How VCRs Work

Courtesy JVC Canada

Follow along on a trip through the inner workings of one of the most popular home entertainment devices.

By Timothy B. Palmer-Benson

Despite their flimsy plastic facias and fluorescent flashing displays, VCRs are little miracles of electronic and mechanical engineering. It is true they are known for producing waxy faces, color shifts, poor resolution and picture noise but on the other hand as one broadcasting engineer told me; "they are still not that bad and they are getting better." The latest VCRs introduced by Sony and JVC prove that an already sophisticated and complicated recording process can be improved to yield results that match or exceed the performance of the laser disc. In order to appreciate how these new machines work, it is necessary to first understand some of the basics of video tape recording. You'll also be able to appreciate what is hype and what is a real improvement.

A video cassette machine is basically an audio tape recorder with helical scanning video heads. (A helix resembles a coil or spring.) Instead of the tape passing at right angles in front of a head as in audio cassettes and open reels, a minimum of two heads are used (except for Sony's Beta movie camcorder) and the tape is looped in something akin to an omega shape around a drum or cylinder that rotates at high speed.

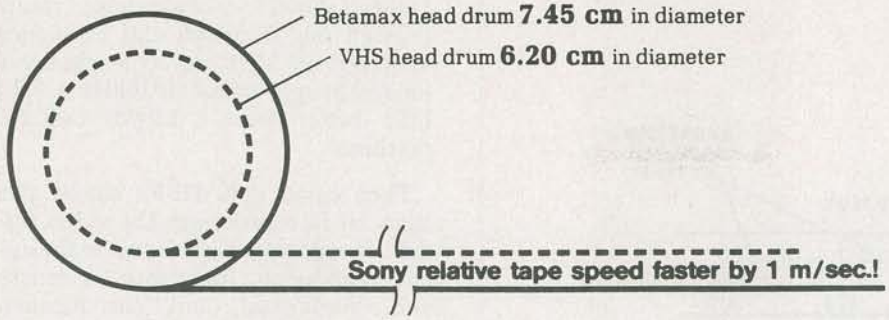
The drum is mounted at an angle (approximately 6°) so that a pair of video heads, mounted on its surface 180° apart, move in a helical fashion as the drum rotates. The angle of the drum, as well as some tape guides, force the tape to touch the bottom part of the drum when it first makes contact and to leave the drum at its top. This results in the two heads either recording or picking up a continuous series of slanted or diagonal signal tracks. In VHS and Beta machines, a track is scanned or recorded at the rate of one every 1/60th of a second by two heads. As the one head completes a track, a second is beginning a second track and so on. Two tracks or fields make up a single frame of a television picture.

Although VCRs are precision pieces of equipment and tolerances are measured in microns, the laying down of tracks next to each other still poses some problems especially since the width of the tracks is so small. Each track on a Beta Two tape, for example, is only 0.03 mm wide! How is it possible that the heads are able to scan the same tracks exactly on playback or to pick up the tracks made by another machine? This has been made especially tricky in consumer VCRs since the so called "guard bands", used in professional machines to separating each track, have been eliminated to make more efficient use of tape. And, how are slight speed differences between machines resolved? The answer to these problems are taken care of with servo systems, control heads, phase inversion and azimuth recording.

Azimuth Recording

In azimuth recording, the angle of the gap in each pair of video heads is mismatched slightly so that each head can only record and pick up high frequencies from the track made by that particular head. Thus in a sequence of tracks, head A will pick up information from track one and three, while head B, on the other side of the head drum will pick up tracks two and four. In 8mm camcorders the head gaps are angled away at +12° and -12°. On Beta machines, the head gaps are angled away from the perpendicular by +7° and -7° while VHS uses +6° and -6°. A strong signal is received from a particular track only when it is scan by a head having the same azimuth. It may scan a bit of an adjacent track but high frequencies won't be picked up because the azimuth in the adjacent track will always be different.

There is another means of ensuring that only the right track gets picked up at any given time and that is with phase- inversion recording. Again it is used by both VHS and Beta and is designed to take care of that portion of the video signal that is so low in frequency that azimuth recording won't



The relationship between Betamax and VHS head drum sizes

Courtesy Sony Canada Inc.

work so well. It achieves the same end - reducing crosstalk between adjacent tracks - by shifting the phase of the lower frequencies (in this case the chrominance signal) by 180° for each track in Beta, and by 90° for each track in VHS. Having adjacent tracks recorded with different phase relationships helps to prevent the video head from picking up information from an adjacent track.

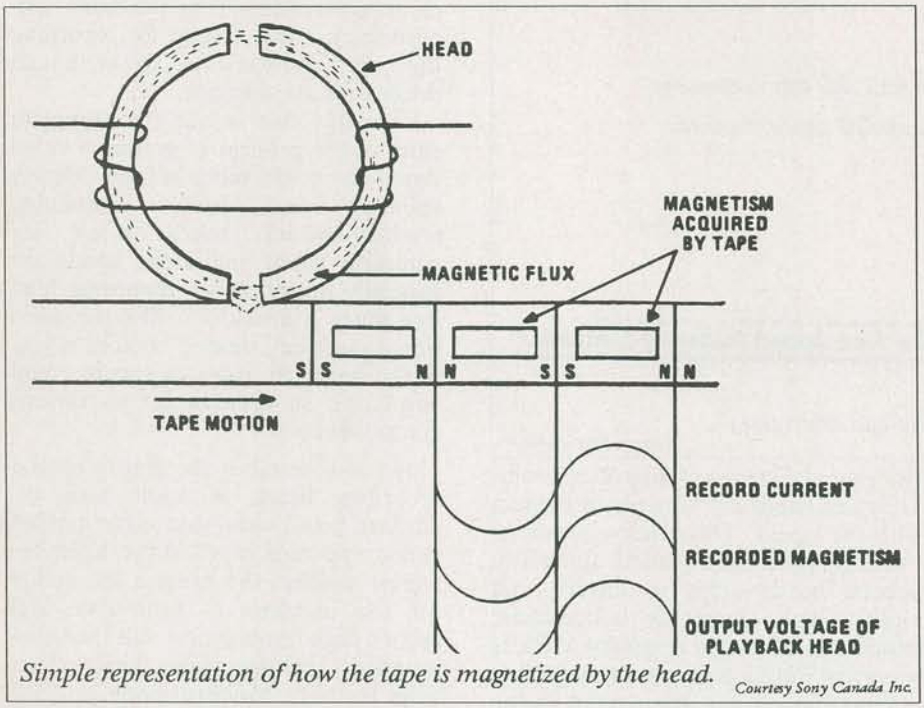
Speed and Heads

Speed accuracy is also very important in VCRs and it's taken care of with various servo systems. Sync pulses that are part of the video signal are used to synchronize the speed of the head drum with the movement of the tape. The pulses, (a 60Hz square wave), are recorded onto a stationary or longitudinal track along the edge of the tape by a control head. This occurs after the tape has left the head drum and is on its way to the take up reel. When a tape is played back, these control pulses (square waves) are detected at the control head. If the shape of the square wave is altered because the mechanism is running too fast or too slow, this distortion of the wave will cause a servo system to adjust the speed of the capstan motor. A tracking control is provided to compensate between slight distortions in square recorded by different machines.

VCRs depend very much on something called "relative speed" to achieve wideband frequency response. Because the heads on the drum are whizzing around at a tremendous rate (1,800 rpm) in a helical fashion, they are able to "simulate" a high recording speed. (The 1,800 rpm is enough to cause the tape to ride on a cushion of air as it travels around the head drum at the infinitesimal distance of only 35 microns. Only the heads are actually in contact with the tape.) This relative speed or "writing speed" as its called, along with special heads helps to ensure that video's high frequency information, which extends out to beyond 4 MHz, is recorded onto a tape even though it is moving passed any given point in the VCR at less than the speed of an audio cassette. (VHS SP or Standard Play speed is 1.31 ips, while Beta's popular Beta Two speed is 0.79 ips.) All video cassette recorders, even the 8mm camcorders, use this system for recording the video portion of a signal though drum sizes are different.

Naturally, this is not the complete story in the process of getting a video signal on or off a piece of tape. Merely spinning a drum containing record/playback heads won't accomplish much unless the heads are specially designed for recording high frequency information. Also the video signal must be "treated" before it gets to the heads in order to ensure equal amplitude or strength for its various components.

If you remember the theory behind recording heads in audio tape recorders, you'll know that as the gap between opposing poles in the head becomes smaller, the greater the ability for the machine to reproduce and record high frequencies. It's the same in video which has taken things somewhat further. Modern manufacturing has managed to produce a gap that is so small that it can be seen only with a powerful microscope. The gap is so small (typically .6 microns) that it ap-



Simple representation of how the tape is magnetized by the head. Courtesy Sony Canada Inc.

proaches the same gap contained in a 4 MHz sine wave displayed on an oscilloscope. If you've ever seen even a 1 MHz signal displayed on an oscilloscope, you'll really appreciate how small these gaps are! Another way of illustrating these head gaps is to compare them with the 100 micron diameter of a human hair. Small head gaps are laudable, but there comes a point in the existence of any head gap when it can no longer record a particular frequency unless tape speed is increased. This is the main reason why Beta One or VHS SP speeds in consumer VCRs produce recordings that have greater bandwidth. The other reason for increased bandwidth and general picture quality at the faster speeds is that more tape is being used (the actual size of the heads is larger) to record the information than at the slower speeds - the tracks of video information are actually wider apart.

Although super narrow head gaps, helical scanning and fast play/record writing speeds are of major importance in VCRs the system still wouldn't work properly without frequency modulation in the same way that an audio signal is transmitted over the broadcast FM band. One of the reasons frequency modulation must be used is because the output voltage from tape recorder heads varies with frequency and the frequencies involved here are particularly high. Another reason is that FM ignores random amplitude variations in playback signals. A tape can be driven into saturation during signal peaks and any amplitude distortion is simply ignored.

There are many similarities between the Beta and VHS systems but at the same time there are some major differences particularly in the way tape is handled. Until just recently for example, you couldn't fast cue in VHS the way you can in Beta. Beta machines use a head drum that's about 20% larger than a VHS one. If you go back to the discussion of "relative speed" you'll realize that a larger drum means a higher relative speed, or writing speed, and a higher writing speed means better high end frequency response for the video signal. Both formats use azimuth and phase inversion techniques and frequency modulate the video signal before it's put onto tape.

Audio Techniques

In audio, both formats began with so called "drag heads" or "longitudinal heads" mounted in part of the control head. But because the speed of the tape is so slow, frequency response was and still is limited despite equalization circuitry. Noise levels are high. VHS has followed with stereo longitudinal heads but with two tracks of hiss, the noise becomes intolerable, so in addition to equalizing the signal VHS has added Dolby noise reduction. The consumer was confused: "Stereo Dolby....Wow!" Salesman rarely pointed out that high end frequency response on VHS stereo machines is limited to approximately 10kHz +3db, little better than a Lloyds cassette machine!

Then came Beta Hi-Fi; simply put Beta Hi-Fi reprocesses the video signal. It separates video's two main signal components, luminance (crispness and brightness) and chrominance (color), to squeeze a frequency modulated stereo signal in between. Then everything gets recorded on the video heads just as before. This method results in a wide band audio response of 20Hz to 20kHz, a dynamic range of more than 80 dB and very low wow and flutter. While this is still not hi-fi in the true sense of the word Beta Hi-Fi is quite satisfactory for watching movies. JVC followed Sony's lead with VHS Hi-Fi and obtained similar specs. But, JVC was forced to use a more complex system because of the way the VHS video signal must be recorded onto tape. There isn't room in VHS signal to squeeze in an FM audio signal and so VHS uses "depth multiplex recording," In this system, the audio is frequency modulated and then sent to separate audio heads positioned 180° apart on the head drum. The process uses the entire tape width to lay down the information but because the azimuth of the head gaps is different (+30° and - 30°) the audio is not picked up by the video heads. The requirement for two additional heads naturally raises the cost of VHS Hi-Fi machines over their Beta counterparts. As you can imagine, the tolerances involved here have become much tighter. If you've ever wondered why some VHS Hi-Fi movies seem to be afflicted with unexplained sputtering on their hi-fi tracks these tolerances are the reason. It only take's a dubbing house to have machines that are slightly out of adjustment and the hi-fi track is ruined. When you're dealing in microns it can happen!

Higher Technology

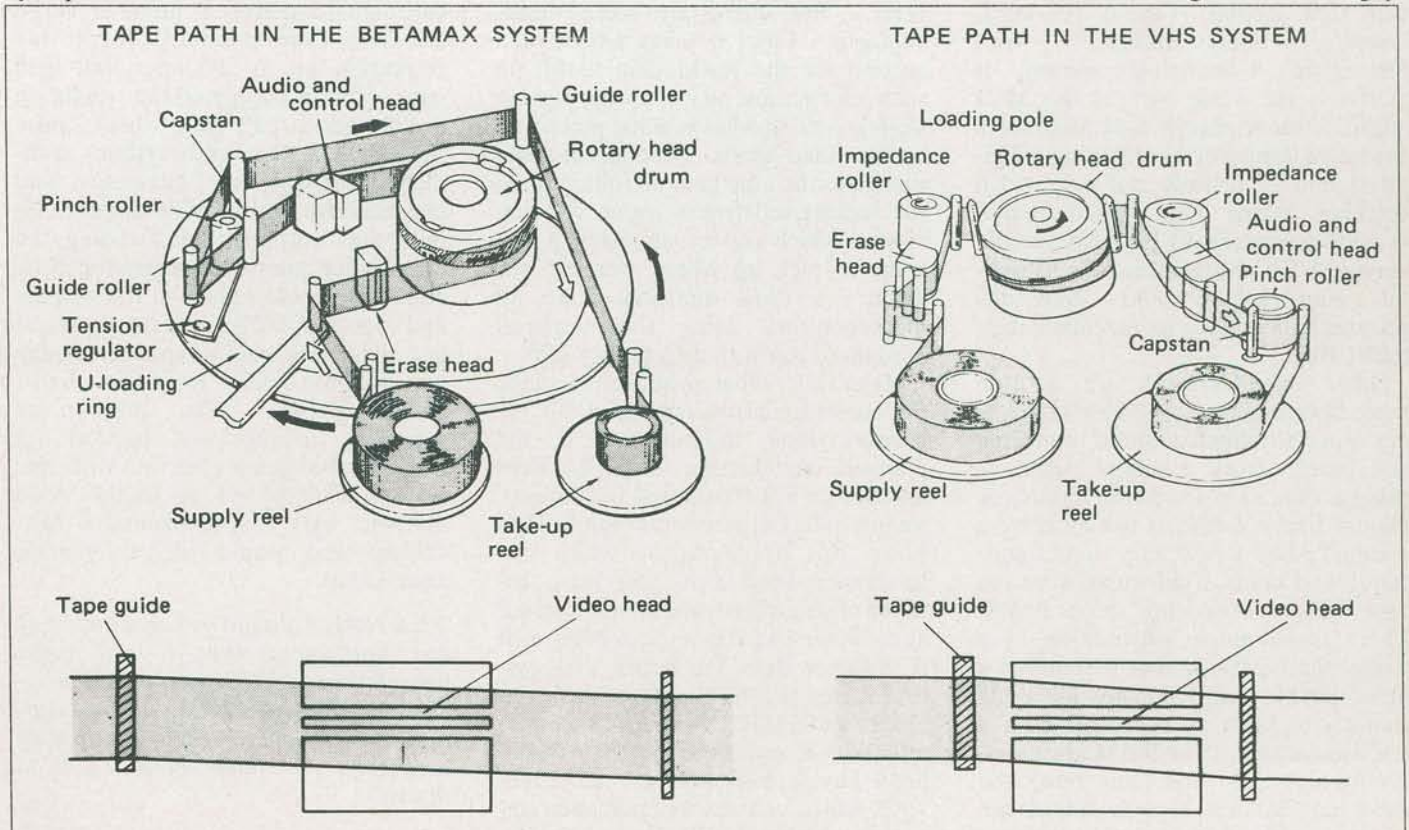
Back in video, Sony's Beta system continues to lead the way in pure technology even if Sony can't do so well in sales. Sony's first step was Super Beta. In this system the frequencies of the luminance signals are boosted by

800kHz resulting in a 20% increase in resolution. Only the luminance part of the signal, the part that gives you that crisper, clearer picture, gets boosted. You get 290 lines of resolution with a Super Beta VCR compared to 240 lines for regular Beta. JVC's reply was HQ (High Quality). This is a package of improvements that include a reduction in noise levels contained in the luminance and chrominance signals as well as an increase in the ceiling or what is termed "the white clip level" of the video. On VHS VCRs without HQ images that have bright edges against a dark background tend to smear because the full video wave form has been clipped in order to get it recorded onto tape. Raising the white clip level enhances the apparent contrast and detail in the picture. Despite these improvements, the horizontal resolution of HQ remains at 240 lines as opposed to Super Beta's 290. On the other hand, VHS HQ is completely compatible with regular VHS while Super Beta sometimes causes difficulty for standard Beta machines because they don't have video heads capable of picking up the higher frequencies used by Super Beta.

No look at how VCRs work would be complete without mentioning the battle for over the video heads themselves, freeze frames and slow motion. Thanks to manufacturing hype, the average VCR buyer has been left with the impression that the more heads a machine has the better its performance but if you've understood this article you'll know that you can only use two heads at a time and that extra heads (aside from the ones for VHS Hi-Fi) are for special effects only. A single pair of heads won't work because when the tape is stopped only one of the heads can scan a track accurately. The other head is unable to pick up the video information because its azimuth setting is wrong, but with one or more heads a second reading of a particular track becomes possible and thus a full frame for a tv is obtained since two fields, or track scans, make up a frame.

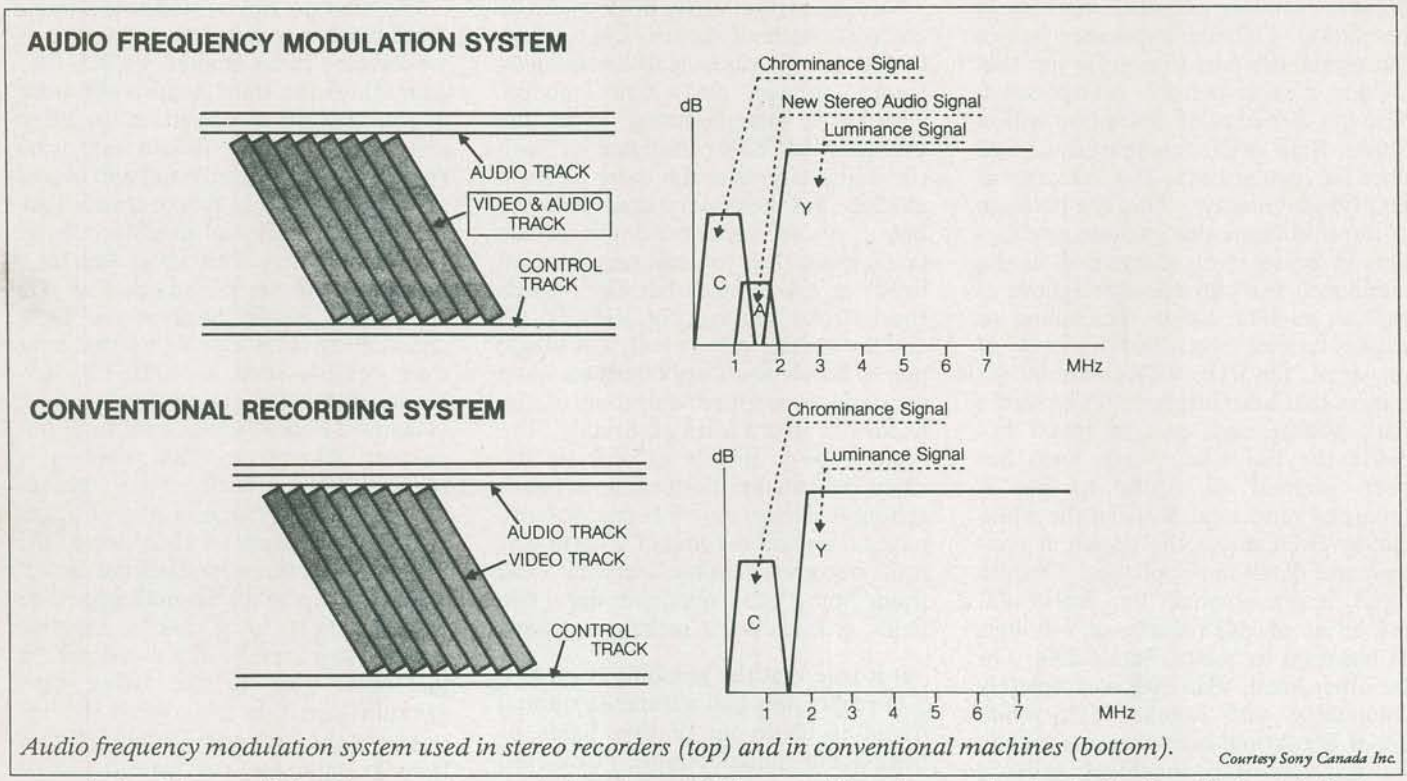
It is true that the resulting tv picture is in reality only half a frame (a normal frame is made up of two fields or tracks) but manufacturers discovered several years ago that a single field, scanned twice gives the best jitter free picture.

The simplest way of scanning a single track twice is to add a third head, thus we have a "three headed VCR." The azimuth of the third head is the same as the azimuth of a head on the other side of the drum. When the drum rotates both this third head and one of the regular heads is able to scan a track or field perfectly and produce a jitter free still picture. This works fine for a tape that has been recorded at one speed and played back at the same speed but what about VCRs that have three speeds such as VHS EP (Extended Play), LP (Long Play) and SP (Standard Play)? One of the most important answers to this problem is Matsushita's Tech 4 system (Panasonic). It places a pair of heads in a single housing on each side of the head drum. Each housing has an SP head with a positive azimuth gap while the one next to it has a negative azimuth gap for EP. The two heads on the other side of the drum have azimuth gaps that are exactly the opposite of the first pair. When a freeze frame is required either an extra EP or an extra SP head is switched in electronically to provide that second, crucial scan of a single track. The gap



Detail of tape path through the works of the Betamax system (left) and through the VHS system (right).

Courtesy Sony Canada Inc.



Audio frequency modulation system used in stereo recorders (top) and in conventional machines (bottom). Courtesy Sony Canada Inc.

on each head is carefully chosen so that good results are obtained not only with still frames on each speed but also with slow motion. One of the latest ways of doing things is with Mitsubishi's 4 head logic system. It works in the same way as the Matsushita system except that Mitsubishi has taken things further by using a digital system to provide not only video tracking during high speed search (similar to Betascan) but also audible cueing in EP. Mitsubishi calls its digital auto-tracking and mercifully refrains from calling its machines digital VCRs.

Other manufacturers are a little more brazen with their digital technology especially when it comes to making still frames from a digital signal or using a data chip for noise reduction. Digital freeze frame is achieved by a computer-like RAM chip that is constantly fed fields of information as the tape passes over the video heads. There is so much information in a single picture frame that it requires a lot of RAM - 550 Kilobytes for a full frame - to light up every pixel on a television screen. The RAM must constantly memorize and then dump the video information as new tracks are scanned by the video heads at the rate of 60 per second. The advantages of this system are that extra heads aren't needed and special features like picture-in-a-picture (PIP for short) come at very little extra cost to the manufacturer. But, there are some disadvantages. First, it takes 1/60th of a second for the RAM chip to fill up with information, so it is always lagging slightly behind what is being picked up by the video heads. Second, on some machines the tape goes on rolling while the memorized freeze frame is being viewed which can be annoying if you want to pick up where you left off. There's a third question; are all manufacturers using the required amount of RAM to do a proper job?

Meanwhile, what promises to make the current controversy over DAT recorders look insignificant, is the planned introduction of Super VHS and Sony's ED (Extended Definition). Simply put, both systems significantly boost the frequency at which the luminance signal is put onto tape. Instead of this information being carried at between 4.4 MHz and 5.6 MHz as it is in Super Beta, the Super VHS system raises the frequency to between 6MHz and 7MHz. A special tape formulation is required for the system. Sony has replied with the ED Beta VCR which carriers its luminance signal even higher at 6.8MHz to 8.6MHz. Both systems provide extremely good resolution - far better resolution than what is obtainable off air with the best possible broadcast signal. For example, typical resolution for a broadcast signal received at home is 330 to 350 lines. Conventional VCRs provide resolution up to 290 lines, but with super VHS it is claimed the resolution is 430 lines in EP! But, what is more significant is that both systems completely separate the luminance and chrominance and provide separate inputs and outputs thus avoiding the cross color interference produced by combining these signals at the outputs and inputs of VCRs and the inputs of tvs. This will enable anyone owning two of these VCRs to obtain almost perfect dubs. "The question of copyright infringement because of DAT is nothing compared to what this new technology will do to the video market," says a spokesman for Mitsubishi who would like to remain anonymous.

Ed. Note: It should be noted that Sony has announced that it will begin manufacturing VHS video cassette recorders. Although BETA units will continue to be produced, it certainly appears as though the future of BETA is in doubt.

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