DIGITAL TECHNIQUES CURE LINE SEGMENTATION SCRAMBLING PROBLEMS

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ABSTRACT

Digital domain techniques are used to correct artifacts encountered in line segmentation video scrambling schemes. In particular, baseband frequency bandlimiting and line tilt distortion corrections are discussed.

INTRODUCTION

Video security is a topic well known by the cable television industry. With proposed future services, it is becoming more and more likely that highly secure image transmission systems will have to be used. These systems will have to provide security commensurate with the value of the visual information being communicated.

It has been ATC's interest to play a role in the selection and development of secure video scrambling systems for the future. With this in mind, this paper discusses the advances made at ATC in the area of line segmentation scrambling.

LINE SEGMENTATION VIDEO SCRAMBLING

Several options are available in the selection of a secure video transmission scheme (reference [1] overviews various video scrambling methods). In typical sync-suppression techniques, the visual portion of the signal often remains relatively uncorrupted with only the sync intervals being modified. This characteristic allows simple reconstruction of the original signal at the subscriber site. However, the interested pirate with a bit of television electronics background can "break" such a system with a minimum of effort.

Digital encryption techniques, on the other hand, offer the ultimate security with the strength of the National Bureau of Standards' Data Encryption Standard (DES) behind them. In this technique, each video frame is digitized into discrete samples, with each sample encrypted using the DES standard. Unfortunately, these systems require the digital transmission of video data, a high-bandwidth mode for which cable systems lack the capacity.

A happy middleground appears to be a scrambling technique that mixes both low video signal corruption and digital control of the descrambling; such a technique is line segmentation. In the line segmentation scheme, the bulk of the visual signal is left unchanged. One or more cuts are made in each video line with the various segments interchanged within the line. The cut points are controlled by pseudo-random number patterns.

The pseudo-random cut patterns are generated at the headend scrambler and subscriber descrambler in synchronism. Pseudo-random pattern "seed" values are passed to authorized subscribers allowing their units to track the patterns of the headend scrambler. An unauthorized subscriber is given bogus "seeds". With the "seed" values digitally encrypted using the DES standard, a high level of security is maintained for their passage.

At ATC, a line segmentation scrambling approach was chosen for study because of its hybrid characteristics between predominately unmodified video and secure encryption techniques. Both parameters pair to provide secure transmission as well as relatively simple reconstruction. Furthermore, by not corrupting the horizontal and vertical sync intervals, NTSC signal compatibility of the scrambled video is maintained.

The system to be discussed herein uses a single cut per video line made at a pseudo-random point within the line. Illicit reconstruction of the video signal without benefit of subscriber authorization codes proves to be exceptionally difficult. One such scenario requires the use of high-speed digital correlators that attempt to match a given line with its previous neighbor. Aside from being rather costly, even this technique tends to fall apart with significant line-to-line video differences.

DISTORTION PROBLEMS

Line segmentation video scramblers suffer from a few self-induced distortion mechanisms. In particular, when a line segmented signal is subjected to baseband frequency limiting and line tilt, serious reconstruction distortions are produced. Where these distortions may normally be imperceivable to the viewer when applied to clear video, the line segmentation reconstruction process introduces resulting visual artifacts that are unacceptable (reference [2] overviews these distortions and their effect on the line segmentation process).

First, baseband frequency limiting, caused by poor high-frequency response baseband processors and mistuned vestigial sideband receivers, adds step response degradation to the video signal. This distortion will typically cause a signal to experience roll off or ringing of its sharp transients. This is a problem at two sharp discontinuous portions of the line segmented signal, particularly at the start of the line between the back porch-to-visual line transition and the end of the line between the visual line-to-front porch transition. These two points must be mated without perturbation in the reconstruction process. Signal roll off or ringing at these points causes an undershoot or overshoot response in the patched reconstructed signal. The visual effect is dark or light sparklets at the reconstruction patch-points.

Second, line tilt is seen as a DC droop across a video line between black-level clamping periods. Even high amounts of this slow luminance variation across the line is typically undetectable by the viewer. However, following line segmentation reconstruction, relatively low amounts of this seemingly minor distortion provide for a chaotic hashing of luminance stridations overlaying the viewed video image. This distortion comes up because the imposed DC droop is cut, along with the visual portion of the line, in the reconstruction process. Once the video line is reconstructed to its original form, the line tilt component appears as a sawtooth luminance variation with the entire magnitude of the tilt making a transition at a single location.

In order to make line segmentation scrambling a viable mode of security in real-world video transmission systems, it is essential that the effects of these two "induced" distortion mechanisms be removed. Where Charge-Coupled-Devices (CCDs) have been classically used for reconstruction of line segmented video signals, analog corrections for line tilt induced distortions, in particular, are extremely difficult to implement. By digitizing the video upon receipt at the subscriber site, simple methods may be used for the corrections of both baseband frequency limiting and line tilt.

CORRECTING THE PROBLEMS DIGITALLY

Digitizing the Video Signal

The line segmentation system constructed at ATC is digitally based. Both the headend scrambler and the subscriber descrambler units work with digitized video for their processing.

Each unit accepts baseband NTSC video as input. Following a standard input buffer and black-level clamp is a high-speed Analog-to-Digital converter. Working on a line-by-line basis, the digitized video is written into a Random Access Memory (RAM) for storage.

The horizontal blanking interval is read out of the RAM unmodified. The visual portion of the line is read out from a pseudo-random point within the line with the end of the visual line butted up with the start of the visual line. In this way the line segmentation process is effected.

The digitized video data is read from the RAM directly into a high-speed Digital-to-Analog converter for conversion back to the analog domain. An output post-aliasing filter serves to reconstruct the converted video signal back to its NTSC form.

All digitizing is carried out at a sample rate of four times the color subcarrier frequency, or 14.318 MHz. Eight-bit digital conversion is used to span the entire video amplitude. A 12.5% amplitude overrange is provided to allow for the capture of a video signal with a line tilt of + or - 6.25% without clipping.

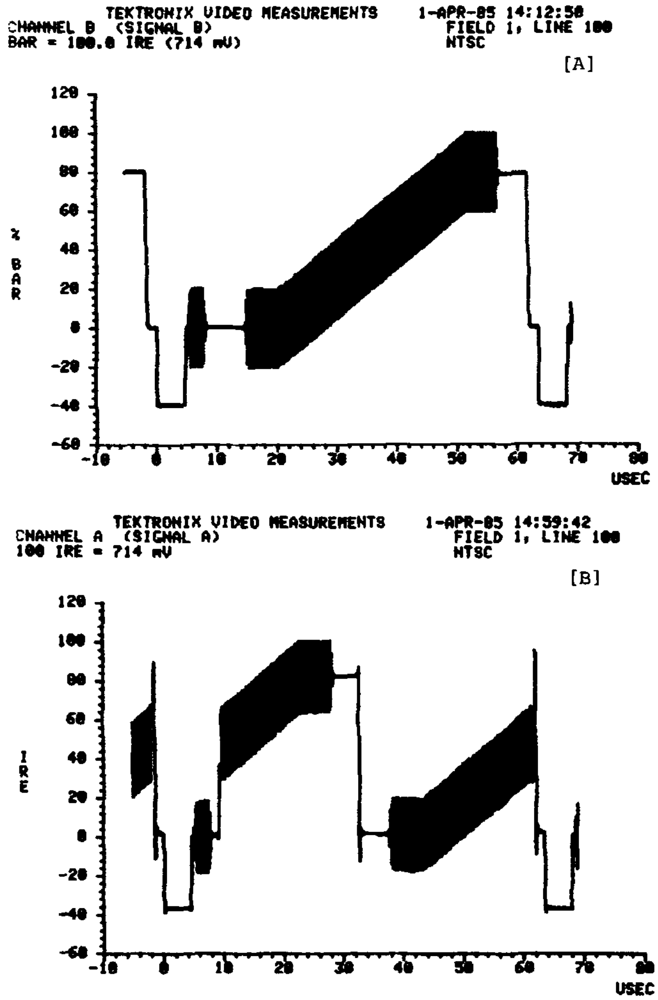
The digital range of the video spans 256 levels. 32 levels (12.5%) are given to overrange leaving 224 levels for the video. This means that the video amplitude has a digital resolution of 1/224, or 0.45% of full-scale resolution.

Correction of Frequency Limiting

With frequency limiting causing the video signal to roll off or ring at its sharp transitions, it is necessary to ensure that the start and end of the visual line be at the same amplitude level when patched together in the reconstruction process. This may be handled through the addition of amplitude hold levels applied to the beginning and ending of the visual line in the scrambling process (see Figure 1).

The hold levels serve to allow roll off and ringing to dampen out to their correct video levels prior to the sample points where the two segments must be patched.

Hold level durations of 500 nS are used. The price paid for this compensation is that the active visual line is reduced by two times 500 nS, or 1 uS. This represents a loss of 1 uS/52.7 uS, or 2% of the visual line. Since television receivers have a line overscan of about 5%, the 2% loss is not visible to the viewer.



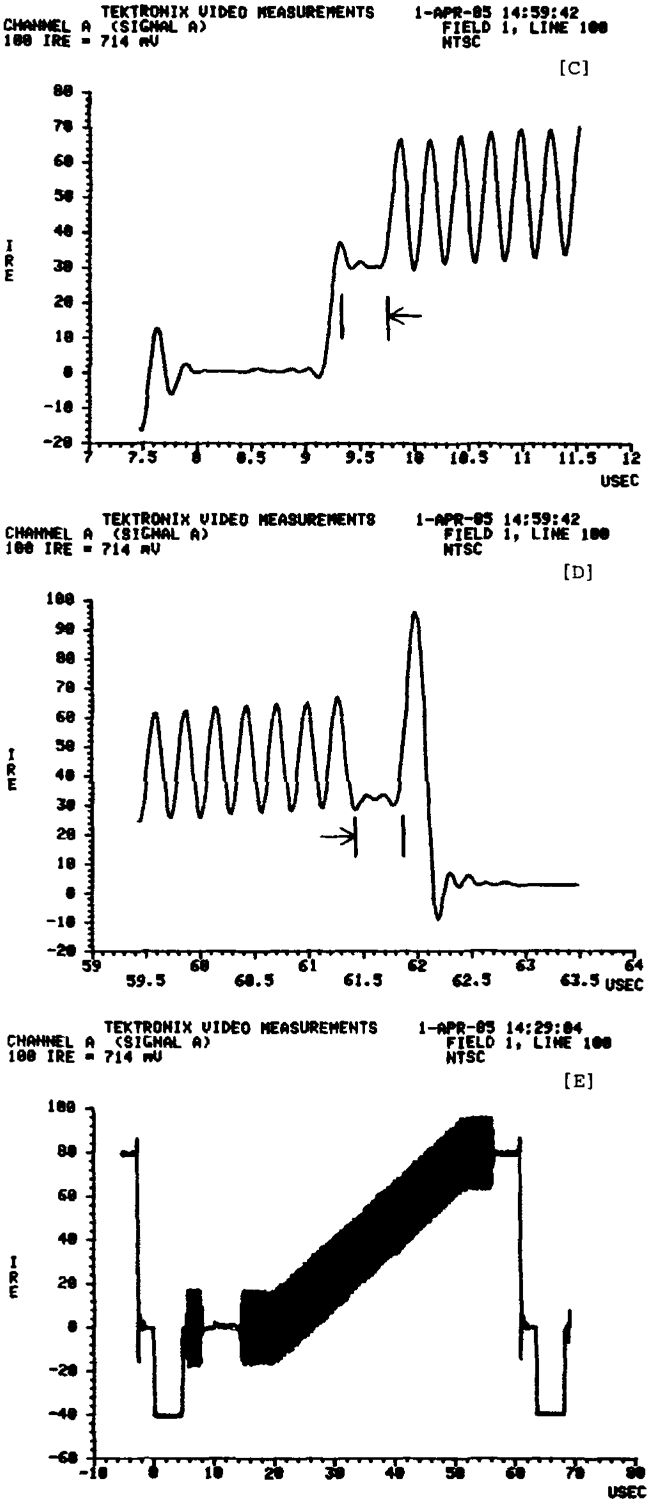


Figure 1- a) Original input video line waveform (80 IRE Modulated Ramp), b)signal following line segmentation (no line tilt), c) hold level applied at start of visual line, d) hold level applied at end of visual line, e) reconstructed video line.

Hold levels are added to the visual portion of the scrambled signal by modified addressing techniques. When the digitized video is read out of the RAM memory in the scrambler system, the address of the first and last samples are held for the 500 nS duration. The visual portion is truncated by 1 uS prior to this operation such that the final visual portion, with holds, is of the original duration as prescribed by the NTSC format.

Correction of Line Tilt

With the presence of line tilt in the scrambled video signal, it is necessary to correct for its disastrous effects caused when descrambled.

In dealing with line tilt distortion, two distinct operations must take place. First, the amount of line tilt incurred by the signal during the transmission process must be measured, and second, the line tilt must either be removed prior to descrambling or its reconstruction sawtooth error must be corrected following descrambling. The method to be discussed in this paper treats the removal of the line tilt prior to the descrambling process.

In order to measure the amount of line tilt in the video signal during its transmission and processing, it is necessary to add some measurable information to the signal. This is accomplished by adding reference levels to each line. A known amplitude is added at the start and end of the visual portion of each line. Both levels are equal. In fact, these levels are one in the same with the baseband frequency limiting hold levels described above.

When the signal is received, these levels are read following the digitizing process. Their difference represents the amount of line tilt imposed upon the signal over the visual portion of the line. By employing averaging techniques across time to the measured amplitude difference, the amount of line tilt may be accurately measured in noisy environments.

Knowing the amount of line tilt in the signal, it is then removed prior to the line segmentation reconstruction process. A temporal look-up table is used to digitally sum in an inverse line tilt component to the incoming video signal. This look-up table has a data value associated with each sample in the line. When loaded with a ramp waveform, inverse to the amount of line tilt in the signal, each sample is compensated in its amplitude to remove the line tilt component (see Figure 2). The same look-up table ramp function is applied to all lines.

As mentioned before, 224 digital amplitude levels are used to represent the digital video signal. Therefore, summation of the inverse ramp to the incoming video may be made with an accuracy of one part in 224, or 0.45%. Also, it was stated that an input signal with + or - 6.25% line tilt could be digitized without clipping. These two digitizing parameters indicate that an input signal with a line tilt of up to + or - 6.25% may be corrected to within 0.45% of the peak-to-peak video amplitude.

A microprocessor is used to measure the amount of line tilt in the signal, calculate the inverse ramp waveform and load the data into the look-up table. In a typical subscriber terminal, the system microprocessor could be used for this function.

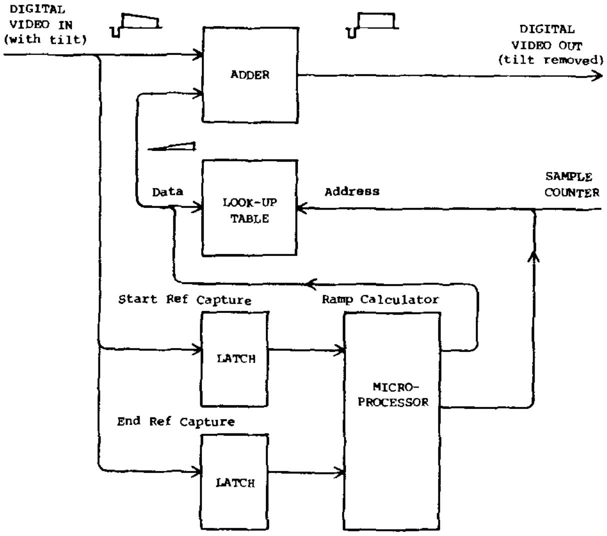


Figure 2- Block diagram of line tilt corrector.

RESULTS OF THE CORRECTION PROCESSES

Baseband frequency limiting corrections through the use of added amplitude hold levels of 500 nS to the visual portion of the signal have proved to mask the effects of simple bandlimiting. Visual patching of line segments where roll off and ringing do not exceed 500 nS is perturbation free.

Although 500 nS hold levels durations are currently used, this could be increased based on further studies of the requirements of typical transmission environments.

The correction of line tilt is being carried out by an 8748 single-chip microprocessor in the laboratory prototype descrambler. The measurement of line tilt, calculation of the inverse ramp data and loading of the look-up table require a fraction of a second to execute. The look-up table loading process is done during the vertical interval providing hidden operation to the viewer. Long-term correction tracking of the video signal over time and through subscriber channel selection has indicated no disturbance to the displayed video signal.

Correction of line tilt to within 0.45% has shown to be satisfactory in subjective tests. All line tilt induced hashing is removed from the displayed video (see Figure 3). Although the need is not clear, it would be possible to tighten the correction tolerance by restricting digitization of the signal to just the visual range. In this case, the sync intervals would have to be re-created in the subscriber terminal.

Figure 4 shows displayed video with both corrections implemented.

CONCLUSIONS

Line segmentation video scrambling offers an excellent compromise between digital encryption techniques and classical sync-suppression scramblers. High security is maintained through the use of DES encrypted descrambling codes while authorized reconstruction of the video signal is left relatively simple.

With the application of digital techniques such as those described in this paper, line segmentation video scrambling systems may overcome the persistent problems of baseband frequency limiting and line tilt induced reconstruction distortions.

Although still somewhat costly to the high-volume user, Analog-to-Digital and Digital-to-Analog converter technologies are advancing to the point where their entrance to the high-volume marketplace is expected within the next few years. At this point, implementation of line segmentation video scrambling schemes will present viable high-security alternatives to the video distribution industries.

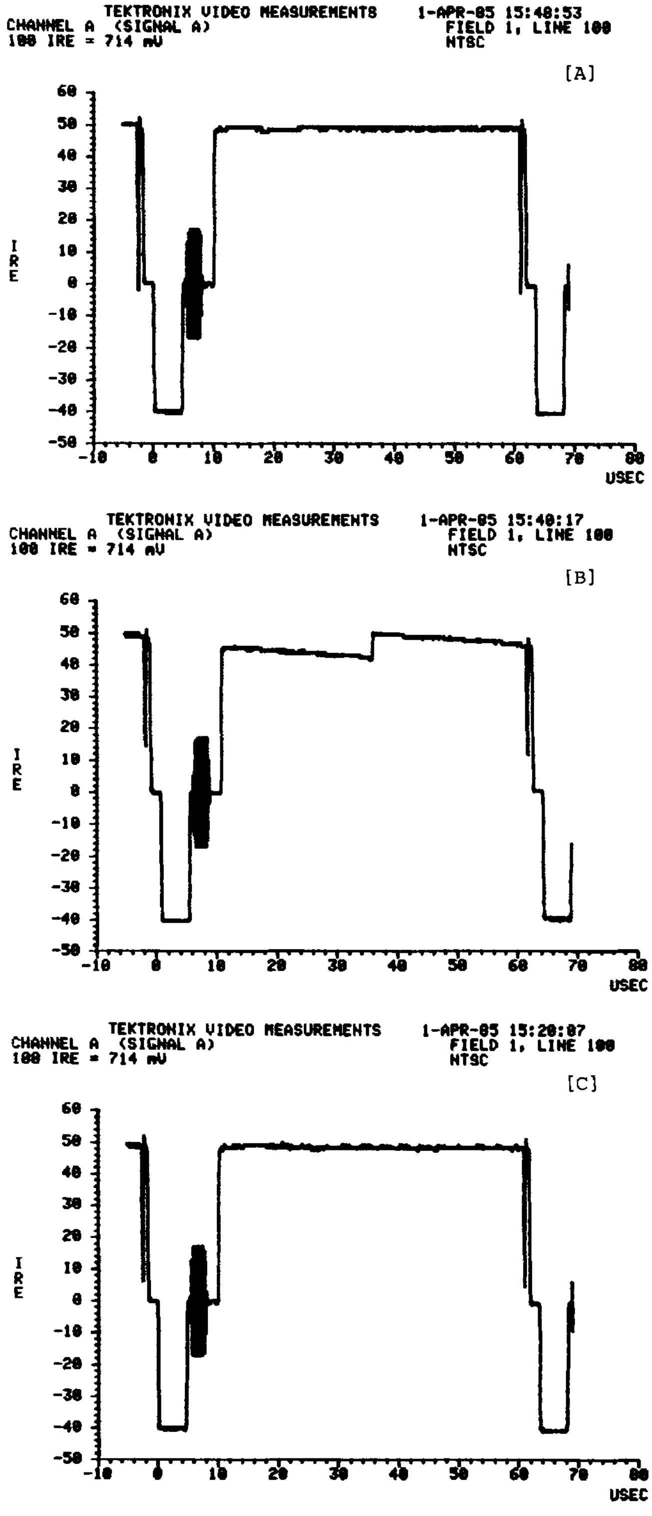


Figure 3- a) Original input video line waveform (50 IRE Pedestal), b) signal following line segmentation with 6% line tilt, c) reconstructed video line with line tilt correction.

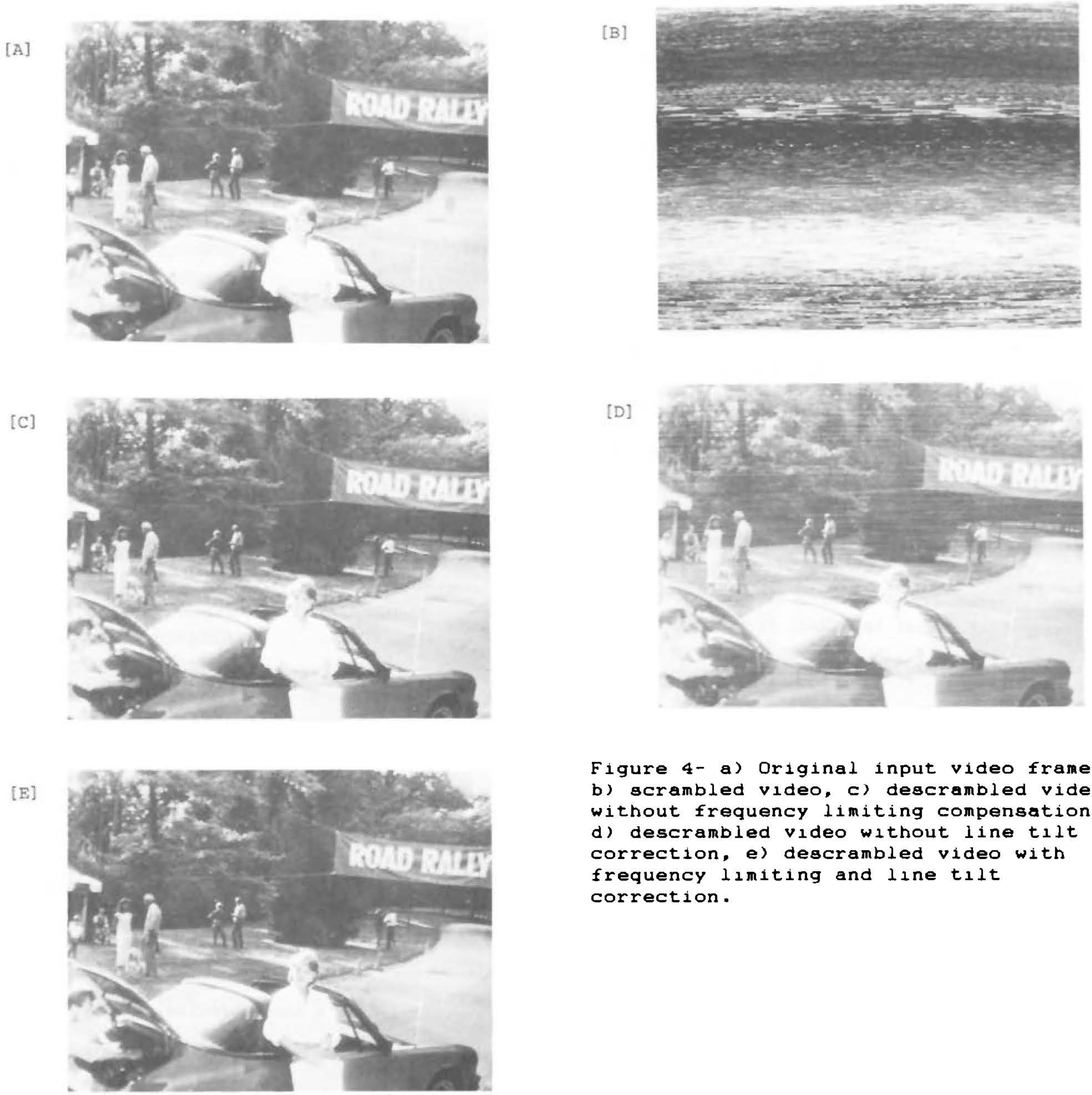


Figure 4- a) Original input video frame, b) scrambled video, c) descrambled video without frequency limiting compensation, d) descrambled video without line tilt correction, e) descrambled video with frequency limiting and line tilt correction.

REFERENCES

[1] V. Bhaskaran, M. Davidov, "Video Scrambling - An Overview," NCTA 1984 Conference Proceedings, pp. 240-246, June 1984.

[2] J. D. Lowry, "B-MAC: An Optimum Format for Satellite Television Transmission," SMPTE Journal, pp. 1034-1043, November 1984.