Digital HDTV Broadcasting

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Introduction to the Special Issue on Digital HDTV Broadcasting

The United States is intensely investigating digital high definition television (HDTV) terrestrial broadcasting systems. Four different digital HDTV systems have been proposed to the FCC Advisory Committee on Advanced Television Service and are being evaluated and tested. This special issue of the IEEE Transactions on Broadcasting examines these four proposals. The papers which follow were written as United States submissions to an international standards committee. They are published here as they were submitted to a November 1991 meeting of the International Radio Consultative Committee (CCIR) Task Group on HDTV.

Significant effort has been expended in the research, writing, and review of these papers by a large number of people. The writing process began when an Ad Hoc group was formed in the Advanced Television Systems Committee (ATSC) to propose and prepare documents for the November 1991 CCIR meeting. The Ad Hoc group initially discussed the philosophy which would be followed in creating documents, the issues which would be highlighted, and an outline of each proposed paper. It was agreed that they should be relatively brief and easy to translate into other languages, that the four proposed systems would be described in four separate documents, and that other papers would analyze sub-systems making specific reference to the four proposed systems in the style of a tutorial. Authors were then assigned. After the papers were written, they were reviewed and modified by the Ad Hoc Group. The documents were then presented to the ATSC Technology Group on Distribution where they again were subjected to modifications. After the papers were approved by the Technology Group, they were presented to the ATSC Executive Committee, further modified, and approved.

The ATSC submitted the papers to the United States Department of State proposing that they become United States documents to the CCIR. The documents then went through the normal Department of State process. They were first subjected to review by a group which prepares for the CCIR Task Group on HDTV meetings. Once they were modified and approved by the preparatory group, they were subjected to a review by the United States CCIR Study Group 11. Finally, they were reviewed by the United States CCIR National Committee.

In the process outlined here, more than 200 persons have reviewed these papers. They have been subjected to peer review and subsequently modified to ensure that they enjoy consensus support in the United States. It is amazing that the papers could survive such a process. Indeed, it is because of their high quality, timely nature, and informative value that they are being published here.

What is the CCIR?

The CCIR is the permanent organ of the International Telecommunication Union (ITU) responsible “to study technical and operating questions relating specifically to radiocommunications without limit of frequency range, and to issue Recommendations on them with a view to standardizing telecommunications on a world-wide basis.” There are several Study Groups in the CCIR. Study Group 11 is responsible for Television Broadcasting Services.

CCIR Study Group 11 began its study of high definition television in 1974 when the first HDTV documents were submitted by Japan. From 1974 until 1986 the emphasis was on achieving a single world-wide standard for production and international program exchange. At this point, no proposal has found world-wide acceptance as a single standard and the emphasis has switched to broadcasting standards.

Both European Administrations and the Japanese Administration have shown interest in HDTV broadcasting

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by satellite. They have shown little, if any, interest in HDTV terrestrial broadcasting. In the United States, however, there is intense interest in HDTV terrestrial broadcasting, and especially, digital HDTV terrestrial broadcasting.

It was in this environment that the papers which follow were written.

Purpose of the Digital HDTV Broadcasting Documents

There are twelve papers on digital HDTV broadcasting which follow. They are organized in a manner which responds to questions posed in the CCIR. Key issues are:

1. Harmonization of high resolution imaging standards among applications
2. Compression algorithms
3. Source coding
4. Channel coding
5. Modulation techniques
6. Spectrum strategy

The ATSC Ad Hoc group asked proponents of the four digital HDTV broadcasting systems to prepare a document describing their proposed system in terms of the issues listed above. Recognizing that any claims made in documents submitted to the CCIR by the United States become United States' claims, the Ad Hoc group avoided disputes on untested claims by inserting at the beginning of each of these four documents a paragraph stating, "The information contained in this document has been supplied by the proponent of the described system. In the United States a process is in place to evaluate and test each proposed system to confirm its performance." Other authors were asked to write a paper on each of these issues making reference to the four systems pointing out common areas and differences. In addition, one author was asked to prepare a table comparing the proposed systems while another author was asked to describe the testing process that is in place under the FCC's Advisory Committee on Advanced Television Service.

Block Diagram of a Typical Digital HDTV Broadcasting System

The information provided to the CCIR did not contain block diagrams of the proposed systems. To assist the reader of this special issue, block diagrams of a "typical" encoder and decoder are provided in this introduction. These diagrams are not precisely descriptive of any of the proposed systems but are generally descriptive of all of them.

<u>Figure 1</u> shows a typical digital HDTV broadcasting encoder. A frame of the input video is referred to as the "new picture." A "difference picture" is obtained by subtracting a "predicted picture" from the "new picture." The process for obtaining the "predicted picture" will be described later.

If the "predicted picture" very closely represents the "new picture," there is little information left that must be transmitted to the decoder. The first step in video compression, then, is to reduce the temporal redundancy in the video.

The next step often used in video compression is reduction of the spatial redundancy. Normally this is carried out by transforming the "difference picture" from a time representation to a spatial frequency representation. This transform is typically performed on a group, or block, of picture elements 8 wide by 8 high. The transformed signal generally consists of the average value of the 64 picture elements plus 63 new values, or coefficients, whose amplitudes represent the strength of higher and higher spatial frequencies in the horizontal and vertical directions. If there is a great deal of spatial redundancy in the video, many of these transform coefficients are small or non-existent.

The Buffer accepts data at whatever rate data is being generated and outputs the data at a constant rate consistent with the capacity of the transmission channel. If the input data rate is too high and cannot be sustained, the Buffer will inform the Adaptive Quantizer of this fact. This is likely to happen whenever there is little temporal redundancy as is the case when the input picture is suddenly switched. In this case the Adaptive Quantizer, in an irreversible manner, will limit the data to a lower bit rate. This can be done in a number of ways. For example, one can "round-off" the transform coefficients maintaining less and less accuracy which in turn requires fewer transmission bits. One can, as well, discard those transform coefficients that are smaller than a predetermined threshold.

The Entropy Coder takes advantage of redundancy in the quantized transform coefficients. For example, rather than transmit multiple sequential zero-value coefficients, the decoder can simply be told the number of sequential zero-value coefficients.

The output of the Adaptive Quantizer is needed in the encoder to simulate the picture which will be reconstructed by the decoder. This simulated picture is used to construct the next "predicted picture." Because the encoder transmits the differences between the "new picture" and the "predicted picture," the encoder needs to construct the same "predicted picture" that the decoder will construct. The inverse function of the Adaptive Quanitzer is performed by the Inverse Quantizer. The output of the Inverse Quantizer will be identical to the input of the Adaptive Quantizer except for any "round-off" which was performed to reduce the data rate.

The inverse function of the Transform Coder is performed by the Inverse Transform operation. The Inverse Transform output is identical to the "difference picture" except for the "round-off." If it is added to the "predicted picture" it simulates the picture which will be seen at the decoder and is identical to the "new picture" except for the "round-off."

The simulated picture is held in a Picture Memory so that it can be compared with the next "new picture" which will be referred to as "new picture B." The simulated picture is compared with "new picture B" by the Motion Estimator. Generally, small portions, or blocks, of the simulated picture are compared with blocks of the new picture to determine if there was movement between the pictures, and if so, to determine the precise motion of each block. The resulting Motion Vectors are used to move these blocks of the simulated picture to produce the "predicted picture B." One could have used the previous "new picture" as the prediction for "new picture B." However, the process described here gives a closer approximation to the "new picture B" than does the previous "new picture."

This "predicted picture B" is then subtracted from the "new picture B" to produce the "difference picture B" and the process repeats as described above.

The Encoded Coefficients from the Buffer and the Motion Vectors from the Motion Estimator are both required at the decoder. They are combined with other data such as Digital Audio, Ancillary/Control Data, and Sync information in the Multiplexer & Formatter. Forward error correction is applied and then the signal modulates a carrier producing the RF output.

A typical digital HDTV broadcasting decoder is shown in Figure 2. Generally, the decoder performs the inverse function of the encoder. The RF input is demodulated; the FEC Decoder reconstructs the transmitted signal and corrects errors; and the Demultiplexer separates the data into the Encoded Coefficients, Motion Vectors, Digital Audio, Ancillary/Control Data, and Sync.

The Encoded Coefficients are also processed in an inverse manner. The Entropy Decoder performs the inverse function of the encoder's Entropy Coder. The Inverse Quantizer and the Inverse Transform perform the inverse function of the encoder's Adaptive Quantizer and Transform Coder. These processes convert the Encoded Coefficients into the "update information." The "update information" is the same as the encoder's "difference picture" except for the "round-off" performed by the encoder's Adaptive Quantizer.

The Picture Memory holds the decoder's last "new picture" so that the Motion Vectors can be used to move blocks of the last "new picture" to produce the next "predicted picture." The "update information" is added to the "predicted picture" to produce the next "new picture."

These descriptions have ignored one very important issue. Consider, for example, the situation when the video is suddenly switched at the input to the encoder. The "predicted picture," constructed from the last "new picture," will probably be nonsense. Provisions must be made to handle this situation. Generally, such situations are detected and the Transform Coder function is applied directly to the "new picture" rather than the "difference picture." The fact that this occurred is signalled to the decoder so that the decoder will interpret

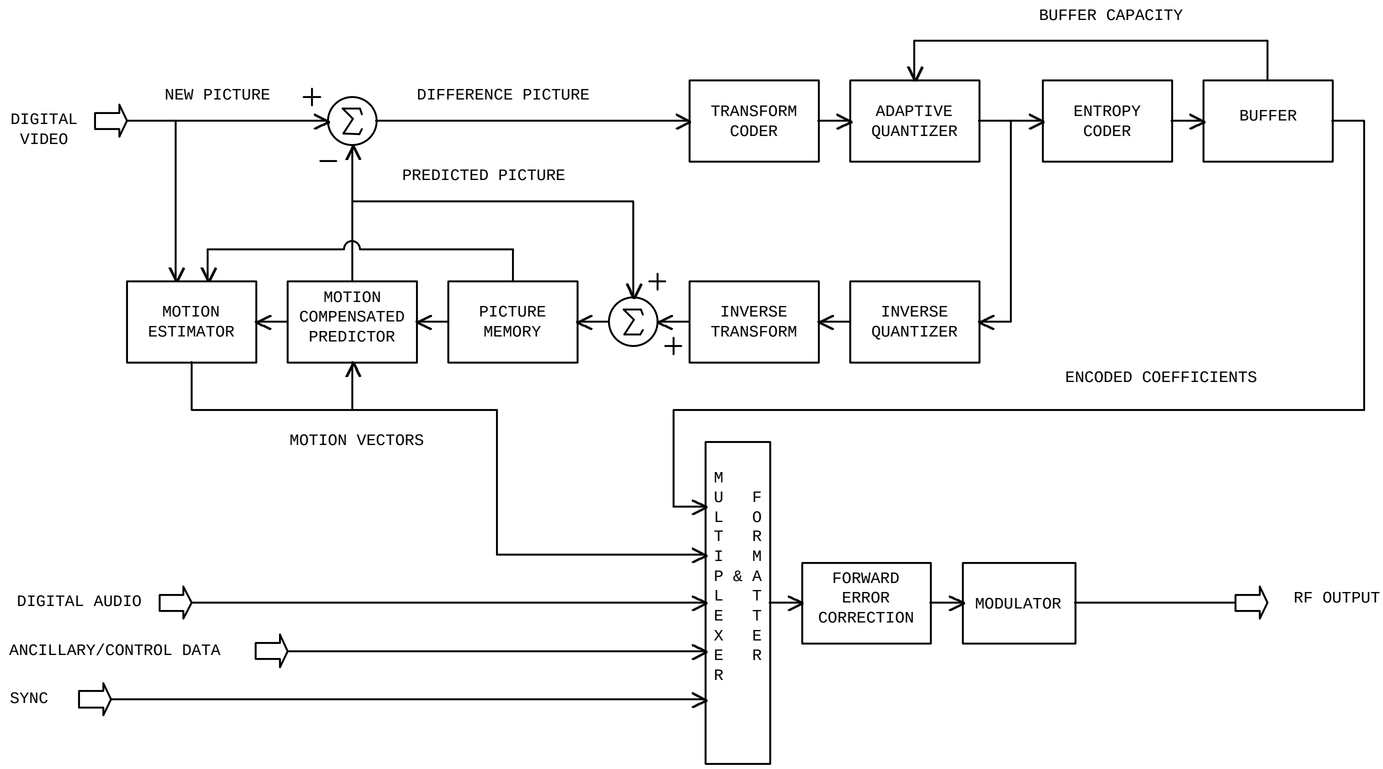

FIGURE 1. TYPICAL DIGITAL HDTV BROADCASTING ENCODER

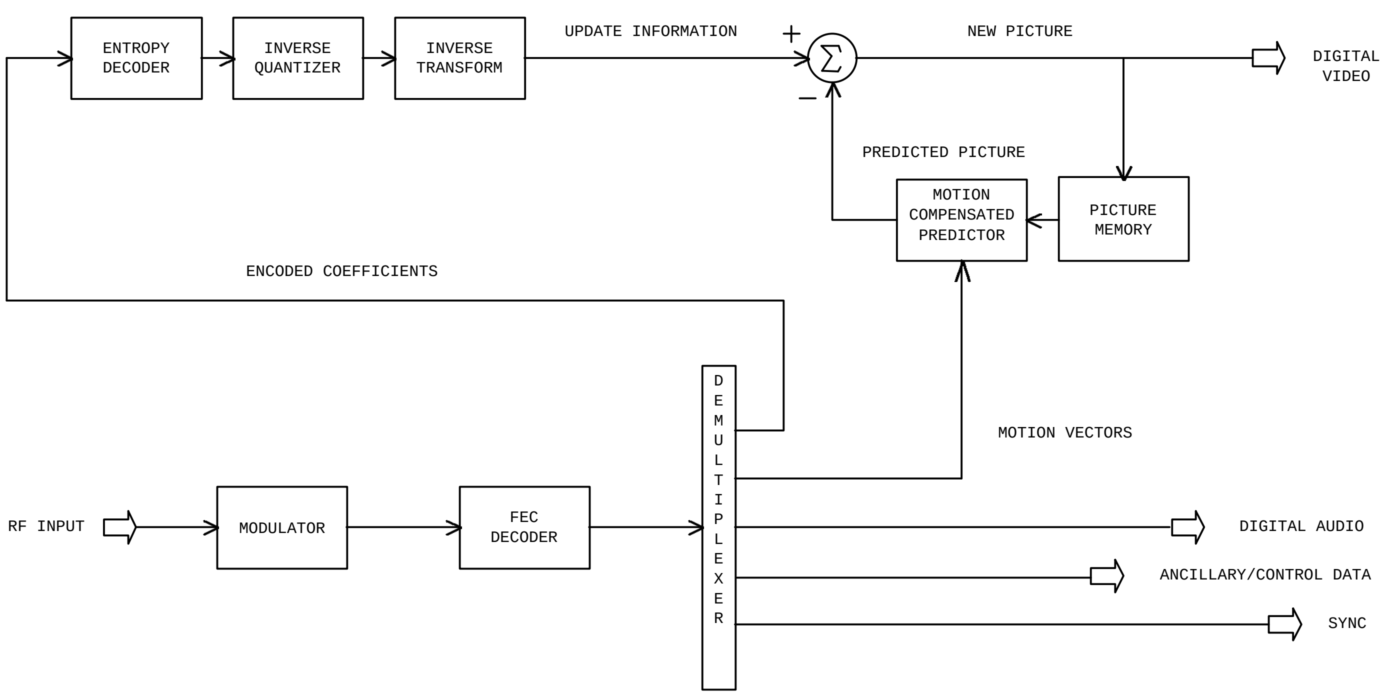

FIGURE 2. TYPICAL DIGITAL HDTV BROADCASTING DECODER

these “encoded coefficients” as a “new picture” rather than as “update information.” Furthermore, the proposed systems generally make these decisions on a block by block basis, not on a picture by picture basis.

These descriptions also imply that the “predicted picture” is based on a picture from the past. It is possible to base the “predicted picture” on a future picture! If the order of pictures is changed at the encoder input so that a future frame of video is taken out of turn (this can be done using frame stores), this future picture can be transmitted to the decoder as described in the previous paragraph and can be used to create a “predicted picture.”

Summary

As stated previously, the papers presented in this Special Issue on Digital HDTV Broadcasting were written as United States submissions to the CCIR. They have survived peer review by many persons and enjoy consensus support in the United States. Their greatest value is the collection and dissemination of information on competing proposals in a similar and balanced manner on new technology being developed in the United States — digital HDTV terrestrial broadcasting. By virtue of this Special Issue, they are being made available to an even larger audience.

BIOGRAPHY

Robert Hopkins is the Executive Director of the United States Advanced Television Systems Committee. Prior to joining ATSC in 1985, he was the Managing Director of RCA Jersey Limited, Jersey Channel Islands, Great Britain, an overseas subsidiary of RCA that manufactured professional television equipment for a worldwide market. He was also employed by RCA at the David Sarnoff Research Center and the Broadcast Systems Division.

Dr. Hopkins serves as the United States spokesman on high definition television in the CCIR. He Chairs the working party in the FCC Advisory Committee on Advanced Television Service that is charged with recommending an advanced television standard. He is a senior member of the IEEE, a fellow of the SMPTE, and past chairman of SMPTE’s Standards Committee, Committee on New Technology, and Working Group on Digital Video Standards. He received the BSEE from Purdue University in West Lafayette, Indiana; PhD from Rutgers University, New Brunswick, New Jersey; and attended the Harvard Business School Program for Management Development.