded slice, P-slice 45, and decoder 220 decodes P-slice 45, it is my opinion that *Chen* ‘677 discloses “decoding the at least one slice above the intracoded slice in the second picture.”

ii. Element [2.2.b]: *Chen* ‘677 discloses “wherein decoding at least a portion of the another picture further comprises: . . . decoding the intracoded slice of the second picture.”

194. *Chen* ‘677 explains that “I-slice 30 and P-slice 45 contained in P-frame P7 provide reference macroblocks that can be used to predict the contents of P-slice 50 contained in P-frame P10.” ¶[0023]. Decoder 220 may decode part of P-frame P7. *See* EX-1004 ¶[0023], Fig. 1. Decoding P-frame P7 requires decoding I-slice 30. *See, e.g.*, ¶[0023], Fig. 1. Because decoding P-frame P7 decodes I-slice 30, *Chen* ‘677 discloses “decoding the intracoded slice of the second picture.”

3. Claim 3

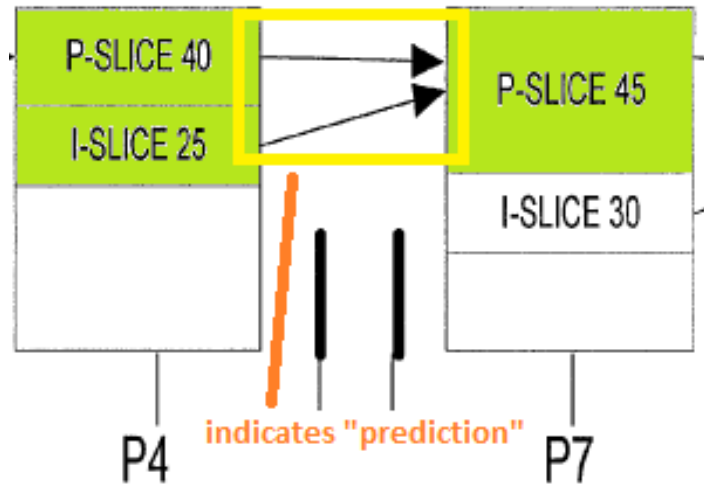
⁵ As I mentioned above, Claim 2 switches between discussing the “another picture” and the “second picture.” I understand these references to be identical.

- a. ***Chen ‘677* discloses “causing decoding the at least one slice above the intracoded slice in the another picture comprises causing: predicting the slices above the intracoded slice in the another picture from the intracoded slice and the slices above the intracoded slice in the picture.”**

195. *Chen ‘677* discloses claim 3. *Chen ‘677* explains that the I-slices and/or P-slices in a first frame can be used to create motion vectors that predict the contents of slices in a following frame:

I-slice 20 contained in P-frame P1 provides reference macroblocks used to create motion vectors that *predict the contents of P-slice 40* in P-frame P4. In the same way, I-slice 25 and P-slice 40 contained in P-frame P4 provide reference macroblocks that can be used to *predict the contents of P-slice 45* contained in P-frame P7. Similarly, I-slice 30 and P-slice 45 contained in P-frame P7 provide reference macroblocks that can be used to *predict the contents of P-slice 50* contained in P-frame P10. I-slice 35 and P-slice 50 contained in P-frame P10 provide the next P-frame (not shown) with reference macroblocks for the predicted part of the picture.

¶[0023]. Annotated Fig. 1 below depicts “I-slice 25 and P-slice 40 contained in P-frame P4” being used to “predict the contents” of P-slice 45 in P-frame P7:



196. Because I-slice 25 and P-slice 40 in P-frame P4 (the claimed “intracoded slice and the slices above the intracoded slice in the picture”) are used to predict the contents of P-slice 45 which is above the intracoded slice, I-slice 30, in P-frame P7 (the claimed “predicting the slices above the intracoded slice in the another picture”), *Chen* ‘677 discloses claim 3.

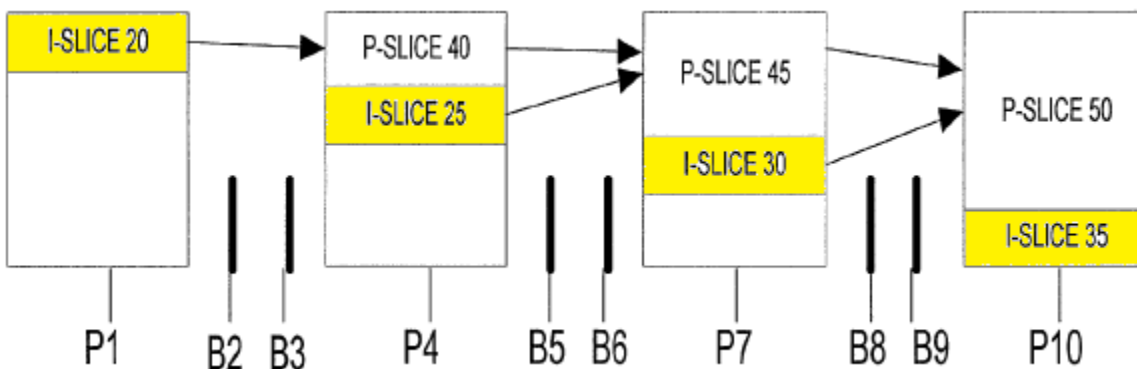
4. Claim 4

197. The ’967 patent appears to refer to a top-to-bottom order of decoding for “raster order.” *See* EX-1001 6:46-52:

Accordingly, aspects of the present invention involve decoding the slices, S, of the HITS stream P-pictures, e.g., $P_0' \dots P_{28}'$ which are above the last intracoded slice I in the picture. If the slices, S, I of the P-pictures, $P_0' \dots P_{28}'$, are decoded in raster order, the video decoder 345 decodes each slice of the P-picture, $P_0' \dots P_{28}'$, until the last intracoded slice, I is decoded.

198. Fig. 4 depicts this top-to-bottom decoding order which decodes the slices (“S”) “which are above the last intracoded slice I in the picture” from top to bottom. *Id.* 6:48-49.

199. Similarly, *Chen* ‘677 teaches slice-by-slice decoding of I-slices stored in top-to-bottom order across P-frames. *See, e.g.*, EX-1004 Fig. 1:



200. *See also* ¶¶[0012], [0022]-[0025]. *Chen* ‘677 explains that each picture provides data (e.g., “reference macroblocks”) usable to predict a portion of a following picture. *Id.* ¶[0023]. *Chen* ‘677 thus teaches decoding a top-most slice (e.g., I-slice 20 in P-frame P1), followed by slices that progressively move from top-to-bottom, until decoding a bottom-most slice (e.g., I-slice 35 in P-frame P10).

201. Accordingly, because *Chen* ‘677 teaches decoding the first rows in a first picture, followed by the first and second rows in a second picture, followed by the first, second, and third rows in a third picture, etc., it is my opinion that *Chen* ‘677 teaches “decoding the at least one slice in raster order” as required by claim 4.

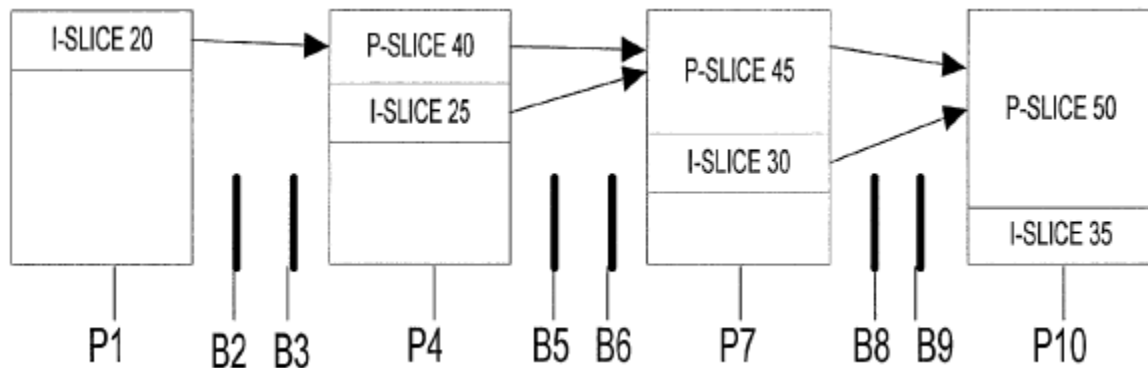
E. Obviousness of claim 5 based on *Chen* '677.

In my opinion, *Chen* '677 renders claim 5 obvious under the constructions offered by Broadcom in the related ITC Investigation. EX-1008.

1. Claim 5

a. *Chen* '677 renders obvious “wherein the picture comprises a P-picture from a HITS stream”

202. As I explained earlier, just like the '967 patent, *Chen* '677 relates to decoding “progressive I-slice refreshed MPEG data streams.” EX-1004 ¶[0003]; *see also* EX-1001 2:6-16. Fig. 1 shows an example of such a stream, where an I-frame is divided into slices and spread across P-frames:



203. *Chen* '677 further explains that “[t]hose skilled in the art will appreciate that *the P-frames* need only be partially decoded in order to recover the I-slices.” *Id.* ¶[0025]. *Chen* '677, therefore, explains that each picture in the stream comprises a P-picture.

204. While *Chen* '677 does not explicitly state that the “progressive I-slice refreshed MPEG data stream,” in Fig. 1, *see* EX-1004 ¶[0003], is a HITS stream, it

is my opinion that a POSITA would understand that a HITS stream is just a type of progressive I-slice refreshed MPEG data stream (the type of stream depicted in *Chen* '677). The '967 patent explains as much: according to the patent, HITS streams are “MPEG-2 streams” that “do not include I-pictures” and “use a progressive refresh mechanism.” EX-1001 2:1-16.

205. Because the streams in *Chen* '677 are progressive I-slice refreshed MPEG data streams, and HITS is a type of that stream, it is my opinion that a POSITA would have found it obvious to implement the teachings of *Chen* '677 over a HITS stream. This implementation would have been a straightforward substitution. A POSITA would have used the teachings of *Chen* '677 to decode HITS streams. Implementing *Chen* '677 to operate on HITS streams would have yielded predictable results and known advantages, such as the ability to perform trick play on HITS streams.

206. Accordingly, in my opinion, a POSITA would have found it obvious to implement decoder 220 in *Chen* '677 so as to operate on “a P-picture from a HITS stream,” as required by claim 5.

F. Obviousness of claims 1-5 based on *Chen* '677 and ISO 13818-2.

207. It is my opinion that *Chen* '677 in view of *ISO 13818-2* also renders obvious claims 1-5 with *ISO 13818-2* under the constructions offered by Broadcom in the related ITC Investigation, EX-1008, for at least the following reasons.

1. Claim 1

- a. **Element [1.1]: *Chen* '677 in view of *ISO 13818-2* renders obvious “a host processor for transmitting transport packets, said transport packets providing a plurality of instructions.”**

208. As I explained before, *Chen* '677 discloses a receiver 210 that receives a plurality of instructions in the form of a stream 10 and transmits the instructions to decoder 200. *See, e.g.*, EX-1004 ¶¶[0009], [0025]-[0027], Figs. 2, 3. And because stream 10 *Chen* '677 is an MPEG stream, stream 10 includes the claimed “transport packets.” However, to the extent there is a dispute about whether *Chen* '677 discloses the claimed “transport packets,” I note that *ISO 13818-2* also does.

209. *ISO 13818-2* relates to the ISO/IEC 13818-2 standard, also referred to as the “H.262” and “MPEG-2 Part 2” standard. EX-1009 v (“the identical text is published as ITU-T Rec. *H.262*”), 154 (discussing the complexity of the “MPEG-2 Standard” embodied in the document); *see also* EX-1001 1:30-33 (referring to “the MPEG-2 video compression standard” as “ISO/IEC 13818-2”).

210. *ISO 13818-2* discusses sending MPEG streams in the form of one or more “transport packets.” For example, *ISO 13818-2* explains that the data contents of the stream may be sent “within transport packets.” EX-1009 160 (§ D.13.2.2). *ISO 13818-2* explains that an encoder that produces a bitstream with “adaptive slice sizes” “keeps track of the data contents within transport packets”

and places the start of each slice “at the first opportunity in *every transport packet*.” EX-1009 160 (§ D.13.2.2). *ISO 13818-2* explains that using adaptive slice sizes and placing the start of each slice in every transport packet “gives an advantage in cell or packet based transmission,” such as transmission over the Internet, “or where error detection occurs over a large block of data.” EX-1009 160 (§ D.13.2.2).

211. *ISO 13818-2* makes other references to storing and transmitting the stream in packet form. *See, e.g.*, EX-1009 154 (referring to storing information for decoding the bitstream in the “PES packet”), 155; *see also* EX-1011 647, defining “PES” as a “Packetized Elementary Stream” in which a media stream is “formatted into packets.”

212. In my opinion, a POSITA would have thought to implement stream 10 in *Chen ‘677* using transport packets. *Chen ‘677* specifically makes reference to, and builds upon, the MPEG-2 standard embodied in *ISO 13818-2*. EX-1004 ¶¶[0006]-[0007] (which discusses “splicing” of MPEG-2 streams), [0042] (“this algorithm can best be performed in a *processor based MPEG-2 decoder chip*”). Such a modification would thus be a clear design choice that *Chen ‘677* itself suggests.

213. In my opinion, this modification would be straightforward to implement. Packetizing data, i.e., reformatting data to place it in the form of

packets, was well-known at the time of filing for the '967 patent, as packet-based transmission enables error correction and retransmission. EX-1011 626 (generally referring to the use of “error correction” and “synchronizing bits” in packets as well as the ability to “identify and correct for lost or errored packets”) And a POSITA would have understood the advantages specifically spelled out in *ISO 13818-2*. EX-1009 160 (§ D.13.2.2).

214. A POSITA, in my opinion, would have considered “transport packets providing a plurality of instructions” obvious in view of the combined disclosures of *Chen '677* and *ISO 13818-2*. Applying the known techniques of *ISO 13838* in *Chen '677* would have yielded predictable results and known advantages.

215. Accordingly, in my opinion, a POSITA would have found it obvious to modify stream 10 in *Chen '677* to include “transport packets, said transport packets providing a plurality of instructions,” as required by element [1.1].

2. Claim 4: *Chen '677* in view of *ISO 13818-2* renders obvious “wherein decoding the at least one slice above the intracoded slice further comprises causing: decoding the at least one slice in raster order.”

216. As I explained earlier, *Chen '677* teaches slice-by-slice decoding of I-slices stored in top-to-bottom order across P-frames. *See, e.g.*, EX-1004 Fig. 1, ¶¶[0012], [0022]-[0025]. Because decoder 220 in *Chen '677* decodes the first rows in a first picture, followed by the first and second rows in a second picture,

followed by the first, second, and third rows in a third picture, etc., *Chen '677* teaches “decoding the at least one slice in raster order” as required by claim 4.

217. However, if there is a dispute whether *Chen '677* discloses “decoding the at least one slice in raster order,” it is my opinion that *ISO 13818-2* also discloses this step.

218. As I explained earlier, *ISO 13818-2* dominated distribution of digital video content for TV display at the time the application that matured into the '967 patent was filed, EX-1001 1:31-33. This standard explains that a “slice” is a “series of an arbitrary number of consecutive macroblocks.” EX-1009 18 (§ 6.1.2).

219. Each slice in a frame “shall occur in the bitstream in the order in which they are encountered, starting at the upper-left of the picture and proceeding by raster-scan order from left to right and top to bottom (illustrated in Figures 6-8 and 6-9 as alphabetical order).” *Id.*; see Figure 6-9:

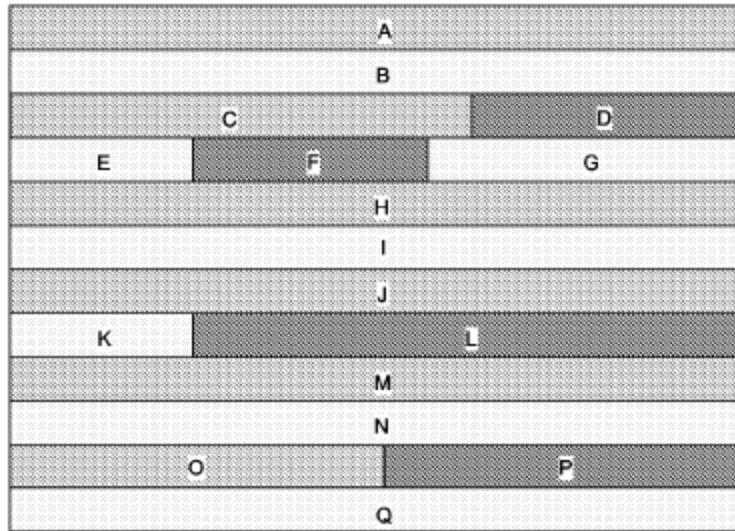


Figure 6-9 – Restricted slice structure


220. Having started with *ISO 13818-2* when implementing the teachings of *Chen '677*, and based on the particular disclosures of *ISO 13818-2*, it is my opinion that a POSITA would have found it obvious to implement *Chen '677* so as to decode at least one slice in raster order. Such implementation would have been straightforward. Because *ISO 13818-2* explains that MPEG data (such as in *Chen '677*) is encoded in raster order, decoding in raster order would be the most straightforward method of decoding. Raster ordering is also a natural method of decoding data because it is a straightforward application of “first-in, first-out” (FIFO) principles. See EX-1010 919 (defining raster order as “the order in which pixels are scanned in a raster display device; usually left-to-right; top-to-bottom”).

221. In my opinion, a POSITA would have considered decoding slices in raster order obvious in view of the combined disclosures of *Chen '677* and *ISO*

13818-2. Applying the known techniques of *ISO 13838* in *Chen '677* would have yielded predictable results and known advantages. So, in my opinion, a POSITA would have found it obvious to implement decoder 220 in *Chen '677* so as to “decod[e] the at least one slice in raster order,” as required by claim 4.

222. I declare that all statements made herein of my knowledge are true, and that all statements made on information and belief are believed to be true, and that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code.

Executed on this 13th day of June 2017, in West Lafayette, Indiana.

By: 
Dr. Edward J. Delp

Attachments:

Appendix A: Curriculum Vitae of Dr. Edward J. Delp

Appendix A

Brief Professional Biography of Edward J. Delp

Edward J. Delp was born in Cincinnati, Ohio. He received the B.S.E.E. (cum laude) and M.S. degrees from the University of Cincinnati, and the Ph.D. degree from Purdue University. In May 2002 he received an Honorary Doctor of Technology from the Tampere University of Technology in Tampere, Finland.

From 1980-1984, Dr. Delp was with the Department of Electrical and Computer Engineering at The University of Michigan, Ann Arbor, Michigan. Since August 1984, he has been with the School of Electrical and Computer Engineering and the School of Biomedical Engineering at Purdue University, West Lafayette, Indiana.

From 2002-2008 he was a chaired professor and held the title The Silicon Valley Professor of Electrical and Computer Engineering and Professor of Biomedical Engineering.

In 2008 he was named a Distinguished Professor and is currently The Charles William Harrison Distinguished Professor of Electrical and Computer Engineering and Professor of Biomedical Engineering and Professor of Psychological Sciences (Courtesy).

His research interests include image and video processing, image analysis, computer vision, image and video compression, multimedia security, medical imaging, multimedia systems, communication and information theory. He has published and presented more than 500 papers.

Dr. Delp is a Fellow of the IEEE, a Fellow of the SPIE, a Fellow of the Society for Imaging Science and Technology (IS&T), and a Fellow of the American Institute of Medical and Biological Engineering.

In 2004 Dr. Delp received the Technical Achievement Award from the IEEE Signal Processing Society for his work in image and video compression and multimedia security.

In 2008 Dr. Delp received the Society Award from IEEE Signal Processing Society (SPS). This is the highest award given by SPS and it cited his work in multimedia security and image and video compression.

In 2009 he received the Purdue College of Engineering Faculty Excellence Award for Research.

In 2014 Dr. Delp received the Morrill Award from Purdue University. This award honors a faculty members' outstanding career achievements and is Purdue's highest career achievement recognition for a faculty member. The Office of the Provost gives the Morrill Award to faculty members who have excelled as teachers, researchers and scholars, and in engagement missions. The award is named for Justin Smith Morrill, the Vermont congressman who sponsored the 1862 legislation that bears his name and allowed for the creation of land-grant college and universities in the United States.

In 2015 Dr. Delp was named Electronic Imaging Scientist of the Year by the IS&T and SPIE. The Scientist of the Year award is given annually to a member of the electronic imaging community who has demonstrated excellence and commanded the respect of his/her peers by making significant and substantial contributions to the field of electronic imaging via research, publications and service. He was cited for his contributions to multimedia security and image and video compression.

He received the 2017 SPIE Technology Achievement Award. The SPIE Technology Achievement award is awarded annually to recognize outstanding technical accomplishment in optics, electro-optics, photonic engineering, or imaging. The SPIE Awards Committee has made this recommendation in recognition of Delp's pioneering work in multimedia security including watermarking and device forensics and for his contributions to image and video compression.

In 2016 Dr. Delp received the Purdue College of Engineering Mentoring Award for his work in mentoring junior faculty and women graduate students.

He received in 1990 the Honeywell Award, in 1992 the D. D. Ewing Award, and in 2004 the Wilfred Hesselberth Award all for excellence in teaching.

In 2001 Dr. Delp received the Raymond C. Bowman Award for fostering education in imaging science from the Society for Imaging Science and Technology (IS&T).

In 2000 Dr. Delp was selected a Distinguished Lecturer of the IEEE Signal Processing Society and in 2002 and 2006 he was awarded Nokia Fellowships.

He is a member of Tau Beta Pi, Eta Kappa Nu, Phi Kappa Phi, Sigma Xi, and ACM.

From 1997-1999 he was Chair of the Image and Multidimensional Signal Processing (IMDSP) Technical Committee of the IEEE Signal Processing Society. Starting in 2008 he is the Chair of the Information Forensics and Security Technical Committee of the IEEE Signal Processing Society. From 1994-1998 he was Vice-president for Publications of IS&T.

He was Co-Chair of the SPIE/IS&T Conference on Security, Steganography, and Watermarking of Multimedia Contents that was held in January 1998-2008. Dr. Delp was the General Co-Chair of the 1997 Visual Communications and Image Processing Conference (VCIP) held in San Jose. He was Program Chair of the IEEE Signal Processing Society's Ninth IMDSP Workshop held in Belize in March 1996. He was General Co-Chairman of the 1993 SPIE/IS&T Symposium on Electronic Imaging.

He was General Chair of the 2009 Picture Coding Symposium held in Chicago. Dr. Delp was the Program Co-Chair of the IEEE International Conference on Image Processing that was held in Barcelona in 2003.

From 1984-1991 Dr. Delp was a member of the editorial board of the *International Journal of Cardiac Imaging*. From 1991-1993, he was an Associate Editor of the *IEEE Transactions on Pattern Analysis and Machine Intelligence*. From 1992-1999 he was a member of the editorial board of the journal *Pattern Recognition*. From 1994-2000, Dr. Delp was an Associate Editor of the *Journal of Electronic Imaging*. From 1996-1998, he was an Associate Editor of the *IEEE Transactions on Image Processing*. He is also co-editor of the book *Digital Cardiac Imaging* published by Martinus Nijhoff.

Dr. Delp is a registered Professional Engineer.

[Dr. Delp's homepage](#)

Professor Edward J. Delp

VITA

February 8, 2017

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Personal:

Date of Birth: January 1, 1949
Place of Birth: Cincinnati, Ohio
Citizenship: U.S.A.

Education:

| <i>Degree</i> | <i>Date</i> | <i>School</i> |
|------------------------|-------------|--|
| BSEE | 1973 | University of Cincinnati |
| MSEE | 1975 | University of Cincinnati |
| Ph.D. | 1979 | Purdue University |
| D.Tech (honoris causa) | 2002 | Tampere University of Technology (Finland) |

Thesis:

"Moment Preserving Quantization and Its Application in Block Truncation Coding," Ph.D. Thesis, Purdue University, 1979.

"Spectral Analysis and Synthesis Using Walsh Functions," M.S. Thesis, University of Cincinnati, 1975.

"Bias-5 Update: A Computer Program for the Nonlinear DC Analysis of Junction Field Effect Transistor Circuits," B.S. Thesis, University of Cincinnati, 1973.

Registration:

Registered Professional Engineer (Ohio) - Certificate Number E-045364.

Honorary Society Memberships:

Tau Beta Pi
Eta Kappa Nu
Sigma Xi
Phi Kappa Phi

Honors:

- [1] Voted One of "10 Best" Teachers in School of Electrical Engineering, 1980.
- [2] Magoon Teaching Award, 1978.
- [3] Graduate Instructor Fellowship, 1978.
- [4] Honeywell Award for Excellence in Teaching, 1990.
- [5] Fulbright Fellowship, awarded to teach and do research at the Institut de Cibernetica of the Universitat Politecnica de Catalunya, Barcelona, Spain, 1990.
- [6] D. D. Ewing Best Teacher Award, 1992.
- [7] Elected IEEE Fellow, 1997.
- [8] Louisiana Distinguished Lecturer, Center for Advanced Computer Studies, University of Southwestern Louisiana, 1998.
- [9] Keynote Address at the IEEE Southwest Symposium on Image Analysis and Interpretation, 1998.
- [10] Elected Fellow of the Society for Imaging Science and Technology (IS&T), 1998.
- [11] Elected Fellow of the SPIE, 1998.
- [12] Distinguished Visiting Professor Award, Tampere University of Technology, Tampere, Finland, 1999.
- [13] Banquet Speaker at Erlangen Watermarking Workshop, Erlangen, Germany, 1999.
- [14] IEEE Signal Processing Society Distinguished Lecturer, 2000.
- [15] Distinguished Visitor, Government of The Netherlands, hosted by The Technical University of Telft, February 2000.
- [16] Plenary Address at the IEEE Southwest Symposium on Image Analysis and Interpretation, February 4, 2000.
- [17] Keynote Address at the Visual Communication and Image Processing (VCIP) Conference, Perth, Australia, June 22, 2000.
- [18] Keynote Address at the European Signal Processing Conference (EUSIPCO), Tampere, Finland, September 6, 2000.

- [19] Received the 2001 Raymond C. Bowman Award from the Society for Imaging Science and Technology on November 8 in Scottsdale, AZ. The Raymond C. Bowman Award is given in recognition of an individual who has been instrumental in fostering and encouraging individuals in the pursuit of a career in imaging science.
- [20] Honorary doctorate from the Tampere University of Technology in Finland. The official title of the degree is: "Honorary Degree of Doctor of Technology," May 17, 2002.
- [21] Keynote Address at the IEEE Southwest Symposium on Image Analysis and Interpretation, March 8, 2002, Santa Fe.
- [22] 2002 Nokia Fellowship – to visit Finland
- [24] Keynote Address at the Wireless Ubiquitous Communication Symposium, Delft, Netherlands, December 2002.
- [25] Appointed The Silicon Valley Professor of Electrical and Computer Engineering - Chaired Professorship (Purdue University), January 2002.
- [26] Elected Fellow of the American Institute for Medical and Biological Engineering, January 2003.
- [27] Keynote Address at the Sixth Baiona Workshop on Signal Processing in Communications, Baiona, Spain, September 8, 2003.
- [28] Received the Wilfred Hesselberth Award for Teaching Excellence, May 2004.
- [29] Plenary Address at the Sixth IEEE Southwest Symposium on Image Analysis and Interpretation, Lake Tahoe, "Image Analysis: Old Problems and New Challenges," March 29, 2004.
- [30] Plenary Address at the 2004 Asilomar Conference on Signals, Systems, and Computers, "Signal and Image Processing: What Went Wrong?," November 8, 2004.
- [31] Received the 2004 Technical Achievement Award from the IEEE Signal Processing Society. For contributions to "image and video compression and multimedia security."
- [32] Keynote Address at the ACM Multimedia and Security Workshop 2004, Magdeburg, Germany, "Multimedia Security: The 22nd Century Approach," September 20, 2004.
- [33] Keynote Address at the 20th Anniversary of the Digital Media Institute at the Tampere University of Technology, Tampere, Finland, June 9, 2005, "Open Research Problems in Content Representation and Delivery"
- [34] Keynote Address at the Fourth International Workshop on Content-Based Multimedia Indexing, Riga, Latvia, June 23, 2005, "The Role Of "Location Awareness" In Media Indexing."
- [35] Keynote Address at the 2nd European Workshop on the Integration of Knowledge, Semantic and Digital Media Technologies, London, November 30, 2005, "Are Low Level Features Too Low for Indexing?"

- [36] Invited Talk, Information Science and Technology Center, Colorado State University, Ft. Collins, “Are You Stealing Content! Multimedia Security: The Good, The Bad, and The Ugly: We are Going to Catch You!,” March 24, 2004.
- [37] Invited Talk, Department of Electrical and Computer Engineering, Colorado State University, Ft. Collins, “Low Complexity Video Coding,” March 24, 2004
- [38] Plenary Address at the IEEE Southwest Symposium on Image Analysis and Interpretation, Denver, “Image Analysis: Old Problems and New Challenges,” March 28, 2006.
- [39] Nokia Fellowship – Visiting Lecturer Scholarship, sponsored by the Nokia Foundation, nominated by the Helsinki University of Technology and Tampere University of Technology – Summer 2006.
- [40] Invited Talk, “Multimedia Security,” University of Iceland, June 6, 2006.
- [41] Finland Distinguished Professorship – sponsored by the Academy of Finland for 2008 sabbatical – January 2008.
- [42] Plenary Speaker at the IEEE International Conference on Image Processing in Atlanta on October 11, 2006. “Multimedia Security: The Good, The Bad, and The Ugly.”
- [43] Banquet Keynote Address at the IEEE Consumer Communications and Networking Conference in Las Vegas on January 13, 2007. “Are You Stealing Content! Multimedia Security: The Good, The Bad, and The Ugly.”
- [44] Plenary Speaker, International Symposium on Signal Processing and its Applications, Sharjah, United Arab Emirates (U.A.E.), “Recent Advances in Video Compression: What's Next?,” February 14, 2007.
- [45] Invited Talk, College of Engineering, University of Sharjah, United Arab Emirates (U.A.E.), “Multimedia Security and Watermarking,” February 16, 2007.
- [46] Invited Talk, The Norwegian University of Science and Technology (NTNU), Trondheim, Norway, “The Forensics of Things,” March 2007
- [47] Plenary Address at the IEEE Southwest Symposium on Image Analysis and Interpretation, Denver, “Image Analysis: Old Problems and New Challenges,” March 2008.
- [48] Distinguished Lecture at eINTERFACE’08 Summer Workshop on Multimodal Interfaces, “Motion Driven Content Analysis of User Generated Video for Mobile Applications,” August 14, 2008, Paris.
- [49] Invited Talk, Workshop on Multimedia Information Retrieval, San Diego, October 2008 (this was part of ICIP).
- [50] Society Award from the IEEE Signal Processing Society, 2008. For contributions to “image and video compression and multimedia security.” This is the highest award given by the Signal Processing Society.

- [51] Appointed member of the Scientific Advisory Board of Nokia Research Center's Media Laboratory, 2008.
- [52] Distinguished Professor, appointed by Purdue's Board of Trustees to the position of the Charles William Harrison Distinguished Professor of Electrical and Computer Engineering, 2008.
- [53] Purdue College of Engineering Faculty Excellence Award for Research, 2009.

- [54] Appointed member of the Scientific Advisory Board of Nokia Research Center's Media Laboratory, 2009.
- [55] General Chair, Picture Coding Symposium, May 2009.

- [56] Keynote address at the 8th International Workshop on Digital Watermarking on August 26, 2009. The title of the talk was "Forensic Techniques for Image Source Classification: A Comparative Study." The meeting was held in Guildford in the UK.
- [57] Selected to attend the Computational Cyberdefense in Compromised Environments Workshop hosted by the National Security Agency and the Office of the Director of National Intelligence. The workshop was limited to 50 invited scholars in the area of security. The workshop was held in August 2009 in Santa Fe, New Mexico.
- [58] Invited to participate in the US Army Research Office Special Workshop on Digital Forensics. This workshop discussed research challenges, approaches, and roadmaps in the area of digital forensics. The workshop was held September 10-11, 2009 in Washington.

- [59] Plenary talk at the IS&T/SPIE Electronic Imaging Conference in San Jose on January 20, 2010. The title of the talk: "Hey! What Is That In Your Pocket? The Mobile Device Future."
- [60] Invited talk: "Hey! What Is That In Your Pocket? The Mobile Device Future," presented at Google, January 22, 2010.

- [61] Plenary talk at the 2010 IEEE Southwest Symposium on Image Analysis and Interpretation in Austin, Texas on May 25, 2010. The title of the talk: "Hey! What Is That In Your Pocket? The Mobile Device Future."

- [62] U.S. Army Research Laboratory (ARL) Director's Coin, presented by Mr. John M. Miller, Director of the US Army Research Laboratory, as recognition for contributions made to ARL through my work on the Standoff Inverse Analysis and Manipulation of Electronic Systems (SIAMES) project under the FY05 Multidisciplinary University Research Initiative (MURI). Specifically, Mr. Miller recognized that my contributions in the development of new approaches to waveform design and analysis contributing to optimal detection and classification of radio transceivers has great potential to improve the performance of the next

generation of military sensor systems. It is extremely rare for a commanding officer or installation director to present this symbol of praise to a private citizen.

- [63] Plenary talk at the EURASIP Signal Processing and Applied Mathematics for Electronics and Communications Workshop in Cluj-Napoca, Romania on August 26, 2011. The title of the talk: “Hey! What Is That In Your Pocket? The Mobile Device Future.”
- [64] Plenary Address at the IEEE Southwest Symposium on Image Analysis and Interpretation, Santa Fe, “Signal and Image Processing: What Went Wrong - Redux?,” April, 2012.
- [65] Keynote Address at the Huawei Technology Conference, “That Thing In Your Pocket Is Really A Computer! - The Future of Mobile Computing,” March 20, 2013, San Clara, CA.
- [66] Raytheon Innovation Tech Talk (Information Security Speaker Series) as part of National Cyber Security Awareness Month, “That Thing In Your Pocket Is Really A Computer! - The Future of Mobile Computing,” October 16, 2013, El Segundo, CA.
- [67] Distinguished Speaker, 100th Anniversary of the Kodak Research Laboratories, “Is Your Document Safe: An Overview of Document and Print Security,” November 12, 2013, Rochester, NY.
- [67] Plenary Talk, IEEE Conference on International Conference on Systems, Signals and Image Processing, “That Thing In Your Pocket Is Really A Computer! - The Future of Mobile Computing,” July 9, 2013, Bucharest, Romania.
- [68] Keynote Address, Electronic Imaging Symposium, “That Thing In Your Pocket Is Really A Computer! - The Future of Mobile Computing,” February 2013, San Francisco, CA.
- [69] 2014 Morrill Award - this award honors West Lafayette faculty members' outstanding career achievements and is Purdue's highest career achievement recognition for a faculty member. The Office of the Provost gives Morrill Awards to faculty members who have excelled as teachers, researchers and scholars, and in engagement missions. The awards are named for Justin Smith Morrill, the Vermont congressman who sponsored the 1862 legislation that bears his name and allowed for the creation of land-grant college and universities. The Morrill Award is accompanied by a \$30,000 prize.
- [70] Plenary Talk, 2014 Southwest Symposium on Image Analysis and Interpretation, “Mobile Connected Health: Personalized Medicine in Your Home and Pocket,” April 2014, San Diego.

- [71] Keynote Talk, IEEE China Summit and International Conference on Signal and Information Processing (ChinaSIP'14), "The Future of Mobile Computing," July 2014, Xi'an, China.
- [72] Invited Talk, "That Thing In Your Pocket Is Really A Computer! - The Future of Mobile Computing," Northwestern University, May 21, 2014.
- [73] Invited Talk, "That Thing In Your Pocket Is Really A Computer! - The Future of Mobile Computing," IIT, April 18, 2014.
- [74] Invited Talk, "Mobile Imaging: The Future Of The Image," The Fourth IEEE International Workshop on Mobile Vision (part of CVPR), June 23, 2014, Columbus.
- [75] Invited Talk and attended Ph.D. defense, Department of Computer Engineering King Mongkut's University of Technology Thonburi, Bangkok, Thailand, February 24-25, 2014.
- [76] Invited Talk, "The Future of Mobile Computing," International Congress Imaging Science (ICIS), Tel Aviv, May 14, 2014.
- [77] 2015 - named Scientist of the Year by the IS&T and SPIE. The Scientist of the Year award is given annually to a member of the electronic imaging community who has demonstrated excellence and commanded the respect of his/her peers by making significant and substantial contributions to the field of electronic imaging via research, publications and service. Cited for my contributions to multimedia security and image and video compression.
- [78] 2015 – my group finished second in NIST/FBI Tattoo Challenge, Tatt-C. First place among all universities. First place went to a commercial company.
- [79] 2016 - received the Purdue College of Engineering Mentoring Award for his work in mentoring junior faculty and women graduate students.
- [80] 2017 – 2017 SPIE Technology Achievement Award. The SPIE Technology Achievement award is awarded annually to recognize outstanding technical accomplishment in optics, electro-optics, photonic engineering, or imaging. The SPIE Awards Committee has made this recommendation in recognition of my pioneering work in multimedia security including watermarking and device forensics and for his contributions to image and video compression.
- [81] Plenary Address at the IEEE Southwest Symposium on Image Analysis and Interpretation, Santa Fe, "Mobile and Connected Imaging," March, 2016.
- [82] Invited Talk at the International Summit on Smart Wearable Systems (WEARABLE 2016) October 14, 2016, EPFL Lausanne, Switzerland, "Food Image Analysis: The Big Data Problem You Can Eat!."

Professional Experience:

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|-----------------------------|--|
| September 1968-January 1971 | Co-op Student, U.S. Naval Ship Research and Development Center, Washington, D.C. |
| May 1973-August 1973 | Research Assistant, National Radio Astronomy Observatory, Greenbank, West Virginia. |
| August 1973-August 1975 | Graduate Teaching and Research Assistant, University of Cincinnati, Department of Electrical and Computer Engineering, Cincinnati, Ohio. |
| August 1975-August 1979 | Graduate Teaching and Research Assistant, Purdue University, School of Electrical Engineering, West Lafayette, Indiana. |
| August 1979-August 1980 | Visiting Assistant Professor, Purdue University, School of Electrical Engineering, West Lafayette, Indiana. |
| August 1980-August 1984 | Assistant Professor, University of Michigan, Department of Electrical Engineering and Computer Science, Ann Arbor, Michigan. |
| August 1984-August 1990 | Associate Professor, Purdue University, School of Electrical Engineering, West Lafayette, Indiana. |
| August 1990-present | Professor, Purdue University, School of Electrical Engineering, West Lafayette, Indiana. |
| Summer-1998 | Visiting Professor, Tampere International Center for Signal Processing at the Tampere University of Technology in Finland. |
| Summer-1999 | Visiting Professor, Tampere International Center for SignalProcessing at the Tampere University of Technology in Finland. |
| August 2000 | Appointment in the School of Biomedical Engineering |
| Summer 2001 | Visiting Professor, Tampere International Center for SignalProcessing at the Tampere University of Technology in Finland. |

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|-------------------------------|--|
| January 2002 -2008 | Appointed to named professorship – The Silicon Valley Professor of Electrical and Computer Engineering. |
| September 2008 | Appointed to distinguished professorship – The Charles William Harrison Distinguished Professor of Electrical and Computer Engineering |
| Summer 2002 | Visiting Professor, Tampere International Center for Signal Processing at the Tampere University of Technology in Finland. |
| Summer 2003 | Visiting Professor, Tampere International Center for Signal Processing at the Tampere University of Technology in Finland. |
| Summer 2004 | Visiting Professor, Tampere International Center for Signal Processing at the Tampere University of Technology in Finland. |
| Summer 2005 | Visiting Professor, Tampere International Center for Signal Processing at the Tampere University of Technology in Finland. |
| Summer 2006 | Visiting Professor, Tampere International Center for Signal Processing at the Tampere University of Technology in Finland. |
| January 2008 – December 20008 | Finland Distinguished Professor, Academy of Finland Distinguished Professor Program (FiDiPro), Tampere University of Technology, Tampere, Finland. |
| July 2012 – present | Professor of Psychological Sciences (Courtesy) |

Research Grants and Contracts Received

- [1] Principal Investigator: Rackham Grant (University of Michigan), "Image Modeling Using Fractals," May 1981 - April 1982, \$6,198.
- [2] Participant: National Science Foundation, "Computer Science and Computer Engineering Research," (Equipment Grant), principal investigator - R. A. Volz, April 1981 - April 1982, \$77,000.
- [3] Participant: Air Force Office of Scientific Research, "Coordinated Research in Robotics and Integrated Manufacturing," principal investigator - R. A. Volz, September 1982 - August 1985, \$3,400,000. (Participated from 9/82 - 8/84.)

- [4] Co-Principal Investigator: National Institute of Health, "Automatic Processing of Digital Echocardiography," July 1983 - June 1986, \$670,745. (Parts of this grant were sub contracted to Purdue. See #12 and #13 below.)
- [5] Principal Investigator: IBM, "Automatic Solder Joint Inspection," September 1983 - August 1984, \$108,701.
- [6] Co-Principal Investigator: Biomedical Research Council and Office of the Vice-President for Research (University of Michigan), "Development of Biomedical Image Analysis Algorithms," January 1983 - December 1983, \$23,500.
- [7] Co-Principal Investigator: Office of the Vice-President for Research (University of Michigan), "Development of Biomedical Image Analysis Algorithms," January 1984 - December 1984, \$7,500.
- [8] Participant: Semiconductor Research Corporation, "Automation in Semiconductor Manufacturing," principal investigator: K. D. Wise, January 1984 - December 1984, \$330,000. (Participated from 1/84-8/84.)
- [9] Principal Investigator: ATT, "Image Processing Laboratory Equipment Enhancements," January 1985, \$20,000.
- [10] Co-Principal Investigator: IBM, "Distributed System Interconnection Study," January 1985 - December 1985, \$25,000.
- [11] Co-Principal Investigator: NRL, "Performance of PASM on ATR Algorithms," January 1985 - September 1985, \$24,500.
- [12] Principal Investigator: NIH via subcontract from University of Michigan, "Automatic Processing of Digital Echocardiography," July 1984 - June 1985, \$44,000.
- [13] Principal Investigator: NIH via subcontract from University of Michigan, "Automatic Processing of Digital Echocardiography," July 1985 - June 1986, \$42,100.
- [14] Co-Principal Investigator: GE, "Research in Automated Inspection," September 1985 - December 1985, \$14,493.
- [15] Co-Principal Investigator: AFOSR, "Using a Reconfigurable Parallel Processing System for Automatic Target Reconfiguration," January 1986 - June 1988, \$198,327.
- [16] Co-Principal Investigator: GE, "Back Projection Reconstruction of Laser-Drilled Cooling Holes," June 1986 - November 1986, \$9,380.
- [17] Co-Principal Investigator: IBM, "Distributed System Interconnection Study," June 1986 - December 1986, \$25,000.
- [18] Co-Principal Investigator: IBM, "Algorithms and Parallel Processor Architectures for Processing Two-Dimensional Images," August 1987 - April 1988, \$25,000.
- *[19] Participant: NSF, "Engineering Research Center on Intelligent Manufacturing," January 1988 to August 1995, ~\$65,000/year.
- [20] Co-Principal Investigator: IBM, "Algorithms and Parallel Processor Architectures for Processing Two-Dimensional Images," May 1988 - December 1988, \$25,000.

* This was a continuing multi-year grant.

- [21] Principal Investigator: Showalter Fellowship, "A Computer Vision Approach to the Analysis of 2D Echocardiograms," July 1988 - June 1989, \$40,000.
- [22] Co-Principal Investigator: AT&T, "AT&T University Equipment Donation Program for AT&T PIXEL Machine," March 1990 - February 1991, \$146,385.
- [23] Investigator: National Science Foundation, CISE Institutional Infrastructure Program, "Infrastructure for Parallel Processing Research," Grant Number CDA-9015696, January 1991 - December 1995, 1995, \$1,421,968.
- [24] Co-Principal Investigator: National Science Foundation, "CISE Research Instrumentation: A Multi-spectral/Multi-Sensor Systems Laboratory," May 1992 - April 1995, \$120,000.
- [25] Co-Principal Investigator: DARPA, "Parallel Scalable Libraries and Algorithms for Computer Vision," Grant Number DABT63-92-C-0022, August 1992 - July 1996, \$940,941.
- [26] Principal Investigator: TRASK, "Real Time 3D Imaging in Diagnostic Radiology," August 1992 - December 1993, \$26,791.
- [27] Co-Principal Investigator: ARPA, "Parallel Scalable Libraries and Algorithms for Computer Vision," September 1994 - August 1997, \$168,670.
- [28] Co-Principal Investigator: National Institutes of Health, "Preclinical ROC Studies of Digital Stereomammography," July 1994 - June 1997, \$250,000 (direct cost).
- [29] Principal Investigator: AT&T, "The Purdue/AT&T Multimedia Testbed," October 1994 - September 1997, \$375,000.
- [29] Co-Principal Investigator: National Science Foundation, "CISE Research Instrumentation: VIADuct: A Testbed to Study Video, Image, Audio, and Data Traffic on a High-Speed Network," May 1995 - March 1996, \$226,217.
- [30] Co-Principal Investigator: Hewlett-Packard Company, "Infrastructure for a New Curriculum in Video and Image Systems Engineering." January 1996 - December 1998, \$999,991.
- [31] Principal Investigator: Rockwell Systems, "Scalable Low Bit Rate Video Compression," April 1996 - March 1998, \$60,000.
- [32] Co-Principal Investigator: National Science Foundation. "CISE Research Instrumentation: Storage and I/O Devices for the Support of Research in Imaging Systems, Networks, and Video and Speech Processing," January 1997 - December 1998, \$236,627.
- [33] Co-Principal Investigator: ERIM/DARPA, "High Performance Architecture Demonstration," October 1996 - August 1997, \$30,000.
- [34] Principal Investigator: Intellectual Protocols 2, "Digital Watermarking," October 1997 - May 1998, \$12,000.
- [36] Principal Investigator: PRF Grant, "Automatic Detection of Spiculated Lesions in Digital Mammograms," January 1998 - December 1998, \$11,666.
- [37] Principal Investigator: Tektronix, "Digital Frame Store PDR 100," (equipment donation), November 1997, \$30,000.

- [38] Principal Investigator: Truevision, "Digital Video Editing TARGA 1000," (equipment donation), February 1998, \$2,000.
- [39] Principal Investigator: Rockwell, "Scalable Low Bit Rate Video Compression," April 1998 - March 1999, \$15,000.
- [40] Investigator: "Error Concealment in Compressed Video," Lucent Technologies (Bell Laboratories), May 1998 - April 1999, \$10,000.
- [41] Principal Investigator: Intellectual Protocols 2, "Digital Watermarking," June 1998 - December 1998, \$7,000.
- [42] Investigator/Participant: Intel, "Technology for Education," (equipment grant), August 1997 - December 2000, \$6,300,000 (my part \$40,000).
- [43] Principal Investigator: Texas Instruments, "Real-Time Image and Video Processing," August 1998 - August 2001, \$220,960.
- [44] Principal Investigator: Purdue Cancer Center, "The Analysis of Digital Mammograms," January 1998 - December 1999, \$19,200.
- [45] Principle Investigator: CERIAS, "Scene Adaptive Video Watermarking," August 1999 - July 2001, \$48,685.
- [46] Investigator: NSF, "IGERT: For Entrepreneurial PhD Students in Science and Engineering," July 2000 - June 2002, \$2,333,428 (PI: Marie Thursby).
- [47] Investigator: NSF, "Multimedia Infrastructure Project (CISE Infrastructure Grant)," January 2000 – December 2004, \$2,201,212 (PI: A. K. Elmagarmid).
- [48] Principle Investigator: Indiana 21st Century Research and Technology Fund, "Entertainment Video Over the Internet," August 2000 - July 2003, \$1,339,361.
- [49] Principle Investigator: Qualia Computing, "Normal Mammogram Analysis," January 2001 – August 2003, \$40,000.
- [50] Investigator, Spanish Fulbright Commission, "An image analysis system for video indexing and face recognition," May 2000 - May 2001 (international travel grant to Spain), \$10,000.
- [51] Co-Principal Investigator, Ford Foundation gift to Purdue University, "Perception-Based Engineering Laboratory," January 2001 to December 2004, \$3,500,000.
- [52] Principal Investigator, Conexant, "Error Concealment in Wireless Video," August 2000 - July 2001, \$25,000.
- [53] Principal Investigator, Digimarc, "Watermarking Streaming Video," August 2001 – December 2003, \$54, 150.
- [54] Principal Investigator, C-SPAN, "Video Search, Browsing, and Understanding of C-SPAN Programs," June 2001 – June 2005, \$290,000.
- [55] Principal Investigator, Air Force Research Laboratories, "Watermarking Test and Evaluation," August 2002 – September 2005, \$376,000.

- [56] Co-Principal Investigator, National Science Foundation, “ITR: Printer Characterization and Signature-Embedding for Security and Forensic Applications,” August 2002 – July 2006, \$423,000.
- [57] Investigator, Indiana 21st Century Research and Technology Fund, “Indiana Center for Wireless Communications and Networking,” January 2003 – December 2006, \$5,496,648 (P. I.: J. Krogmeier; Purdue funding: \$837,883).
- [58] Principle Investigator, Indiana 21st Century Research and Technology Fund, “Advanced Digital Video Compression: New Techniques for Security Applications,” March 2004 – March 2008, \$2,600,579 (From the Fund: \$856,576).
- [59] Co-Principal Investigator, Intel, “The Design of A Location-Aware Image Database,” Equipment Donation, \$24,000, December 2003.
- [60] Principle Investigator, Motorola, “A Study of Low Complexity Pseudo-Semantic Features,” June – December 2004, \$39,246
- [61] Principle Investigator, Motorola, “A Study of Low Complexity Tools for Mobile Video,” January – December 2005, \$36,080
- [62] Principle Investigator, Motorola, “Mobile Video Indexing,” August 2005- August 2008, \$74,000 (Saba Fellow grant)
- [63] Principle Investigator, Nokia, “Video Compression Research: HVS and Low Complexity Approaches,” June 2005 – June 2006, \$65,000.
- [64] Co-Principal Investigator, National Science Foundation, “CT-ISG: Printer and Sensor Forensics,” August 2005 – July 2008, \$400,000.
- [65] Co-Principal Investigator, Army MURI, “Standoff Inverse Analysis and Manipulation of Electronic Systems,” July 2005 – June 2011, \$1, 650,000 (the Purdue part).
- [66] Investigator, Navy (Crane), “Naval Smartships that Anticipate and Manage”, March 2005 – March 2006, \$29,000.
- [67] Principle Investigator, Software Engineering Research Center (Ball State University/NSF), “Low Complexity Video Coding for Surveillance Applications: Motion Estimation,” September 2005 – April 2006, \$22,000.
- [68] Co-Principal Investigator, Next Wave/ DARPA (STTR), “Rosetta Phone,” August 2006 – December 2007, \$60,000.
- [69] Co-Principal Investigator, Next Wave/ Indiana 21st Century Research and Technology Fund, “Mobile Language Translator: Rosetta Phone Supplement,” August 2006 – August 2007, \$40,000.

- [70] Co-Principal Investigator, National Institute of Justice, “The Use Of HDTV For In-Vehicle Cameras,” August 2006 – August 2007, \$92,000.
- [71] Co-Principal Investigator, Samsung Advanced Institute Of Technology Contract, March 2006 – February 2007, \$43,000.
- [72] Investigator, Army/ARINC, “C4ISR Testbed Support For Muscatatuck Urban Warfare, August 2006 – October 2007, \$125,000.
- [73] Co-Principal Investigator, Next Wave/ DARPA (STTR, Phase 2), “Hand Held Reader (Rosetta Phone),” January 2008 – December 2010, \$356,000.
- [74] Principal Investigator, Cine-tal/ Indiana 21st Century Research and Technology, “Color Management System,” January 2008 – December 2010, \$268,643 (no indirect cost).
- [75] Investigator, Navy, “Naval Smartships that Anticipate and Manage,” August 2007-August 2008, \$80,000.
- [76] Investigator, NIH- NIDDK, “Improving Diet Assessment in Adolescents,” August 2007 – July 2012, \$2,228,034 (direct cost) (\$400,000 my part)
- [77] Investigator, NIH-NCI, “Improving Dietary Assessment Methods Using The Cell Phone And Digital Imaging,” August 2007 – July 2012, \$2,177,710 (direct cost) (\$400,000 my part).
- [78] Investigator, NIH – NIDDK (George M. O'Brien Kidney Research Center), Indiana University School of Medicine's Division of Nephrology, August 2007 – July 2017, \$6,000,000 (\$300,000, my part).
- [79] Investigator, NRL/DHS, “Study of Potential Sensing Methodologies for Standoff Detection of Vehicle Borne Improvised Explosive Devices for Screening Purposes Prior to Vehicle Check Points,” May 2009 – April 2010, \$180,000.
- [80] Investigator, DHS Center of Excellence, “Visual Analytics for Command, Control, and Interoperability Environments (VACCINE),” November 2009 – June 2017, \$19,000,000.
- [81] Principal Investigator, Curtin University (Australia), “Mobile Telephone Dietary Assessment,” September 2010 – May 2012, \$40,000.
- [82] Investigator, NIH, “Visualizing Dietary Patterns with Pattern Recognition: Formats for the Future,” September 2010 – August 2011, \$24,983.
- [83] Principal Investigator, Hill-Rom, “Image Analysis for Hospital Bed,” January 2012 – December 2012, \$135,626.
- [84] Principal Investigator, NIH, “Domoic Acid Neurotoxicity in Native Americans,” April 2012 – February 2017, \$340,00

- [85] Principal Investigator, NIH, “Center for Advanced Renal Microscopic Analysis,” August 2012 – June 2016, \$269,000.
- [86] Principal Investigator, Trask Fund, “TADA Commercialization,” January – August 2013, \$32,943.
- [87] Principal Investigator, Mitre, “Tattoo Localization and Matching for Image Retrieval,” July-September 2015, \$39,884.
- [88] Principal Investigator, Google, “Error Resilient Video Coding For Real-Time Communication” 9/1/2015- 8/30/2016, \$ 40,089.
- [89] Co-Investigator, DOE, “Automated Sorghum Phenotyping and Trait Development Platform,” 08/01/2015-07/31/2019, \$7,000,000.
- [90] Principal Investigator, DARPA, “Media Forensics Integrity Analytics,” 6/1/2016-5/30/2020, \$4,400,000.
- [91] Co-Principal Investigator, Google, “Media Video Coding Using Texture Analysis and Synthesis,” 10/30/2016-10/29/2017.

Professional Society Activities

Organization: IEEE
 Activity: Student Member
 1968 to 1979
 Member
 1979 to 1986
 Senior Member
 1986 to 1996
 Fellow
 1997 to present

Organization: IEEE Signal Processing Society
 Activity: Image and Multidimensional Signal Processing Technical Committee
 Member
 1993 to 2000
 Vice-Chair
 1996 to 1997
 Chair
 1998 to 2000
 Conference Board

1998 to 2000

Organization: IEEE Signal Processing Society
 Activity: Information Forensics and Security Technical Committee
 Member
 2006 to 2009
 Chair
 2008 to 2009

Organization: IEEE Signal Processing Society
 Activity: Fellow's Committee
 Member
 2011 to 2013

Organization: IEEE Signal Processing Society
 Activity: Award's Committee
 Member
 2011 to 2013

Organization: Optical Society of America
 Activity: Member
 1980 to 1995

Organization: Pattern Recognition Society
 Activity: Member
 1978 to 2000

Organization: SPIE
 Activity: Member
 1989 to present
 Fellow
 1998 to present

Organization: IS&T
 Activity: Member
 1992 to present
 Vice-President of Publications
 1994 to 1998
 Special Advisor to the Board of Directors
 1998 to present
 Fellow

Ph.D. Thesis Supervision Completed

- [1] Paul H. Eichel, May 1985, "Sequential Detection of Linear Features in Two-Dimensional Random Fields" (University of Michigan)
- [2] Nirwan Ansari, August 1988, "Shape Recognition – A Landmark-Based Approach"
- [3] Chee-Hung Henry Chu, August 1988, "The Analysis of Image Sequence Data with Applications to Two-Dimensional Echocardiography"
- [4] Hin Leong Tan, December 1988, "Edge Detection by Cost Minimization"
- [5] Heidi A. Peterson, May 1990, "Image Segmentation Using Human Visual System Properties with Applications in Image Compression"
- [6] Aly A. Farag, May 1990, "A Stochastic Modeling Approach to Region and Edge Based Image Segmentation"
- [7] Robert L. Stevenson, August 1990, "Invariant Reconstruction of Curves and Surfaces with Discontinuities with Applications in Computer Vision"
- [8] Charles Scott Foshee, December 1990, "Goal Driven Three Dimensional Object Inspection From Limited View Backprojection Reconstruction"
- [9] Jisheng Song, August 1991, "A Generalized Morphological Filter"
- [10] C. Ravishankar, August 1991, "Tree-Structured Nonlinear-Adaptive Signal Processing"
- [11] Mary L. Comer, December 1995, "Multiresolution Image Processing Techniques With Applications In Texture Segmentation and Nonlinear Filtering"
- [12] Ke Shen, December 1997, "A Study of Real-time and Rate Scalable Image and Video Compression"
- [13] Moses Chan, May 1999, "Psychologically Plausible Algorithm For Binocular Shape Reconstruction,"
- [14] Sheng Liu, May 1999, "The Analysis of Digital Mammograms: Spiculated Tumor Detection and Normal Mammogram Characterization"
- [15] Paul Salama, August 1999, "Error Concealment In Encoded Images and Video"
- [16] Eduardo Asbun, August 2000, "Improvements in Wavelet-Based Rate Scalable Video Compression"
- [17] Greg Cook, December 2002, "A Study Of Scalability In Video Compression: Rate-Distortion Analysis And Parallel Implementation"
- [18] Lauren Christopher, May 2003, "Bayesian Segmentation Of Three Dimensional Images Using The EM/MPM Algorithm"

- [19] Sahng-Gyu Park, December 2003, “Adaptive Lossless Video Compression”
- [20] Jinwha Yang, May 2004, “A Study of Error-Resilient Interleaving with Applications in the Transmission of Compressed Images and Video”
- [21] Nariman Majdi Nasab, May 2004, “Stochastic and Biological Metaphor Parameter Estimation on the Gaussian Mixture Model and Image Segmentation by Markov Random Field”
- [22] Cuneýt Taskiran, December 2004, “Automatic Methods For Content-Based Access And Summarization Of Video Sequences”
- [23] Yajie Sun, August 2004, “Normal Mammogram Analysis”
- [24] Yuxin Lui, August 2004, “Layered Scalable And Low Complexity Video Encoding: New Approaches And Theoretic Analysis”
- [25] Eugene Lin, May 2005, “Video and Image Watermark Synchronization”
- [26] Zhen Li, August 2005, “New Methods For Motion Estimation With Applications To Low Complexity Video Compression”
- [27] Hyung Cook Kim, May 2006, “Watermark And Data Hiding Evaluation: The Development Of A Statistical Analysis Framework”
- [28] Hwa Young Um, August 2006, “Selective Video Encryption Of Distributed Video Coded Bitstreams And Multicast Security Over Wireless Networks”
- [29] Limin Liu, December 2007, “Backward Channel Aware Distributed Video Coding”
- [30] Anthony Martone, December 2007, “Forensic Characterization Of RF Circuits”
- [31] Liang Liang, August 2009, “Error Resilient Video Streaming Algorithms Based On Wyner-Ziv Coding”
- [32] Nitin Khanna, December 2009, “Forensic Characterization Of Image Capture Devices”
- [33] Golnaz Abdollahian, December 2009, “Content Analysis of User Generated Video”
- [34] Ying Chen Lou, December 2010, “Video Frames Interpolation Using Adaptive Warping”
- [35] Satyam Srivastava, May 2011, “Display Device Color Management and Visual Surveillance of Vehicles”
- [36] Ka Ki Ng, December 2011, “Background Subtraction And Object Tracking With Applications In Visual Surveillance”

- [37] Fengqing Zhu, December 2011, "Multilevel Image Segmentation With Application In Dietary Assessment And Evaluation"
- [38] Marc Bosch Ruiz, May 2012, "Visual Feature Modeling and Refinement with Application in Dietary Assessment"
- [39] Meilin Yang, May 2012, "Multiple Description Video Coding with Adaptive Error Concealment"
- [40] Aravind Mikkilineni, August 2012, "Information Hiding in Printed Documents"
- [41] Kevin Lorenz, August 2012, "Registration and Segmentation Based Analysis of Microscopy Images"
- [42] Ye He, May 2014, "Context Based Image Analysis With Application In Dietary Assessment And Evaluation"
- [43] Chang Xu, May 2014, "Volume Estimation And Image Quality Assessment With Application In Dietary Assessment And Evaluation"
- [44] Albert Parra Pozo, August 2014, "Integrated Mobile Systems Using Image Analysis With Applications In Public Safety"
- [45] Bin Zhao, December 2014, "Image Analysis Using Visual Saliency with Applications in Hazmat Sign Detection and Recognition."
- [46] Neeraj J. Gadgil, August 2016, "Error Resilient Video Coding Using Bitstream Syntax And Iterative Microscopy Image Segmentation."

M.S. Thesis Supervision Completed

- [1] David R. Beering, December 1987, "The Use of the AT&T DSP32 Digital Signal Processing Development System: Applications and New Developments"
- [2] Cameron Wright, May 1988, "A Study of Target Enhancement Algorithms to Counter the Hostile Nuclear Environment"
- [3] Enrique Garcia-Melendo, August 1988, "The Use of Image Processing Techniques for the Analysis of Echocardiographic Images"
- [4] Mary L. Comer, May 1993, "The Use of Mathematical Morphology in Color Image Processing"
- [5] Vladimir Kljajic, May 1997, "MTEACH: A Remote Lecturing System Using Multicast Addressing"
- [6] Michael Igarta, December 2004, "A Study Of MPEG-2 And H.264 Video Coding"

- [7] Ashok Raj Kumaran Mariappan, August 2006, “A Low Complexity Approach To Semantic Classification Of Mobile Multimedia Data”
- [8] Fengqing Zhu, December 2006, “Spatial And Temporal Models For Texture-Based Video Coding”
- [9] A. Mariappan, September 2008, “Personal Dietary Assessment Using Mobile Devices”
- [10] Albert Parra Pozo, December 2011, “An Integrated Mobile System For Gang Graffiti Image Acquisition And Recognition”

M.S. and Ph.D. Thesis Students Currently Being Supervised

Soonam Lee
 Joonsoo Kim
 Khalid Tahboub
 Wang Yu
 Jeehyun Choe
 He Li
 Di Chen
 Daniel Mas
 Qingshuang Chen
 Yuhao Chen
 Dahjung Chung
 Shaobo Fang
 Chichen Fu
 David Ho
 Chang Liu
 Javi Ribera
 Ruiting Shao
 Jiaju Yu

Courses Developed

EE 642 Information Theory and Source Coding
 EE 440 Laboratory - Developed entire new laboratory based on using Lab View
 EE 640 An Introduction to Ill-Posed Inverse Problems in Computational Vision
 EE 695 Introduction to Cryptography and Secure Communications
 EE 640X An Introduction to Analog and Digital Video Systems
 EE 640Y An Introduction to Digital Video Compression
 EE 640Z An Introduction to Biomedical Imaging Systems
 EE 640Z An Introduction to Satellite Based Navigation

EE 695 An Introduction to Biomedical Imaging Systems
 EE 695 Introduction to Digital Video Systems
 EE495M Mobility (helped Jan Allebach develop course)
 EE 495V Vertically Integrated Projects (with Allebach and Coyle)
 Started 4 new EPICS Teams (see below)

Courses "In Charge Of"

EE 440 Transmission of Information, 1990 - 1998

Other Contributions to Teaching

EE 440 Transmission of Information - currently redesigning all laboratory experiments using Lab View and Windows NT, 1998

EPICS – Team Advisor for the Tippecanoe County Historical Association Team

EPICS – Team Advisor for the C-SPAN Team

EPICS – Team Advisor for the APPS Team

EPICS – Team Advisor for the Image Processing Team

School Committee Activities

Committee: EE Curriculum Committee
 Activity: Member 1984 to 1987

Committee: EE Graduate Committee
 Activity: Member
 1987 to 1990

Committee: Communications and Signal Processing Area Committee
 Activity: Member
 1984 to present
 Chairman
 1987 to 1989

Committee: Computer Engineering Area Committee
 Activity: Member
 1984 to 1987

Committee: Purdue Electrical Engineering Industrial Institute
 Activity: Liaison Faculty Member for AT&T Corporation
 October 1984 to December 2000

| | |
|------------|---|
| Committee: | PDE Committee |
| Activity: | Member 1985 to 1987 |
| Committee: | PDE Review Committee |
| Activity: | Member 1990 to 1992 |
| Committee: | Computational Needs Committee |
| Activity: | Member 1991 to 1993 2001 to 2004 |
| Committee: | Head's Advisory Committee |
| Activity: | Member 1994 to 1998 2000 – 2009 |
| Committee: | EE Head Search Committee |
| Activity: | Member 1995 to 1996 |
| Committee: | Biomedical Engineering Area Committee |
| Activity: | Member 1996 to present |
| Committee: | Awards Committee |
| Activity: | Member 1997 to 1998 2005 to present |
| Committee: | Graduate Committee |
| Activity: | Member 2005 to 2007 |
| Committee: | BME Graduate Committee |
| Activity: | Chair 2003 to 2007 |

Engineering-Wide Committee Activities

| | |
|------------|-----------------------------------|
| Committee: | Dean's Faculty Advisory Committee |
| Activity: | Member 2010 to 2013 |

Chair
2012-2013

Committee: Engineering Area Promotion Committee
Activity: Member
2009 to present

Committee: Engineering Library Committee
Activity: Member
1987 to 1995
Chairman
1989 to 1995

Committee: MS in Manufacturing Engineering Committee
Activity: Member
1990 to 1994

Committee: Campus-Wide Network Committee
Activity: Member
1992 to 1994

University-Wide Committee Activities

Committee: University Senate
Activity: Member
1991 to 1997
2009 to 2012

Committee: Faculty Affairs Committee
Activity: Member
1991 to 1994

Committee: Library Committee on Serials
Activity: Member
Fall 1991

Committee: Steering Committee - Center for Image Analysis and Data Visualization
Activity: Member
1996 to 2001

Committee: Steering Committee - Computer Systems Research Institute
Activity: Member
1997 to 2001

Committee: VBNS/Internet 2 Committee
Activity: Member

1998 to 2001

Patents

- [1] US Patent 6,625,295 – “Authentication of Signals Using Watermarks,” inventors: Raymond W. Wolfgang and Edward J. Delp III, issued September 23, 2003.
- [2] US Patent 6,912,658 – “Hiding of Encrypted Data,” inventors: Jordan J. Glogau, Edward J. Delp III, Raymond W. Wolfgang and Eugene Ted Lin, issued June 28, 2005.
- [3] US Patent 7,840,005 B2 – “Synchronization Of Media Signals,” inventors: Edward J. Delp and Eugene T. Lin, issued November 23, 2010
- [4] US Patent 7,886,151 – “Temporal Synchronization Of Video And Audio Signals,” inventors: Edward J. Delp and Eugene T. Lin, issued February 8, 2011.
- [5] US Patent 8,331,451 B2 – “Method And Apparatus For Enhancing Resolution Of Video Image,” inventors: Yousun Bang, Edward J. Delp, Fengqing Zhu, Ho-young Lee, Heui-keun Choh, issued December 11, 2012.
- [6] US Patent 8,363,913 – “Dietary Assessment System and Method,” inventors: Carol Boushey, Edward John Delp, David Scott Ebert, Kyle DelMar Lutes, Deborah Kerr, issued January 29, 2013.
- [7] US Patent 8,605,952 B2 – “Dietary Assessment System and Method,” inventors: Carol Boushey, Edward John Delp, David Scott Ebert, Kyle DelMar Lutes, Deborah Kerr, issued December 10, 2013, 2013.

Patent Applications

- [1] Application PCT/US2016/014587, “Prevention Of Temporal Pumping Artifacts In Video Coding,” Mark Shaw, Jan Allebach, Edward, J. Delp, filed January 22, 2016.
- [2] Application PCT/US2014/060933, “Video Coding Using A Saliency Map,” Mark Shaw, Jan Allebach, Edward, J. Delp, filed: May 6, 2014.

Research Book Contributions and Books Published

- [1] A. J. Buda, E. J. Delp, J. M. Jenkins, D. N. Smith, C. R. Meyer, F.L. Bookstein, B. Pitt, "Digital Two-Dimensional Echocardiography: Line-mode Data Acquisition, Image Processing, and Approaches to Quantitation," in *Advances in Noninvasive Cardiology*, edited by J. Meyer, P. Schweizer, R. Erbel, Martinus Nijhoff, The Hague, 1983, pp. 237-247.
- [2] A. J. Buda and E. J. Delp, editors, *Digital Cardiac Imaging*, Martinus Nijhoff, The Hague, 1985.
- [3] E. J. Delp and A. J. Buda, "Digital Image Processing," in *Digital Cardiac Imaging*, edited by A. J. Buda and E. J. Delp, Martinus Nijhoff, The Hague, 1985, pp. 5-23.

- [4] E. J. Delp, "Computer Hardware Considerations in Digital Imaging" in *Digital Cardiac Imaging*, edited by A. J. Buda and E. J. Delp, Martinus Nijhoff, The Hague, 1985, pp. 42-47.
- [5] A. J. Buda and E. J. Delp, "Digital Two-Dimensional Echocardiography," in *Digital Cardiac Imaging*, edited by A. J. Buda and E. J. Delp, Martinus Nijhoff, The Hague, 1985, pp. 155-181.
- [6] F. Weil, L. Jamieson, and E. Delp, "An Algorithm Database for an Image Understanding Task Execution Environment," in *Multicomputer Vision*, edited by S. Levialdi, Academic Press, London, 1988, pp. 35-51.
- [7] E. J. Delp, editor, *Nonlinear Image Processing*, Proceedings of the SPIE Conference on Nonlinear Image Processing, February 15-16, 1990, Vol. 1247, Santa Clara, California.
- [8] S. B. Gelfand and E. J. Delp, "On Tree Structured Classifiers," in *Artificial Neural Networks and Statistical Pattern Recognition: Old and New Connections*, edited by I. K. Sethi and A. K. Jain, North-Holland, New York, 1991, pp. 51-70.
- [9] H. A. Peterson and E. J. Delp, "An Overview of Digital Image Bandwidth Compression," in *Handbook of Communications Systems Management*, 2nd Edition, edited by J. W. Conard, Auerbach, Boston, 1991, pp. 501-515.
- [10] R. L. Stevenson and E. J. Delp, "Investigation into Building an Invariant Surface Model for Sparse Data," in *Active Perception and Robot Vision*, edited by A. Sood and H. Wechler, Springer Verlag, New York, 1992, pp. 539-557.
- [11] J. Song and E. J. Delp, "The Generalized Morphological Filter," in *Mathematical Morphology: Theory and Application*, edited by R. M. Haralick, Oxford University Press, New York, 1992.
- [12] E. J. Delp, J. P. Allebach, and C. A. Bouman, "Digital Image Processing," in *The Electrical Engineering Handbook*, edited by R. C. Dorf, CRC Press, 1993, pp. 329-345.
- [13] R. L. Stevenson and E. J. Delp, "Three-Dimensional Surface Reconstruction: Theory and Implementation," in *Three-Dimensional Object Recognition Systems*, edited by A. K. Jain and P. J. Flynn, Elsevier, 1993, pp. 89-113.
- [14] L. H. Jamieson, S. E. Hambruch, A. A. Khokhar, and E. J. Delp, "The Role of Models, Software Tools, and Applications in High Performance Computing," in *Developing a Computer Science Agenda for High Performance Computing*, edited by Uzi Vishkin, ACM Press, 1994, pp. 90-97.
- [15] M. L. Comer and E. J. Delp, "Morphological Operations," in *The Colour Image Processing Handbook*, edited by S. Sangwine and R. E. N. Horne, Chapman and Hall, 1998, pp. 210-227.
- [16] P. Salama, N. B. Shroff, and E. J. Delp, "Error Concealment in Encoded Video Streams," in *Signal Recovery Techniques for Image and Video Compression and Transmission*, edited by N.P. Galatsanos and A. K. Katsaggelos, Kluwer, 1999, pp. 199-233.
- [17] E. J. Delp, M. Sanez, P. Salama, "Block Truncation Coding," in *The Image and Video Processing Handbook*, edited by A. C. Bovik, Academic Press, 2000.

- [18] L. Liu, F. Zhu, M. Bosch, and E. J. Delp, "Recent Advances in Video Compression: What's next?," in *Statistical Science and Interdisciplinary Research: Pattern Recognition, Image Processing, and Video Processing*, Edited by Bhabatosh Chanda et al., World Science Press., 2007

Journal Editorial Positions

Member Editorial Board, *International Journal of Cardiac Imaging*, 1984 to 1991.

Associate Editor, *IEEE Transactions on Pattern Analysis and Machine Intelligence*, 1991 to 1993.

Member Editorial Board, *Pattern Recognition*, 1992 to 2000.

Associate Editor, *Journal of Electronic Imaging*, 1995 to 2000.

Associate Editor, *IEEE Transactions on Image Processing*, 1996 to 1999.

Editor of Special Issue on Multimedia Systems, *Journal of Electronic Imaging*, August 1996.

Editor of Special Section on the Awards Papers from the 1997 Visual Communications and Image Processing Conference, *Journal of Electronic Imaging*, January 1998.

Editorial Advisory Board, *IEEE Transactions on Medical Imaging*, 1999 to 2000.

Editor of Special Issue on Watermarking, *Journal of Electronic Imaging*, November 2000.

Associate Editor of Special Issue on Watermarking, *IEEE Transactions on Signal Processing*, 2002.

Serial Journal Regular Articles

- [1] O. R. Mitchell, E. J. Delp, and P. L. Chen, "Filtering to Remove Cloud Cover in Satellite Imagery," *IEEE Transactions on Geoscience Electronics*, Vol. GE-15, No. 3, July 1977, pp. 137-141.
- [2] E. J. Delp and O. R. Mitchell, "Image Compression Using Block Truncation Coding," *IEEE Transactions on Communications*, Vol. COM-27, No. 9, September 1979, pp. 1335-1342.
- [3] E. J. Delp, R. L. Kashyap, and O. R. Mitchell, "Image Data Compression Using Autoregressive Time Series Models," *Pattern Recognition*, Vol. 11, No. 5/6, 1979, pp. 313-323.
- [4] O. R. Mitchell and E. J. Delp, "Multilevel Graphics Representation Using Block Truncation Coding," *Proceedings of the IEEE*, Vol. 68, No. 7, July 1980, pp. 868-873.
- [5] O. R. Mitchell, S. C. Bass, E. J. Delp, T. W. Goeddel, and T. S. Huang, "Image Coding for Photo Analysis," *Proceedings of the Society for Information Display*, Vol. 21/3, 1980, pp. 279-292 (invited paper).

- [6] A. J. Buda, E. J. Delp, C. R. Meyer, J. M. Jenkins, D. N. Smith, F.L. Bookstein, and B. Pitt, "Automatic Computer Processing of Digital 2-Dimensional Echocardiograms," *American Journal of Cardiology*, Vol. 52, August 1983, pp. 384-389.
- [7] X. Youren, C.M. Vest, and E. J. Delp, "Digital and Optical Moire Detection of Flaws Applied to Holographic Nondestructive Testing," *Optics Letters*, Vol. 8, August 1983, pp. 452-454.
- [8] E. J. Delp and C. H. Chu, "Detecting Edge Segments," *IEEE Transactions on Systems, Man, and Cybernetics*, Vol. SMC-15, No. 1, January 1985, pp. 144-152.
- [9] T. F. Knoll, L. L. Brinkley, E. J. Delp, "Difference Picture Algorithms for the Analysis of Extracellular Components of Histological Images," *Journal of Histochemistry and Cytochemistry*, Vol. 33, No. 4, 1985, pp. 261-267.
- [10] P. Besl, E. J. Delp, and R. Jain, "Automatic Visual Solder Joint Inspection," *IEEE Journal of Robotics and Automation*, Vol. RA-1, No. 1, March 1985, pp. 42-56.
- [11] J. W. Lee, E. J. Delp, and L. L. Brinkley, "Automatic Segmentation and Quantification of Electron Micrographs: Extracellular Components," *Computers and Biomedical Research*, Vol. 18, 1985, pp. 587-604.
- [12] T. F. Knoll and E. J. Delp, "Adaptive Gray Scale Mapping to Reduce Registration Noise in Difference Images," *Computer Vision, Graphics, and Image Processing*, Vol. 33, 1986, pp. 129-137.
- [13] E. R. Wolfe, E. J. Delp, C. R. Meyer, F. L. Bookstein, and A. J. Buda, "Accuracy of Automatically Determined Borders in Digital 2D Echocardiography Using a Cardiac Phantom," *IEEE Transactions on Medical Imaging*, Vol. MI-6, No. 4, December 1987, pp. 292-296.
- [14] C. H. Chu, E. J. Delp, and A. J. Buda, "Detecting Left Ventricular Endocardial and Epicardial Boundaries by Digital Two-Dimensional Echocardiography," *IEEE Transactions on Medical Imaging*, Vol. MI-7, No. 2, June 1988, pp. 81-90.
- [15] C. H. Chu and E. J. Delp, "A Computer Vision Approach to the Automatic Analysis of Two-Dimensional Echocardiograms," *Automedica*, Vol. 10, 1988, pp. 49-65.
- [16] P. H. Eichel, E. J. Delp, K. Koral, and A. J. Buda, "A Method for Fully Automatic Definition of Coronary Arterial Edges from Cineangiograms," *IEEE Transactions on Medical Imaging*, Vol. MI-7, No. 4, December 1988, pp. 313-320. (Reprinted in *Computer Vision: Advances and Applications*, edited by R. Kasturi and R. C. Jain, IEEE Computer Society Press, 1991, pp. 53-60.
- [17] C. H. Chu and E. J. Delp, "Impulsive Noise Suppression and Background Normalization of Electrocardiogram Signals Using Morphological Operators," *IEEE Transactions on Biomedical Engineering*, Vol. 36, No. 2, February 1989, pp. 262-273.
- [18] E. Garcia-Melendo and E. J. Delp, "A Technique for the Visualization and Analysis of Wall Motion by Two Dimensional Echocardiography," *IEEE Transactions on Medical Imaging*, Vol. 8, No. 1, March 1989, pp. 104-106.
- [19] C. H. Chu, E. J. Delp, L. H. Jamieson, H. J. Siegel, F. J. Weil, and A. B. Whinston, "A Model for an Intelligent Operating System for Executing Image Understanding Tasks

- on a Reconfigurable Parallel Architecture," *Journal of Parallel and Distributed Computing*, Vol. 6, No. 3, June 1989, pp. 598-622.
- [20] C. H. Chu and E. J. Delp, "Estimating Displacement Vectors from an Image Sequence," *Journal of the Optical Society of America A*, Vol. 6, No. 6, June 1989, pp. 871-878.
 - [21] H. L. Tan, S. B. Gelfand, E. J. Delp, "A Comparative Cost Function Approach to Edge Detection," *IEEE Transactions on Systems, Man, and Cybernetics*, Vol. 19, No. 6, December 1989, pp. 1337-1349.
 - [22] C. H. G. Wright, E. J. Delp, and N. C. Gallagher, "Nonlinear Target Enhancement for the Hostile Nuclear Environment," *IEEE Transactions on Aerospace and Electronic Systems*, Vol. 26, No. 1, January 1990, pp. 122-145.
 - [23] P. H. Eichel and E. J. Delp, "Quantitative Analysis of a Moment Based Edge Operator," *IEEE Transactions on Systems, Man, and Cybernetics*, Vol. 20, No. 1, January 1990, pp. 59-66.
 - [24] H. A. Peterson and E. J. Delp, "An Overview of Digital Image Bandwidth Compression," *Journal of Data and Computer Communications*, Vol. 2, No. 3, Winter 1990, pp. 39-49.
 - [25] R. L. Stevenson and E. J. Delp, "Invariant Recovery of Curves in M-Dimensional Space from Sparse Data," *Journal of the Optical Society of America A*, Vol. 7, No. 3, March 1990, pp. 480-490.
 - [26] N. Ansari and E. J. Delp, "Partial Shape Recognition: A Landmark-Based Approach," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, Vol. 12, No. 5, May 1990, pp. 470-483.
 - [27] J. Song and E. J. Delp, "The Analysis of Morphological Filters with Multiple Structuring Elements," *Computer Vision, Graphics, and Image Processing*, Vol. 50, June 1990, pp. 308-328.
 - [28] N. Ansari and E. J. Delp, "On the Distribution of a Deforming Triangle," *Pattern Recognition*, Vol. 23, No. 12, 1990, pp. 1333-1341.
 - [29] S. B. Gelfand, C. S. Ravishankar, and E. J. Delp, "An Iterative Growing and Pruning Algorithm for Classification Tree Design," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, Vol. 13, No. 2, February 1991, pp. 163-174.
 - [30] E. J. Delp and O. R. Mitchell, "The Use of Block Truncation Coding in DPCM Image Coding," *IEEE Transactions on Signal Processing*, April 1991, Vol. 39, No. 4, pp. 967-971.
 - [31] E. J. Delp and O. R. Mitchell, "Moment Preserving Quantization," *IEEE Transactions on Communications*, Vol. 39, No. 11, November 1991, pp. 1549-1558.
 - [32] N. Ansari and E. J. Delp, "On Detecting Dominant Points," *Pattern Recognition*, Vol. 24, No. 5, 1991, pp. 441-450.
 - [33] F. J. Weil, L. H. Jamieson, E. J. Delp, "Dynamic Intelligent Scheduling and Control of Reconfigurable Parallel Architectures for Computer Vision/Image Processing," *Journal of Parallel and Distributed Computing*, Vol. 13, 1991, pp. 273-285.

- [34] J. Song and E. J. Delp, "A Study of the Generalized Morphological Filter," *Circuits, Systems, and Signal Processing*, Vol. 11, No. 1, 1992, pp. 229-252.
- [35] H. L. Tan, S. B. Gelfand, and E. J. Delp, "A Cost Minimization Approach to Edge Detection," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, Vol. 14, No. 1, January 1992, pp. 3-18.
- [36] R. L. Stevenson and E. J. Delp, "Viewpoint Invariant Recovery of Visual Surfaces from Sparse Data, *IEEE Transactions on Pattern Analysis and Machine Intelligence*, Vol. 14, No. 9, September 1992, pp. 897-909.
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- [38] A. A. Farag and E. J. Delp, "Image Segmentation Based on Composite Random Field Models," *Optical Engineering*, Vol. 31, No. 12, pp. 2594-2607, December, 1992.
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- [43] L. A. Overturf, M. L. Comer, and E. J. Delp, "Color Image Coding Using Morphological Pyramid Decomposition," *IEEE Transactions on Image Processing*, Vol. 4, No. 2, February 1994, pp. 177-185.
- [44] G. W. Cook and E. J. Delp, "An Investigation of Scalable SIMD I/O Techniques with Application to Parallel JPEG Compression," *Journal of Parallel and Distributed Computing*, Vol. 30, March 1995, pp. 111-128.
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Invited Lectures

- [1] "Image Bandwidth Compression," presented at the University of Cincinnati, Department of Electrical and Computing Engineering, November 22, 1978.
- [2] "Digital Image Processing," presented at Kodak Research Laboratories, Rochester, NY, March 29, 1979.
- [3] "Computer Vision for Industrial Robots," presented at the Steelcollar Revolution Symposium, Troy, MI, April 7, 1981.
- [4] "Three-Dimensional Computer Vision," presented at Robotics Today and Needs for Tomorrow Symposium, Ann Arbor, MI, December 1, 1981.
- [5] "Robot Vision: Today and Tomorrow," presented at Michigan Robotics Research Circle, Ann Arbor, MI, January 28, 1982.
- [6] "Computational Issues in Computer Vision," presented at the SME Applied Machine Vision Conference, Cleveland, OH, April 8, 1982.
- [7] "Digital Image Processing," presented at New Perspectives in Cardiac Imaging, September 29, 1983, Dearborn, Michigan (sponsored by American Heart Association).
- [8] "A Tutorial on Digital Image Processing," presented at University of Michigan Medical School Symposium on Medical Imaging, Ann Arbor, MI, March 19, 1985.
- [9] "Current Research Issues in Image Processing and Computer Vision," a series of three lectures, Departamento de Ingenieria Electrica, Universidad Autonoma Metropolitana - Iztapulapa, Mexico City, Mexico, January 20-24, 1986.
- [10] "Optics and Signal Processing in SDI, " (with N. Gallagher) presented at U.S. Air Force Academy, Colorado Springs, CO, August 5, 1987.
- [11] "The Generalized Morphological Filter," presented at the Department of Electrical and Computer Engineering, Johns Hopkins University, Baltimore, MD, March 29, 1990.
- [12] "Image Processing and Computer Vision," a series of six lectures, Institut de Cibernetica, Universitat Politecnica de Catalunya, Barcelona, Spain, July 2-10, 1990.

- [13] "An Overview of Computer Vision and Image Processing Research Problems: Where Psychologists Can Help," presented at the Department of Psychology, Purdue University, October 7, 1992.
- [14] "Some New Approaches in Stereo Medical Imaging and Color Image Enhancement," presented at the Department of Electrical and Computer Engineering, Illinois Institute of Technology, September 10, 1993, Chicago.
- [15] "Image and Video Compression Techniques for Multimedia Systems," presented at the Department of Electrical and Computer Engineering, University of Illinois at Chicago, March 30, 1994, Chicago.
- [16] "Image and Video Compression Techniques for Multimedia Systems," presented at the Eli Lilly Research Laboratories, September 20, 1994, Indianapolis.
- [17] "Image and Video Compression," presented at the School of Veterinary Medicine, Purdue University, February 22, 1995, West Lafayette, IN.
- [18] "Introduction to Multimedia Systems," presented at Kraft Foods, March 7, 1995, Chicago, IL.
- [19] "Image and Video Compression Techniques," presented at AT&T, February 20, 1996, Indianapolis.
- [20] "Image and Video Compression Techniques for Multimedia Systems," presented at Northern Illinois University, March 21, 1996, DeKalb, IL.
- [21] "Image and Video Compression Techniques for Multimedia Systems," presented at the Department of Electrical Engineering, University of Louisville, March 1996, Louisville.
- [22] "Video Compression: What's New at Purdue?," presented at the Universitat Politecnica de Catalunya, Barcelona, Spain, September 1996.
- [23] "Video and Image Compression Research at Purdue," presented at Motorola, Schumberg, IL, January 1997.
- [24] "Image and Video Compression Techniques for Multimedia Systems," presented at Motorola, Schumberg, IL, November 4, 1996.
- [25] "Image and Video Compression," presented at the the Second International Conference on Image Technologies: Techniques and Applications in Civil Engineering in Davos, Switzerland, May 1997.
- [26] "Video Compression Techniques for Multimedia Systems," presented at Texas Instruments, November 3, 1997.
- [27] "Scalable Image and Video Compression," presented at Rockwell, December 12, 1997.
- [28] "Scalable Image and Video Compression," presented at the University of Southwestern Louisiana, the Center for Advanced Computer Studies, March 6, 1998, (this seminar is part of the Louisiana Distinguished Lecture Series).
- [29] "Error Concealment in Compressed Video Streams," presented at the Univerity of Illinois, Beckman Institute, March 31, 1998.
- [30] "Image Analysis: Old Problems and New Challenges," Keynote Address, presented at, IEEE Southwest Symposium on Image Analysis and Interpretation, April, 6, 1998.

- [31] "Scalable Image and Video Compression," presented at the University of Oklahoma, Department of Electrical Engineering, April 16, 1998.
- [32] "Error Concealment in Compressed Video Streams," presented at Oklahoma State University, Department of Electrical Engineering, April 17, 1998.
- [33] "Recent Advances in Image and Video Processing," a series of 7 lectures presented at Tampere University of Technology, Tampere, Finland, June 1998.
- [34] "Scalable Image and Video Compression," presented at the Illinois Institute of Technology, Department of Electrical and Computer Engineering, October 16, 1998.
- [35] "Scalable Image and Video Compression," presented at the University of Pennsylvania, Department of Electrical Engineering, February 18, 1999.
- [36] "Recent Progress in Image and Video Processing," a series of 5 lectures presented at the University of Louisville, Department of Electrical Engineering, March 1-5, 1999.
- [37] "Scalable Image and Video Compression," presented at the University of Minnesota, Department of Electrical Engineering, March 11, 1999.
- [38] "Watermarking: An Overview," presented to the Intragency Group on Counterfeiting and Security, US Department of the Treasury, Washington, March 8, 1999.
- [39] "Image and Video Processing with Applications in Multimedia Systems," a series of four lectures, Arizona State University, Department of Computer Science and Engineering, March 22-23, 1999.
- [40] "Scalable Image and Video Compression," presented to the Central Arizona Chapter of the IEEE, Phoenix, March 24, 1999.
- [41] "The Analysis of Digital Mammograms," presented at Ohio State University, Department of Electrical Engineering, April 2, 1999.
- [42] "Scalable Image and Video Compression," presented at Ohio State University, Department of Electrical Engineering, April 2, 1999.
- [43] "Scalable Image and Video Compression," presented at the University of Notre Dame, Department of Electrical Engineering, April 6, 1999.
- [44] "Rate Scalable Video Compression," presented at the Intel Architecture Laboratory, Hillsboro, OR, April 20, 1999.
- [45] "The Analysis of Digital Mammograms," presented at the University of California at Berkeley, Department of Electrical Engineering and Computer Science, September 2, 1999.
- [46] "Recent Advances in Image and Video Processing II," a series of 5 lectures presented at Tampere University of Technology, Tampere, Finland, June 1999.
- [47] "Video and Image Processing At Purdue," presented at the Texas Instruments DSPS Research and Development Center, Dallas, September 27, 1999.
- [48] "ViBE: A Video Database Structured for Browsing and Search," presented at the University of Southern California, Los Angeles, November 10, 1999.
- [49] "Multimedia Security: Are We There Yet?," presented at the Copy Protection Technical Working Group meeting, Burbank, November 11, 1999.

- [50] "Video and Image Processing At Purdue," presented at the Intel Research Center, Santa Clara, December 3, 1999.
- [51] "Video and Image Processing At Purdue," presented at Bell Laboratories (Lucent), Murray Hill, NJ, January 12, 2000.
- [52] "Watermarking: What is the Future?," presented at Panasonic Research Center, Princeton, NJ, January 13, 2000.
- [53] "An Overview of Watermarking," presented at Oce Corporation, Venlo, The Netherlands, February 2, 2000.
- [54] "Watermarking and Multimedia Security," presented at Philips Research Center (NatLab), Eindhoven, The Netherlands, February 3, 2000.
- [55] "The ViBE Video Database System," presented at the Technical University of Delft, Delft, The Netherlands, February 4, 2000.
- [56] "An Overview of the Global Positioning Satellite System," presented at the Technical University of Delft, Delft, The Netherlands, February 4, 2000.
- [57] "Watermarking and Multimedia Security," presented at the US Air Force Academy, Colorado Springs, CO, March 16, 2000.
- [58] "Multimedia Security: Is this a Myth?," Plenary Talk presented at the IEEE Southwest Symposium on Image Analysis and Interpretation, Austin, TX, April 4, 2000.
- [59] "Video Databases and Security," a series of talks presented in Spain, May 2000.
- [60] "Is Image and Video Compression Research Dead?," Keynote Address presented at Visual Communications and Image Processing (VCIP), Perth, Australia, June 21, 2000.
- [61] "Video Compression and Watermarking," a series of talks in Australia, June 2000.
- [62] "Overview of Multimedia Security: What Role Does Signal Processing Have in Securing Our Digital Future," Plenary Talk presented at the European Signal Processing Conference (EUSIPCO), Tampere, Finland, September 6, 2000.
- [63] "Watermarking: What is the Future?," presented at the Signal et Image au service de la Securite dans la Societe de l'Information, Paris, October 10, 2000.
- [64] "Watermarking: What is the Future?," presented at the Universite de Bordeaux I, Bordeaux, France, October 12, 2000.
- [65] "Image and Video Databases: Who Cares?," presented to the Rochester IEEE Section, December 7, 2000.
- [66] "ViBE: A Video Databases for Browsing and Search," presented at the Department of Electrical and Computer Engineering, Texas A&M University, October 5, 2000.
- [67] "An Overview of Watermarking Research at Purdue," presented at the Swiss Institute of Technology Lausanne (EPFL), May 22, 2000.
- [68] "New Results in Scalable Image and Video Compression," presented at Rice University, August 4, 2000.
- [69] "An Overview of Error Resilience Techniques in Video Compression," presented at Intel, Chandler, AZ, August 11, 2000.

- [70] "Multimedia Security: Is there Hope in Securing our "Digital Future?," an invited talk, presented at the Institute for Mathematics and Its Applications (University of Minnesota), February 13, 2001.
- [71] "An Overview of Cryptography," an invited talk, presented at the Institute for Mathematics and Its Applications (University of Minnesota), February 14, 2001.
- [72] "Vibe: A Video Database for Browsing and Search," an invited talk, presented at the Institute for Mathematics and Its Applications (University of Minnesota), February 27, 2001.
- [73] "An Overview of Watermarking at Purdue," presented at CMU, April 19, 2001.
- [74] "Video Streaming: What Are The Research Issues," presented at the Swiss Institute of Technology Lausanne (EPFL), May 21, 2001.
- [75] "Video Streaming: What Are The Research Issues," presented at the Universitat Politecnica de Catalunya in Barcelona, Spain, July 16, 2001.
- [76] "Watermarking: An Overview," Invited talk to celebrate the 150th Anniversary of the Electrical Engineering Department at Universite Catholique de Louvain, Belgium, May 11, 2001.
- [77] "An Introduction To Cryptography," a series of talks presented at the Tampere International Center for Signal Processing (TICSP), Tampere University of Technology, Finland, June 7-8, 2001.
- [78] "An Overview of Media Streaming," a series of talks presented at the Tampere International Center for Signal Processing (TICSP), Tampere University of Technology, Finland, June 18-21, 2001.
- [79] "The Analysis of Digital Mammograms: What is normal?" presented at the Tampere International Center for Signal Processing (TICSP), Tampere University of Technology, Finland, May 28, 2002.
- [80] "Home Networks: How Wired and/or Wireless Is Your Home?" presented at the Tampere International Center for Signal Processing (TICSP), Tampere University of Technology, Finland, May 29, 2002.
- [81] "An Overview of Satellite Radio Services." presented at the Tampere International Center for Signal Processing (TICSP), Tampere University of Technology, Finland, May 30, 2002.
- [82] "Home Networks: How Wired and/or Wireless Is Your Home?" presented at the Lapenratta University of Technology, Finland, June 3, 2002.
- [83] "Multimedia Security: So What's the Big Deal?" presented at the University of Notre Dame, March 18, 2003.

- [84] "Multimedia Security: So What's the Big Deal?" presented at the University of Texas, March 20, 2003.
- [85] "Multimedia Security: So What's the Big Deal?" presented at the Purdue Silicon Valley Alumni Association, July 25, 2003.
- [86] "Multimedia Security: So What's the Big Deal?" presented at the Iowa State University, December 5, 2003.
- [87] "Entertainment Over the Internet", presented at the IBM T. J. Watson Research Laboratory, November 20, 2003.
- [88] "Over of Video Compression and Analysis Research at Purdue University," presented at the Nokia Research Center, Tampere, Finland, July 1, 2003.
- [89] "The Role of Security In Multimedia Wireless Systems," presented at the Tampere International Center for Signal Processing at the Tampere University of Technology in Finland, June 24, 2003.
- [90] "Characterizing the Performance of Watermarking and Data Hiding Methods" presented at the Tampere International Center for Signal Processing at the Tampere University of Technology in Finland, June 24, 2003.

Published Reviews

- [1] "*Applied Multidimensional Systems Theory*," by N.K. Bose, published by Van Nostrand Reinhold, review appeared in *Math Reviews*, June 1984, p. 2492.

Symposium Chairman

- [1] General Chair, SPIE/IS&T Symposium on Electronic Imaging, February 6-10, 1994.

Conference Chairman

- [1] Conference Chairman, SPIE/SPSE Symposium on Electronic Imaging, Conference on Nonlinear Image Processing, Santa Clara, CA, February 11-16, 1990.
- [2] General Co-Chairman, IS&T/SPIE Symposium on Electronic Imaging, Conference on Still Image Compression, San Jose, CA, February 5-10, 1995.
- [3] Conference Co-Chairman, IS&T/SPIE Symposium on Electronic Imaging, Conference on Digital Video Compression, San Jose, CA, February 5-10, 1995.
- [4] Conference Co-Chairman, Visual Communication and Image Processing (VCIP), San Jose, CA, February 12-14, 1997.

- [5] Conference Co-Chairman, IS&T/SPIE Symposium on Electronic Imaging, Conference on Security and Watermarking of Multimedia Contents, San Jose, CA, February 1999.
- [6] Conference Co-Chairman, IS&T/SPIE Symposium on Electronic Imaging, Conference on Security and Watermarking of Multimedia Contents II, San Jose, CA, January 2000.
- [7] Conference Co-Chairman, IS&T/SPIE Symposium on Electronic Imaging, Conference on Security and Watermarking of Multimedia Contents III, San Jose, CA, February 2001.
- [8] Conference Co-Chairman, IS&T/SPIE Symposium on Electronic Imaging, Conference on Security and Watermarking of Multimedia Contents IV, San Jose, CA, February 2002.
- [9] Conference Co-Chairman, IS&T/SPIE Symposium on Electronic Imaging, Conference on Security and Watermarking of Multimedia Contents, Santa Clara, CA, February 2003.
- [10] Conference Co-Chairman, IS&T/SPIE Symposium on Electronic Imaging, Conference on Security, Steganography, and Watermarking of Multimedia Contents, San Jose, CA, January 2004.
- [11] Conference Co-Chairman, IS&T/SPIE Symposium on Electronic Imaging, Conference on Security, Steganography, and Watermarking of Multimedia Contents, San Jose, CA, January 2005.
- [12] Conference Co-Chairman, IS&T/SPIE Symposium on Electronic Imaging, Conference on Security, Steganography, and Watermarking of Multimedia Contents, San Jose, CA, January 2006.
- [13] Conference Co-Chairman, IS&T/SPIE Symposium on Electronic Imaging, Conference on Security, Steganography, and Watermarking of Multimedia Contents, San Jose, CA, January 2007.
- [14] Conference Co-Chairman, IS&T/SPIE Symposium on Electronic Imaging, Conference on Security, Steganography, and Watermarking of Multimedia Contents, San Jose, CA, January 2008.
- [15] Chairman, Picture Coding Symposium, Chicago, Spring 2009.

Conference Program Committee Chairman

- [1] Chairman, Program Committee, IEEE Ninth IMDSP Workshop, March 1996, Belize City, Belize.
- [2] Co-Chairman, Program Committee, IEEE 5th Southwest Symposium on Image Analysis and Interpretation, April 2002, Santa Fe.

- [3] Co-Chairman, Program Committee, IEEE International Conference on Image Processing, October 2003, Barcelona, Spain.

Conference Program Committees

- [1] Member, Program Committee, 1991 IEEE Computer Vision and Pattern Recognition Conference, Maui, HI, June 3-6, 1991.
- [2] Member, Program Committee, IEEE Workshop on Applications of Computer Vision, Palm Springs, November 1992.
- [3] Member, Program Committee, 1994 IEEE Computer Vision and Pattern Recognition Conference, Seattle, June 1994.
- [4] Member, Program Committee, IEEE Workshop on Biomedical Image Analysis, Seattle, June 1994.
- [5] Member, Program Committee, SPIE/IS&T Conference on Nonlinear Image Processing V, San Jose, February 1994.
- [6] Member, Program Committee, SPIE/IS&T Conference on Digital Video Compression on Personal Computers: Algorithms and Technologies, San Jose, February 1994.
- [7] Member, Program Committee, Second IEEE Workshop on Applications of Computer Vision, Sarasota, December 1994.
- [8] Member, Program Committee, SPIE/IS&T Conference on Digital Video Compression: Algorithms and Technologies, San Jose, February 1996.
- [9] Member, Program Committee, International Conference on Parallel Processing, Bloomingdale, IL, August 1996.
- [10] Member, Program Committee, IEEE Workshop on Mathematical Methods in Biomedical Image Analysis, San Francisco, June 21-22, 1996.
- [11] Member, Program Committee, ACM Workshop on Parallel Processing and Multimedia, 11th International Parallel Processing Symposium (IPPS '97), Geneva, April, 1-5, 1997.
- [12] Member, Program Committee, 1997 IEEE Computer Vision and Pattern Recognition Conference, San Juan, May 1997.
- [13] Member, Program Committee, IS&T/SPIE Conference on Storage and Retrieval for Image and Video Databases, San Jose, February 13-14, 1997.
- [14] Member, Program Committee, Visual Communication and Image Processing (VCIP), San Jose, January 25-30, 1998.
- [15] Member, Program Committee, IS&T/SPIE Conference on Storage and Retrieval for Image and Video Databases, San Jose, January 25-30, 1998.
- [16] Member, Program Committee, IEEE/ACM IPPS/SPDP 1998 Workshop on Parallel Processing and Multimedia, Orlando, March 30, 1998
- [17] Member, Program Committee, SPIE Conference on Parallel and Distributed Methods for Image Processing II, San Diego, CA, July 19-24, 1998.

- [18] Member, Program Committee, IS&T/SPIE Visual Communication and Image Processing, San Jose, January 23-29, 1999.
- [19] Member, Program Committee, IS&T/SPIE Conference on Storage and Retrieval for Image and Video Databases, San Jose, January 23-29, 1999.
- [20] Member, Program Committee, 1999 IEEE-EURASIP Workshop on Nonlinear Signal and Image Processing, Antalya, Turkey, June 20-23, 1999.
- [21] Member, Program Committee, IS&T/SPIE Conference on Storage and Retrieval for Image and Video Databases, San Jose, January 26-28, 2000.
- [22] Member, Program Committee, IS&T/SPIE Conference on Image and Video Communications and Processing, San Jose, January 25-28, 2000.
- [23] Member, Program Committee, Visual Communication and Image Processing, Perth, Australia, June 20-23, 2000.
- [24] Member, Program Committee, Packet Video Workshop, Sardinia, Italy, May 1-2, 2000.
- [25] Member, Program Committee, IEEE-EURASIP Workshop on Nonlinear Signal and Image Processing, Baltimore, 2001.
- [26] Member, Program Committee, IS&T/SPIE Conference on Storage and Retrieval for Image and Video Databases, San Jose, January 2001.
- [27] Member, Program Committee, Visual Communication and Image Processing, San Jose, January, 2001.
- [28] Member, Program Committee, IS&T/SPIE Conference on Storage and Retrieval for Image and Video Databases, San Jose, January 2002.
- [29] Member, Program Committee, Conference on Visual Communication and Image Processing, San Jose, January 2002.
- [30] Member, Program Committee, Conference on Visual Communication and Image Processing, San Jose, January 2003.
- [31] Member, Program Committee, IS&T/SPIE Conference on Storage and Retrieval for Image and Video Databases, San Jose, January 2003.
- [32] Member, Program Committee, Conference on Visual Communication and Image Processing, San Jose, January 2004.
- [33] Member, Program Committee, IS&T/SPIE Conference on Storage and Retrieval for Image and Video Databases, San Jose, January 2004.

Conference Session Chairman

- [1] Session Chairman and Organizer, "Machine Vision in Robotics," 1985 IEEE Robotics and Automation Conference, St. Louis, MO, March 1985.

- [2] Session Chairman and Organizer, "Image Processing," 1985 IEEE International Conference on Communications, Chicago, IL, June 1985.
- [3] Session Chairman, "Image Processing," Twenty-Fourth Annual Allerton Conference on Communication, Control, and Computing, Allerton, IL, October 1986.
- [4] Session Chairman, "Programming Environments for Supercomputers: Parallelization of Different Backtracking Algorithms," Second International Conference on Supercomputing, Santa Clara, CA, May 1987.
- [5] Session Chairman and Organizer, "Morphological Image Processing," 1988 IEEE International Symposium on Circuits and Systems, Espoo, Finland, June 1988.
- [6] Session Chairman and Organizer, "Nonlinear Image Processing," 1989 IEEE International Symposium on Circuits and Systems, Portland, OR, May 1989.
- [7] Session Chairman, "Pose Estimation and Surface Reconstruction," and "Smoothing and Differential Operators," International Workshop on Robust Computer Vision, Seattle, Washington, October 1-3, 1990.
- [8] Session Chairman, "Video Coding Methods and Techniques II," SPIE/IS&T Conference on Digital Video Compression on Personal Computers: Algorithms and Technologies, San Jose, February 1994.
- [9] Session Chairman, "Miscellaneous Coding Techniques," SPIE/IS&T Conference on Image and Video Compression, San Jose, February 1994.
- [10] Session Chairman, "Image Analysis I," International Conference on Acoustics, Speech and Signal Processing, April 1994, Adelaide, Australia.
- [11] Session Chairman, "Image/Texture Analysis," International Conference on Acoustics, Speech and Signal Processing, April 1995, Detroit, MI.
- [12] Session Chairman, "Motion Estimation," IEEE International Conference on Image Processing, September 16-19, 1996, Lausanne, Switzerland.
- [13] Session Chairman and Organizer, "Video and Imaging," OSA Annual Meeting, October 21-25, 1996, Rochester, NY.
- [14] Session Chairman, "Processing of Video Signals," 1997 IEEE Workshop on Nonlinear Signal and Image Processing, September 8-10, 1997, Mackinac Island, MI.
- [15] Session Chairman, "Image Filtering I," 1998 IEEE International Conference on Acoustics, Speech, and Signal Processing, May 12-15, 1998, Seattle.
- [16] Session Chair, "Systems and Sensors," 1998 IMDSP Workshop, July 12-16, 1998, Alpbach, Austria.
- [17] Session Chairman, "Edge Detection," 1998 IEEE International Conference on Image Processing, October 4-7, 1998, Chicago.
- [18] Session Chair, "Image Coding," SPIE/IS&T Conference on Visual Communications and Image Processing (VCIP), January 23-29, 1999, San Jose, California.
- [19] Session Chair, "Image Databases," SPIE/IS&T Conference on Storage and Retrieval for Image and Video Databases VII, January 23-29, 1999, San Jose, California.

- [20] Session Chair, "Image Watermarking I," SPIE/IS&T International Conference on Security and Watermarking of Multimedia Contents, January 23-29, 1999, San Jose, California.
- [21] Session Chair "Image Watermarking II," SPIE/IS&T International Conference on Security and Watermarking of Multimedia Contents, January 23-29, 1999, San Jose, California.
- [22] Session Chair, "Video Compression and Processing," IEEE International Conference on Acoustics, Speech, and Signal Processing, March 16-19, 1999, Phoenix.
- [23] Session Chair, "Video Compression," IEEE International Conference on Image Processing, October 1999, Kobe, Japan.
- [24] Session Chair, "Video Compression," IEEE International Conference on Acoustics, Speech, and Signal Processing, June 2000, Istanbul, Turkey.
- [25] Session Co-Chair and Co-Organizer, "Video Compression: The Future," European Signal Processing Conference (EUSIPCO), Tampere, Finland, September 2000.
- [26] Session Chair, "Video Compression," Conference on Visual Communication and Image Processing (VCIP), Perth, June, 2000.
- [27] Session Chair, "Motion Estimation," Conference on Visual Communication and Image Processing (VCIP), San Jose, January 2001.
- [28] Session Chair, "Image and Video Coding," 45th IEEE International Midwest Symposium on Circuits and Systems.
- [29] Session Chair, "Watermarking and Coding," 45th IEEE International Midwest Symposium on Circuits and Systems.

Conference Panel

- [1] Organizer and Member, "The Role of Computer Vision and Multimedia," IEEE Computer Vision and Pattern Recognition Conference, Seattle, June 1994.
- [2] Member, "Multimedia Databases," SPIE Conference on Multimedia Storage and Archiving Systems IV, September 20-22, 1999, Boston.
- [3] Member, "Image Retrieval," International Workshop on Very Low Bitrate Video Coding, Kyoto, Japan, October 1999.
- [4] Member, "Media Information Systems and the Internet: What Are the Opportunities and How Far Have We Gone?," SPIE/IS&T Conference on Storage and Retrieval for Media Databases, San Jose, January 2000.
- [5] "Who Needs MPEG-21?" Visual Communication and Image Processing Conference, San Jose, January 2001.
- [6] "New Frontiers of Media Management and Media Content Analysis," SPIE Conference on Storage and Retrieval for Media Databases, San Jose, January 2001.

- [7] "Defining the Next Generation Challenges in Media Composition, Compression, and Communication Research and Development", IEEE International Conference on Multimedia and Expo, August 28, 2002, Lausanne, Switzerland.

Conference (Other)

- [1] Media Chair, 1997 IEEE Workshop on Nonlinear Signal and Image Processing, September 8-10, 1997, Mackinac Island, MI.

Activities as a Referee

National Science Foundation
 IEEE Transactions on Acoustics, Speech and Signal Processing
 IEEE Transactions on Signal Processing
 IEEE Transactions on Image Processing
 IEEE Transactions on Aerospace and Electronic Systems
 IEEE Transactions on Automatic Controls
 IEEE Transactions on Biomedical Engineering
 IEEE Transactions on Circuits and Systems
 IEEE Transactions on Communications
 IEEE Transactions on Medical Imaging
 IEEE Transactions on Pattern Analysis and Machine Intelligence
 IEEE Transactions on Robotics and Automation
 IEEE Transactions on Software Engineering
 IEEE Transactions on Systems, Man, and Cybernetics
 IEEE Computer Magazine
 Mathematical Biosciences
 SIAM Journal on Applied Mathematics
 Computer Vision, Graphics, and Image Processing
 Journal of the Optical Society of America
 Journal of Machine Vision and Applications
 Pattern Recognition
 Optical Engineering

Short Courses

"Principles and Applications of Digital Signal Processing," Lecturer, Purdue University, 1980.
 "Computer Vision and Image Processing," Course Co-Chairman and Lecturer, University of Michigan, 1984.
 "Machine Vision," (Video Tape Course), Course Chairman and Lecturer, Purdue University, 1985.
 "Computer Vision and Image Processing," Lecturer, University of Michigan, 1985.
 "Image Processing," Ball Aerospace Corporation, Course Organizer and Lecturer, 1985.

- "Computer Vision and Image Processing," Lecturer, University of Michigan, 1986.
- "Computer Vision and Image Processing," Course Organizer and Lecturer, IBM Corporation, 1986.
- "Medical Imaging," (Video Tape Course), Course Organizer and Lecturer, 1987.
- "Nonlinear Image Processing," Course Co-Organizer and Lecturer, SPIE/SPSE Symposium on Electronic Imaging, Santa Clara, CA, 1990.
- "Sensing and Measurements Seminar Course," Course Co-Organizer and Lecturer, ERC Short Course, Purdue University, 1992.
- "Simulink," ECN Short Course, October 5, 1993.
- "Simulink," ECN Short Course, March, 1994.
- "Simulink," ECN Short Course, October 4, 1994.
- "Image and Video Compression," Lecturer, IEEE Custom Integrated Circuits Conference, May 1, 1994, San Diego, CA. "Simulink," ECN Short Course, February 15, 1995.
- "Image and Video Compression," Lecturer, IEEE Custom Integrated Circuits Conference, May 1, 1995, Santa Clara, CA.
- "Simulink," ECN Short Course, January, 25, 1996.
- "An Introduction to Cryptography and Data Security with Applications to Imaging, Video, and Multimedia Systems," Lecturer and Course Organizer, IS&T/SPIE Symposium on Electronic Imaging, January 31, 1996, San Jose.
- "An Introduction to Cryptography and Data Security with Applications to Imaging, Video, and Multimedia Systems," Lecturer and Course Organizer, Visual Communication and Image Processing Conference (VCIP), March 17, 1996, Orlando.
- "An Introduction to Cryptography and Data Security with Applications to Imaging, Video, and Multimedia Systems," Lecturer and Course Organizer, SPIE Symposium on Photonics East, November 21, 1996, Boston.
- "Simulink," ECN Short Course, September 4, 1996.
- "An Introduction to Cryptography and Data Security with Applications to Imaging, Video, and Multimedia Systems," Lecturer and Course Organizer, IS&T/SPIE Symposium on Electronic Imaging, February 12, 1997, San Jose.
- "Simulink," ECN Short Course, February 1997.
- "An Introduction to Cryptography and Data Security," Lecturer and Course Organizer, SPIE Conference Voice, Video, and Data Communications, November 4, 1997, Dallas.
- "Simulink," ECN Short Course, February 3, 1998.
- "An Overview of Cryptography and Watermarking," Lecturer and Course Organizer, Thomson Consumer Electronics, August 17-18, 1998, Indianapolis.
- "An Introduction to Cryptography Watermarking," Lecturer and Course Organizer, SPI Conference Voice, Video, and Data Communications, November 5, 1998, Boston.

"An Introduction to Cryptography and Watermarking," Lecturer and Course Organizer, IS&T/SPIE Symposium on Electronic Imaging, January 28, 1999, San Jose.

"An Introduction to Cryptography and Watermarking," Lecturer and Course Organizer, IS&T PICS Conference, April 25, 1999, Savannah, Georgia.

"An Overview of Image and Video Compression," Lecturer and Course Organizer, IS&T PICS Conference, April 25, 1999, Savannah, Georgia.

"Image Watermarking," Lecturer and Course Organizer, IEEE International Conference on Image Processing, October 1999, Kobe, Japan.

"An Introduction to Cryptography and Watermarking," Lecturer and Course Organizer, IS&T/SPIE Symposium on Electronic Imaging, January 2000, San Jose.

"Texture Analysis and Its Applications in Medical Imaging," Lecturer and Course Co-Organizer, SPIE Medical Imaging Symposium, February 12, 2000, San Diego.

"Data Hiding/Watermarking," Lecturer and Course Organizer, ICASSP, June 5, 2000, Istanbul, Turkey.

"An Introduction to Watermarking," Lecturer and Course Organizer, Visual Communication and Image Processing Conference (VCIP), Perth, Australia, June 2000.

"An Introduction to Cryptography and Watermarking," Lecturer and Course Organizer, IS&T/SPIE Symposium on Electronic Imaging, January 2001, San Jose.

"A Mathematical Approach to Watermarking and Data Hiding" Lecturer and Course Organizer, International Conference on Image Processing, Greece, October 2001.

"An Introduction to Cryptography and Watermarking," Lecturer and Course Organizer, IS&T/SPIE Symposium on Electronic Imaging, January 2002, San Jose.

"An Introduction to Cryptography and Digital Watermarking with Applications to Multimedia Systems," Lecturer and Course Organizer, 45th IEEE International Midwest Symposium on Circuits and Systems, August 4, 2002, Tulsa, OK.

"An Introduction to Cryptography and Watermarking," Lecturer and Course Organizer, IS&T/SPIE Symposium on Electronic Imaging, January 2003, Santa Clara.

"An Introduction to Cryptography and Watermarking," Lecturer and Course Organizer, IS&T/SPIE Symposium on Electronic Imaging, January 2004, San Jose.

"An Introduction to Cryptography and Watermarking," Lecturer and Course Organizer, IS&T/SPIE Symposium on Electronic Imaging, January 2005, San Jose.