Video Compression

(1) Will the MPEG standard be formalized early enough to be the Sky Cable standard as assumed in this RFI?

The MPEG committee has announced a schedule for adopting a standard which targets September 1990 for specification of a Draft Proposal. Since they have only recently agreed on a simulation model for the 1.15 Mbps MPEG standard, it seems likely that this recommendation will not be ready before the end of 1990. Progress toward the 5-6 Mbps standard (MPEG II), is not as far along as 1.15 Mbps MPEG, and a schedule for issuance of documents has not been established. Although progress appears to be delayed, movement toward an MPEG II standard could accelerate rapidly as did work on the CCITT p x 64 kbps standard during the 1987-88 time frame. This may be particularly true since likely potential algorithms for the 1.15 Mbps MPEG have common components with the p x 64 kbps algorithm. The MPEG II algorithm will also share coding elements with MPEG.

The time-table for the MPEG process is not inconsistent with the 1992 design verification target of Sky Cable, however, it will require both action by the MPEG committee to clarify the state of the standards process and a clear understanding of the likely trends for MPEG II. If these events occur, prototype hardware can be constructed for the initial phases of testing. Significant portions of the test-bed could be made programmable to permit tracking of the MPEG process as the standard is refined and revised.

(2) Will MPEG provide a quality level equivalent to a CCIR grade 4.5? At what bit rate? Characterize the quality achieved as a function of bit rate. What subjective measurement criteria should be used to judge compressed digital video?

Since the MPEG II algorithm is not defined, it is premature to try to quantify its image quality. However, it is anticipated that its sampling rate will be twice that of 1.15 Mbps MPEG, both horizontally and vertically. Therefore, its maximum picture spatial resolution probably will be at full NTSC quality. The initial MPEG algorithm for CD-ROM applications will <u>not</u> be NTSC resolution.

NTSC resolution requires the transmission of a minimum of 6.4 Mpixel/second (active picture area only). This means the algorithm will have a source coding rate of ~ 1 bit/pixel. At 6 - 7.5 Mbps, the quality should be quite respectable. A 40 dB (or greater) unweighted Signal-to-Noise ratio might be expected for most scenes, however decoded image quality will be scene dependent. Performance with entertainment video using sophisticated special effect techniques remains to be seen. Overall MOS performance of 4.5 for all scenes might be difficult, but a quality level of ~4.0 during most scenes is likely. For very complex scenes like those of a music video or fast action sports, MOS < 4.0 might very well result.

Since each algorithm introduces unique impairments, there is no one universally accepted image quality measurement criteria. The 5 point Mean Opinion Score is perhaps the best known procedure for subjective testing and is a good candidate for this application. The relative nature of subjective comparisons means the test subjects will be strongly influenced by the reference material. If the reference is a studio quality component signal, the MOS may be significantly lower than expected. The control picture (the display the testing subjects are asked to accept as "perfection, 5.0) should not exceed NTSC bandwidths. The absolute rating of the compressed picture may not be as important as its rating relative to a competing service such as a CATV or Broadcast equivalent signal. Therefore, signals equivalent to <u>received</u> CATV or Broadcast should be tested for comparison. Additionally, objective tests with some well designed test sequences should be conducted.

(3) What channel error rate will be required for normal (Clear Sky) and faded conditions? Characterize the quality as a function of bit error rate. Should the image be turned off entirely at a certain bit rate?

Since MPEG II is not defined, the efficacy of its refresh, variable word length decoding, error detection, and error concealment mechanisms are not known. In particular, the MPEG algorithm does not refresh in a distributed manner (a few pixels each frame), but rather encodes every N^{th} frame in an intraframe mode. The choice of N is made for use with special effects and random access on the CD-ROM, and is <u>not</u> chosen for refreshing channel errors. A study of the error control attributes of this should be made. Based on the CCITT p x 64 kbps example, a residual bit error rate of 10^{-7} - 10^{-8} after FEC decoding probably is required before the onset of "noticeability" of channel errors.

The opportunity to modify the FEC for the satellite channel, while still exploiting the MPEG video protocol should be considered. The channel quality of this application is quite different the the CD-ROM and might benefit from an inner code for the satellite. (Here we define the outer code to be the FEC which is first applied to the encoded stream, and the inner code to be a subsequent further protection). The MPEG protocol will have some nominal FEC such as a 239,255 BCH code. Two options exist. The first is to discard this part of the protocol in the interest of cost containment, and to substitute an FEC chosen for the satellite. However, as will be discussed in (5) it may be desirable to leave the MPEG stream intact and to let the BCH serve as and outer-code in the interest of compatibility with other consumer decoding equipment.

Image quality will not be a smooth function of bit error rate, but will exhibit a classical threshold effect. In analog FM, the picture is still intelligible under similar conditions, however with digital compression, the picture will be unusable after exceeding some BER and perhaps should be squelched. As stated above, since the algorithm is meant for digital recording, it has occasional frames with intracoding only. One graceful failure mode might be to degrade from full-motion video to a succession of freeze frames resulting from displaying the intracoded frames only. Only after this information was hopelessly corrupted would squelching be invoked.

One final comment relates to some possibilities for further optimization if the MPEG algorithm is not used in its entirety. Certain data types are intrinsically more fragile than others and by adding FEC to this data only, improved performance might be achieved. In particular, the intracoded frame might be give extra redundancy to extend its threshold well below the full motion video. This makes the above degradation model more plausible.

(4) If the MPEG format is broadcast by Sky Cable; will IRD supplier have flexibility to produce units with a variety of picture quality levels and cost?

Since the MPEG II can still take on many forms, yet to be defined, it is premature to consider this question in detail. Because of the recursive nature of the encoding/decoding process it is unlikely that there is much chance of doing a less costly "incomplete decoding" (lower resolution arithmetic, less coefficients, etc.), but two possibilities might be mentioned. First, there is a real possibility that the 1.15 Mbps MPEG protocol will be a subset of the MPEG II algorithm. If this is the case, a low resolution, low cost decoder might be possible. Less than VCR resolution is likely to result, however if open architectures are adopted a "set-top" modem might strip the MPEG data from an MPEG II transmission for feeding to another vendors MPEG decoder. This suggests 2 grades of modem-only units, with compressed digital MPEG and MPEG-II outputs. Another possible algorithm feature, not yet adopted by the standards committee, is the use of "frame dropping" at the transmitter with motion compensated frame interpolation at the receiver. If this type of processing is chosen, it might be possible to market decoders which eliminate this potentially costly component and replace it with double shuttering of the decompressed pictures. The cost savings may not warrant the loss in temporal performance which would result.

(5) When is MPEG technology expected to appear in home PC technology? In what types of devices--thatis, accelerator cards or embedded in disk controllers

elsewhere? Could this technology and a PC monitor be accessed by the Sky Cable signal?

At this time we are not aware of the marketing plans of the MPEG participants. Since the standard is driven by the CD-ROM application, it is a forgone conclusion that such low-cost consumer devices will exist. When such devices exist, a compressed digital video output from a low cost Sky Cable receiver could be interfaced to an MPEG decoder. For this scenario to be possible, specific to Sky Cable, such as encryption and/or special FEC, would need to be inner-codes applied to the standard MPEG data stream. The modem would do the processing of the Sky Cable specific codes, and would output a "standard" digital data stream.

(6) Are simple enhancements for the MPEG format available--by changing parameters or adding data fields for example--which could improve quality without depriving Sky Cable's access to the LSI planned to be MPEG capable? The range of video bit rates envisioned is approximately 2.5 to 7 Mbps. Can one algorithm with fixed parameters span this data rate?

(Note: the last sentence in this question seems ambiguous - one needs to vary parameters to achieve a single rate. Operating over a variety of rates certainly implies a variety of parameter settings)

If the 1.15 Mbps MPEG algorithm is similar to the p x 64 kbps algorithm, then image quality improvements at higher transmission rate can be attained parametrically by changing the frame rate, DCT component quantization, and intra-frame processing (refresh) rate. Of key importance is the fact the several vendors are already marketing LSI components for the type of algorithm most likely to be selected. These common chips are invariably programmable, which means Sky Cable could opt to exploit the basic technology while using proprietary coding parameters which will not be identical with the MPEG standard. One algorithm, with fixed pixels density, could span the rates described, but this requires that coding parameters be varied.

Perhaps more problematic is the desire to use 16x9 source material mentioned later in the RFI. The MPEG protocol is inherently 4x3 and it is important to evaluate its theoretical maximum horizontal resolution relative to a 16x9 source.

(7) Are there advantages to Sky Cable in using a proprietary algorithm? Of differing quality?

The main disadvantage of using a proprietary algorithm is the time schedule for the offering of Sky Cable service. It is unlikely that proprietary algorithms, employing different technology, will provide a significant improvement in performance, in the time allotted. The availability of common VLSI components for inexpensive decoders should favor an algorithm substantially similar to a standard. In addition, the MPEG process is considering the problem of working with CD-ROM, and certain special effects (fast forward, fast reverse, random access, etc.) may be applicable to future Digital VCR's. Since the primary interest in using a compression algorithm related to a "standard" is VLSI and third party equipment, it is important to be aware of another potential digital standard, namely the FCC terrestrial HDTV standard. Digital simulcast proponents will continue to emerge as the process unfolds.

[some aspects of the asymmetrical potential of non-MPEG algorithms will be discussed in (8)]

(8) The algorithms for MPEG and for p x 64 teleconferencing assume a "symmetric" application--that is, where a terminal both encodes and decodes. Sky Cable is fundamentally "asymmetric," in that a signal is encoded at a single location and broadcast to millions of receive-only installations. Can MPEG LSI be produced more cheaply where only decoding is desired? Are totally different algorithms available which are superior for Sky Cable's broadcast application.

A decoder only installation will be less than one-half the complexity as a bi-directional codec. This is because the MPEG algorithm will make substantial use of Motion Compensation which is <u>not</u> a symmetric operation, but requires considerably more computation at the transmitter.

Other algorithms, such as Vector Quantization, have a more pronounced asymmetry than described above. Certainly, algorithms designed for this application should have some improved operating/cost characteristics, however this is inconsistent with the deployment schedule for the Sky Cable service. Consideration of such algorithms might be relevant, however, the large body of work by the international standards bodies would not be applicable.

(9) Characterize the nature of HDTV at 30 Mbps. At 20 Mbps. Is it expected that HDTV sets sold in the U.S. will have a baseband interface such that Sky Cable's signal can be displayed or will a transcoder be required?

Digital HDTV in the 20-30 Mbps is still a very active research topic. Some reports of HDTV in this rate regime have been made, but the technology is still unproven. Conventional definitions of HDTV imply that 60 Mpixels/second must be transmitted. This requires that compression algorithms which give good quality at 1/2 bit/pixel are required at 30 Mbps. The problem is compounded if 20 Mbps is the transmission rate. Compression technology will certainly improve, but consistently high quality video compressed to these rates is not a certain proposition.

One of the primary attractions of using the MPEG algorithm is the availability of cost effective chips and the similar equipment (particularly where such equipment might have an open architecture). An equally compelling argument could be made for using technologies hierarchically related to any potential digital HDTV simulcast standard. The sales of home HDTV receivers will most likely far exceed those of CD-ROM decoders, with a corresponding economy in VLSI components. Unfortunately the FCC process for selecting an HDTV standard will lag behind the MPEG process by several years. It is likely that system proponents will announce new algorithms over the next 18 months. Considering the difficulty the the HDTV compression problem, as described above, these yet unknown proposals will likely be quite different in the technologies employed. Understanding the likelihood of these developments is perhaps all Sky Cable can do at this time, since exploiting them is not possible before the complete situation is known.

The EIA Multiport Receiver Technical Committee is presently drafting recommendations and specifications for ATV receivers with a variety of input options. An interface for baseband video input is contemplated, however, the organization cannot issue a binding recommendation. Market considerations will determine if such architectures are adopted. The important fact is that the receiver manufacturers are considering this question.