

Technical Choices for a Video Recorder

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Introduction

Since the introduction of Video Tape Recorders there has been a steady improvement in technology which first went into improving picture quality as black and white gave way to color and low band to high band. When the 2" transverse recorder gave way to the 1" helical recorder the advance was not so much in picture quality, except for the elimination of segmented fields, but in economy and operational features. Variable speed reproduction and picture in shuttle are now so well established that users wonder how they ever managed without these features. The advent of affordable digital processing has added a bewildering array of capabilities to the producer's bag of tricks. It is also contributing to an awareness that the number of tape generations, which present VTR technology allows without significant degradation in picture quality, is not adequate for the effects being sought. In addition there is an awareness that a degradation in picture quality does not necessarily accompany storage and retrieval. The time is ripe for the definition of a new generation of Video Tape Recorders which offer more than just a marginal improvement in picture quality.

Digital technology promises a quality which is limited only by the data rate one is prepared to pay for, and computer systems have given digital recording a reputation of being free from errors and free from maintenance. It is natural, therefore, to look to digital recording for the new generation of video tape recorders. Digital recording has, however, had to wait for improvements in recording technology before it was able to offer a sufficiently high data rate at an economical cost. These improvements in technology have on the whole not been incorporated into analog VTR's. It is natural, then, to ask whether an analog VTR format could not be designed today which would offer the desired improvement in picture quality without incurring the cost and complexity commonly associated with an equivalent digital VTR. This paper will compare Composite and Component digital recording with a conceptual specification for improved analog recording. Comparisons will be based on picture quality, cost and utility.

The Digital Video Tape Recorder

Given appropriate error protection the picture quality in a digital system is fully determined by the initial digitization of the original analog signal. For a component system the standard has been set at 8 bit samples taken at a rate of 13.5 M samples per second for the luminance channel and 6.75 M samples per second for each of two chrominance channels. This standard allows virtually transparent coding and decoding except for the most critical picture material. DVTR standardization efforts on both sides of the Atlantic are converging on a strawman format, the essential details of which are compared with corresponding parameters from the "C" format in Table I. The product of head/tape speed and number of channels is 100m/sec. While not required by the format, practical considerations require 4 head channels. Both systems use 1" tape.

	DVTR STRAWMAN	"C" FORMAT
Track pitch (μm)	40	182
Shortest wavelength (μm)	0.9	2.5*
Number head channels	4	1
Head/tape speed (m/sec.)	25	25.4
Long. tape speed (m/sec.)	0.2	0.24

* WHITE LEVEL

Table 1. Comparison Between DVTR Strawman and C Format.

While no standard has been set for digitizing a composite video signal, it is generally recognized that 8 bit samples should be taken at either 3 or 4 times the color subcarrier frequency. As 3 times is marginally adequate for the video bandwidth requiring sharp cut off filters, and a sampling rate of $4 f_c$ is more convenient for processing, the rate chosen will be a compromise between tape cost and performance. If four f_c is chosen then the resultant sampling rate of 14.3 MHz for NTSC is only a little more than half the gross sampling rate for the component system. If the recorded wavelength is reduced to $0.85\mu\text{m}$, the same basic recorder, but with half the number of heads, may be used for composite recording.

The Analog Video Tape Recorder

To be competitive with a DVTR the AVTR would have to be able to dub to 10 generations and maintain a quality at least as good as a first generation "C" format recording. This would require an improvement of at least 10dB in signal to noise ratio and a reduction by 20dB of any spurious components which add linearly. For the composite AVTR an improvement of greater than 10dB would be required of the chrominance signal.

In order to compare the advantages and disadvantages of analog recorders with the new standards being defined for digital recorders, we will first examine a format for component and composite analog recorders which attempts to significantly improve quality by making use of advances in recording technology which are implicit in the digital standards. These include the recording of shorter wavelengths on better tapes, better tracking which allows the use of narrower tracks, and processing which allows time expansion and contraction.

For the composite AVTR the signal to be recorded will be divided into two channels, one containing the odd TV lines and the other the even lines. Each line will be stretched by a factor of two to make a continuous signal of half the original bandwidth. An additional 7% of the bandwidth is saved by stretching the active part of each line into part of horizontal blanking. Using a grey level frequency of 16MHz and a deviation of $\pm 3\text{MHz}$, each channel is recorded into a separate $32\mu\text{m}$ track on the tape recorder. With a head to tape speed of 25 meters per second the tape consumption will be half that of a 'C' format recorder.

The component AVTR will record on four tracks in parallel. The luminance channel will be divided between two tracks as described above for the composite recorder and each chrominance channel will be recorded on its own track. The tape consumption will be approximately the same as that of a 'C' format recorder.

Table II list the factors which govern the signal to noise ratio of a tape recorder and compares the AVTR format as described above with the 'C' format and the format of the Ampex XVR-80, a special VTR, which is used for recording x-ray images. Each of the factors and its influence on signal to noise ratio is discussed briefly in what follows. The table assumes a $2\frac{1}{2}$ MHz bandwidth for each channel. In order to achieve a $5\frac{1}{2}$ MHz luminance bandwidth and $2\frac{3}{4}$ MHz chrominance bandwidths the tape speeds and FM frequencies for the component AVTR could all be scaled up by 10%.

	Reference Type 'C' System	XVR-80 Recorder	AVTR
Tape Channel Bandwidth (MHz)	15½	18 (-.6db)	29 (-2.7db)
Grey level carrier (MHz)	9	16	16
Grey level wavelength (µm)	2.8	1.6	1.6
Grey level spacing loss (db)	7.8	13.8 (-6db)	9.3 (-1.5db)
FM deviation (MHz)	±1	±2 (+6db)	±3 (+9.5db)
Base Bandwidth (MHz)	5.0	10 (-9db)	2.5 (+9db)
Line expand into blanking			7% (+0.9db)
Track width (µm)	128	128 (0db)	32 (-7db)
Improved tape			(+2db)
Total Relative Signal/Noise		(-9.6db)	(+10.2db)

Note: Number in parentheses are estimated S/N relative to 'C' format

Table 2. Factors in Signal-to-Noise Ratio.

Due to spacing and other losses the signal to noise ratio of a tape channel deteriorates rapidly as the recorded wavelength decreases. In a 'C' format recorder the optimum playback equalization results in a straight line response which goes through zero at between 16 and 17MHz. The resulting channel noise, before demodulation, has a nearly white spectrum. The integrated noise power is thus proportional to the channel bandwidth, which in this case is approximately $15\frac{1}{2}$ MHz, extending from 1 MHz to $16\frac{1}{2}$ MHz. It will be assumed that this proportionality holds true for the bandwidths chosen for the AVTR considered in this paper. The channel bandwidth required extends to include pre-emphasis overshoots for full black to white or white to black transients on the carrier plus sidebands for the base band frequencies. The amount of pre-emphasis used involves a trade off between several practical and theoretical considerations which will not be considered here. It will be assumed that the AVTR will use the same pre-emphasis of 8dB ($2\frac{1}{2}$ x) as is specified for the 'C' format recorder and that the break point will be appropriately scaled. The component version could possibly benefit from a nonlinear pre-emphasis similar to that used on $\frac{1}{2}$ " component ENG recorders, but that will not be considered either. For a low frequency deviation from 13MHz to 19MHz, a pre-emphasis of 8dB and an allowance of $2\frac{1}{2}$ MHz for baseband sidebands the AVTR will require a tape channel which extends from $1\frac{1}{2}$ Mhz to $30\frac{1}{2}$ MHz.

Within the 'C' format equalized bandwidth the carrier amplitude decreases linearly with frequency, but as the bandwidth is extended for the AVTR it will be assumed that the carrier amplitude falls off exponentially with the ratio of equivalent spacing loss to wavelength, in accordance with the Wallace model.

$$\text{Spacing loss} \sim \frac{\text{spacing}}{\text{Wavelength}} \times 55 \text{ dB}$$

For a 'C' format recorder the equivalent spacing is about $0.4\mu\text{m}$. For the AVTR we will assume a tape, with the surface finish and high frequency response of that required for the digital recorders, which has an equivalent spacing loss of about $0.27\mu\text{m}$. Another assumption implicit in the above is that the relative contribution of electronics and tape noise to the total noise remains the same as in present 'C' format recorders. This will require more careful design, the choice of devices with improved noise performance, and shorter gap lengths in reproduce heads, all of which are part of contemplated designs for digital recorders.

Other things being equal, the signal to noise ratio of an FM system is proportional to the deviation. Due to noise triangulation the noise power is proportional to the cube of the base bandwidth. Pre-emphasis can modify this to some extent, but as the pre-emphasis is appropriately scaled Table II assumes the cubic relationship. This relationship applies to the bandwidth reduction of 2x derived from multiplexing the signal between two tracks as well as the 7% reduction derived from expanding the active part of the line into part of the horizontal blanking.

The dependency of signal-to-noise ratio on track width is a function of the relative contribution of tape noise power, which is proportional to track width, and electronics noise power, which is independent of track width. With the improvements in electronics noise assumed earlier it will be assumed that tape noise is still the major contributor in a system with $\frac{1}{4}$ the track width of the 'C' format. Table II provides for a 7dB degradation in signal to noise ratio which allows 1dB for a greater contribution from electronics.

Not only do the tapes envisioned for the new generation of digital recorders have a better high frequency response, but they also have a higher absolute output due to a higher coercivity, and less modulation noise. An improvement of 2dB in signal to noise ratio has been assumed.

In Table II the column for the XVR-80 predicts loss of 9.6dB in signal-to-noise ratio, relative to a 'C' format recorder, which agrees reasonably well with the specifications for this recorder. Although it does not make use of narrower tracks or improved tape, this result does lend some credence to the prediction of approximately 10dB improvement for the AVTR. In addition to the simple improvement in signal-to-noise ratio the increase in modulation index by a factor of 3 is expected to reduce the chroma noise dependence on modulation noise by making the system less sensitive to dynamic equalization changes. The folded sideband corresponding to the significant 12th harmonic of the color sub-carrier is 55dB down in this AVTR format, so that moire' will not be a problem. Combining the above factors is expected to allow the 10th generation composite AVTR quality to be equivalent to the first generation 'C' format quality. As the chroma signal-to-noise ratio is still expected to be a limiting factor, the component version of this recorder might be expected to provide better quality over more generations, as well as providing all the processing advantages associated with a component signal.

A limiting factor for all analog recorders which does not exist for digital recorders is the requirement for the signal to pass through several low pass filters with each tape generation. The high carrier frequency and narrow base bandwidth relax the requirements for a very sharp cut off on the demod filter, and the sampling rate for the digital processing can be raised sufficiently to ease the design of anti aliasing filters. The cumulative effects of many filters in tandem is not expected to be a limiting factor.

Alternate Composite AVTR

For the composite AVTR an alternate, pseudo component multiplexing scheme can be considered which has the promise of offering better chroma quality at the expense of a higher tape consumption, better control of the base band transient response, and an additional tape channel. In this system the composite signal to be recorded is sampled at 3 times the color sub-carrier frequency and then distributed amongst 3 analog FM tape channels with each channel always receiving the same phase of samples. This has the advantage of converting the color sub-carrier into 3 DC components, the relative magnitudes of which define its phase and amplitude.

This removes problems associated with noise at the high end of the band, sensitivity to phase distortion, etc. In some sense this is equivalent to decoding the composite signal into chrominance components, but each component will contain many aliases, due to under sampling, which are only resolved (cancelled) when the components are resampled and recombined with the appropriate phase relationships after play back. In principle, each of the 3 components require a bandwidth of $\frac{1}{2}$ of the color sub-carrier frequency resulting in a gross bandwidth requirement of 5.4MHz. In practice real filters will require a greater bandwidth to avoid intersymbol interference between samples on each of the playback channels. Such interference will be inconsequential in picture areas with little detail, but will generate beat components and color shifts in areas with either luminance or chrominance detail. The same will hold true for time base errors but the absence of a color sub-carrier would make it feasible to use a pilot tone for time-base correction. The amplitude responses of the channels will have to be matched as in a component system. If an excess band width of 20% is allowed, for a gross bandwidth of 6.5MHz, and the three channel FM standards are appropriately scaled with a corresponding speed change, then the tape consumption for this pseudo component recorder will be 30% greater than for the composite recorder. The final recombined and bandlimited output signal will have a better signal-to-noise ratio.

Comparison between the DVTR and the AVTR

Table III compares estimates of the manufacturing cost of the AVTR and DVTR, both composite and component, with those for a current 'C' format recorder. It may be seen that approximately 50% of the cost of a studio VTR is independent of whether it is digital or analog, and also of the number of channels. The main reason for the rapid rise in cost of the analog recorders in the progression from one channel ('C' format) through two channels (composite AVTR) to four channels (component AVTR) is that each channel requires a digital time base corrector with codecs and velocity compensation. It should be noted that the composite DVTR does not include codecs which would be required if it were to be used in an analog environment. It is estimated that this would add approximately 4% to the cost.

ITEM	CURRENT 'C' FORMAT	AVTR		DVTR	
		COMPOSITE	COMPONENT	COMPOSITE	COMPONENT
(1) SCANNER	10	13	16	13	16
(2) TRANSPORT MECHANICS	9	9	9	7	7
(3) VIDEO ELECTRONICS	22	38	71	29	52
AUDIO ELECTRONICS	7	7	7	9	9
SERVO AND CONTROL	9	9	9	9	9
(4) FST	11	13	15	8	10
(5) PACKAGE, MDA, PWR SUPPLIES	29	24	24	24	24
CONTROL PANEL	3	3	3	3	3
TOTAL	100	116	154	109	130

Table 3. Percent of Costs Relative to Current C Format Total.

Notes:

- (1) Scanner includes AST and heads.
- (2) Digital transports have no longitudinal audio.
- (3) Analog video electronics include TBC with A/D and D/A.
- (4) FST of digital electronics, particularly audio, less than analog.
- (5) VPR-2B higher because of separate TBC packaging.

A factor not taken into account in Table II is the effect of new manufacturing technology such as the use of VLSI. If the expected sales volume warrants the additional investment, then significant savings in production costs can be achieved, chiefly in digital electronics. It is estimated, for example, that the cost of the composite DVTR could be reduced by 23%, and the composite AVTR by 15%.

It may be seen that, contrary to a common misconception, the cost of a DVTR is not expected to be significantly different from that of present analog recorders. If a new format, higher quality analog recorder were to be designed along the lines presented in this paper, it would probably cost more to produce than the equivalent digital recorder.

The advantages that are associated with digital recorders are well known, so they will be only briefly mentioned here. Although the quality of the first few generations of analog pictures may be just perceptibly higher on critical material than that of a digital system, the AVTR could in no way claim to be transparent over many generations to the extent of a DVTR. Even in the first generation a DVTR will handle, virtually transparently, tape defects which would be noticeable on the AVTR. In addition, the proliferation of digital processing in other television equipment would benefit from the absence of codecs in an all-digital system. Within the recorder itself digital recording allows greater use of self diagnostics on the signal path. Monitoring of raw error rates can give warning of impending problems before they are serious enough to defeat error protection and become evident to the user.

There would seem to be very little to recommend a new generation of analog recorders. Even if all the interfaces, whether component or composite, were analog, the recorders themselves should still be digital.

Comparison between Component and Composite

The choice between component and composite recording is not nearly as simple. There is probably no single correct solution as a composite recorder would be correct in a composite environment and a component recorder would be correct in a component environment. Until fairly recently it was held by many that because final transmission to the user would remain composite for the foreseeable future, and because of the substantial investment in composite production equipment, that the market for component recorders would never be significant. It was held that their use would be restricted to a very few specialist, top-of-the-line applications. The advent of component ENG recorders has however, seen growth at the opposite end of the picture quality spectrum with component switchers and other equipment being produced as the need arises. The same will no doubt occur at the top end as well, justifying the position of the SMPTE and the EBU. In large installations the change over to digital components will take place in one studio or in one editing suite at a time.

The facts of composite broadcasting and of investment in composite equipment in small installations will however not go away. The incentive to upgrade to the advantages of digital recording while maintaining compatibility with existing equipment will result in much pressure for a composite digital recorder. Compatibility is not the only issue. Composite recorders offer positive advantages to the broadcaster. Firstly, the cost of ownership is less in terms of purchase price, maintenance (head replacement) and tape cost. Secondly, a given size of cassette will run for twice as long on a composite recorder as it will on a component recorder. The longest cassette being considered, 7-1/2" X 13", will play for 3 hours using 1" tape or 2 hours using 3/4" tape on a composite DVTR. Many observers feel that the market for composite DVTR's will be larger, at least initially, than for component DVTR's.

The present trend in the DVTR standardization process will ensure the emergence of a component standard, but the interest in a mechanically compatible composite standard is not very strong. There are many, particularly in Europe, who feel that if there is to be a 1/2 rate subset of the standard it should be for a 2.1.1 component recorder, not a composite recorder. If the conclusions of the previous paragraph are correct, then those who would like to see a composite DVTR should make themselves heard.



John P. Watney was born in South Africa and received degrees in engineering and in physics from the University of Cape Town and an engineering degree from Stanford University. He worked at Marconi's Wireless Telegraph Co. in England and for the C.S.I.R. in South Africa before joining Ampex Corp., California, in 1964.