LARRY ZIDE

The Making of the Ampex ATR-100

A visit to Ampex's Redwood City, California headquarters, and a talk with the development people, reveal the work that went into this state-of-the-art tape machine.

WE WERE SEATED in the office of Frank Santucci, the Ampex Audio Product Manager who, in many ways is the "godfather" of the ATR-100 project. Seated around the microphone of my cassette deck were Frank and the three engineers responsible for the development of this system: Robert P. Harshberger Jr., staff engineer who did the motors and control systems; Alastair M. Heaslett, senior staff engineer whose responsibility was the signal electronics; and Roger R. Sleger, senior engineer who created the mechanical system.

The resulting transcript of this talk took 31 typewritten double spaced pages but there was some doubling back and over-detailing that is not important. What follows will show the brain work that went into the ATR-100.

The first area of discussion centered on the use of ferrite tape heads on the machine. Ampex is not the first such user in pro audio, but ferrite has yet to be common as a replacement for classic metal laminated heads.

"The answer has to be multifold. The first reason is the very greatly improved longevity of the head. From a professional user's point of view, what this means is that adjustment of the machine to maintain a certain level of performance need not be made as frequently as with a metal head. It is no longer necessary to compensate for the fact that its performance as a transducer is changing during its life as the metal is worn away.

"The second reason is that it becomes possible to create a reproducer head where the noise and the high frequency region is not dominated by intrinsic noise generated by the head.

"The third reason is that because of this low loss, it becomes possible to use a biasing frequency which is sufficiently high, so that at the higher tape speeds (high in level or high in frequency), we can avoid or substantially reduce the effects of bias modulation noise at the higher tape speeds. Now, as tape's short wave length capability gets better, a greater and greater amount of bias signal is left recorded on the tape. In this respect, the bias is no different than any other type of signal that produces modulation noise.

"For example, at 30 inches per second, you can use a bias frequency of 150-250 kHz, which is common today (ATR-100 uses 432 kHz). When you take a tape you just recorded at 30 in./sec. with no signal going into it, rewind and then move it slowly past the head, you will actually hear a discrete signal coming back off the tape—recorded bias. True, when you play it at 30 in./sec. this frequency is 150-250 kHz, so one might say therefore that it doesn't matter. But the point is that the discrete signal having been recorded is saturating the tape. The effect on the over-all signal-to-noise ratio (the bias noise signal to noise ratio) at 30 in./sec. is really quite substantial.

If you attempt to produce a conventional laminated metal head with any kind of lifetime at all, that had to run with 400+ kHz bias frequency, you will find that you require an exceptionally large amount of bias power pumped into the head, most of which would be dissipated as heat losses in the head and very little of which would arrive at the gap as a useful plus. That's another reason why ferrite head technology was turned to. It permits us to realize significant performance improvements, particularly at the higher tape speeds."

TAPE AND MACHINE

One of the main points brought out in the discussion was the interrelationships that existed among divisions of the company. The development of the ATR-100 was interfaced with the construction and marketing of Ampex Grand Master tape—with the tape actually hitting the market place sooner.

Frank Santucci at his desk.

It came out that the tape division and this group worked closely over more than two years in which tape samples flowed in, were evaluated and changed, and a machine took shape as well.

It turns out that the machine did not really take final shape until the tape existed, then the final stages could be completed and an ATR-100 launched.

MECHANICAL CONSTRUCTION

The pinchroller-less design of this new machine is an obvious feature. It was revealed that this was a design feature that was sought right from the beginnings of design.

The ATR-100 is capable of handling 14 inch reels—though it is to be admitted that they are not yet readily available to studios. It is expected as more machines enter the field—as is now happening—these reels will come forth as well.

As for the mechanical construction, it was decided that a constant tension transport was needed, tension to be held constant regardless of reel size or position of tape on the reel.

"Once we made that decision, we looked at the tape transport and realized that the tension differential across the capstan is going to be constant since friction is relatively constant in tape. And once this is studied for a while, you become aware that a pinchroller isn't really needed because you can control that differential tension closely with pure electronics means by servo controls, so you can then do away with the pinchroller.

"Essentially this is what we did. We went a step further. Most machines would normally have a pinchroller covered with rubber, a high friction material. We don't do that, in fact, we use an anodized capstan which is relatively low friction. You can be running along in a play mode and grab the tape and the capstan will slip, even though the wrap is 135 degrees.

Alastair Heaslett, invariable cigarette in his hands, talks while Roger Slegel listens.

"This system, however, absolutely eliminates slip during normal motion. In fact, the grab from the capstan to the tape is so good that if you misadjust the tensions on the machine deliberately, you'll find that while the machine itself won't function suitably, it will still pull the tape. So there's a lot of margin."

FLUTTER

One of the demonstrations done at the recent AES show was to take the two reels and deliberately move them off center and run them, and still no wow or flutter was created.

"The servo is a lot more powerful than it need be for normal operations. The motors are a lot bigger than are really required to move that tape, they are rated at ¼ horsepower. It is a bi-direction servo in that you are never required to use the tape to pull the reels around. There is much less transient type of tension disturbance. The force that you're able to get with a reel servo is approximately 130 inch-ounces in either direction, which is twice as much as you can get on any other ½-inch mastering type of machine. Therefore, it can keep up with the offset reel.

"Another part of the servo is the way that the tension is sensed. The tension arms are actually driven magnetically, they are not spring-loaded. They are driven by a rotary solenoid and the force that they exert on the tape is controlled by the current throughout the solenoid. The force is also relatively independent of the position of the arm. So, while the position of the arm is used to sense the tension, it indirectly actually senses the actual position of the arm—which then controls the motor. The fact that the arm can move slightly does not affect the tension. It just controls the position of that arm and the reel will feed or take up in that position."

This time Heaslett, cigarette still there expounds while Bob Harshberger listens. But in spite of these appearances, both Harshberger and Slegel also contributed heavily to these discussions.

CAPSTAN SYSTEM

My next question had to do with whether the capstan itself enters into the servo operation.

"Yes. It is a phase lock capstan. The capstan moves—it is being directly driven—the reel servo control logic senses that the capstan is moving in a particular direction, programming these torques for the proper tensions. The tape will then follow by virtue of the errors created in the reel circle. It will just follow the capstan in either direction.

"On the fast modes (fast forward or rewind) the capstan functions as a velocity servo rather than a phase-lock servo. It goes to a certain velocity at a constant acceleration. When it reaches that velocity it stays at that velocity. The reel servos follow in the same way that they did in play modes. So that no matter which direction it is going, it creates the same error. In fast forward the tape simply accelerates to the maximum speed that the motor is capable of.

SERVO RELATIONSHIPS

"Now there is a control action as well. Under ordinary circumstancces (10 inch NAB reels), ¼ inch tape) it accelerates at a fixed acceleration to a top speed, stays there, decelerates if you press the stop button, at the deceleration that it accelerated at. However, there are conditions such as with a 14 inch reel with ½ inch tape, where it is not advisable to accelerate that big of a pack as fast as the capstan can accelerate. Remember that there is no control given to the reel servos, it's only applied to the capstan.

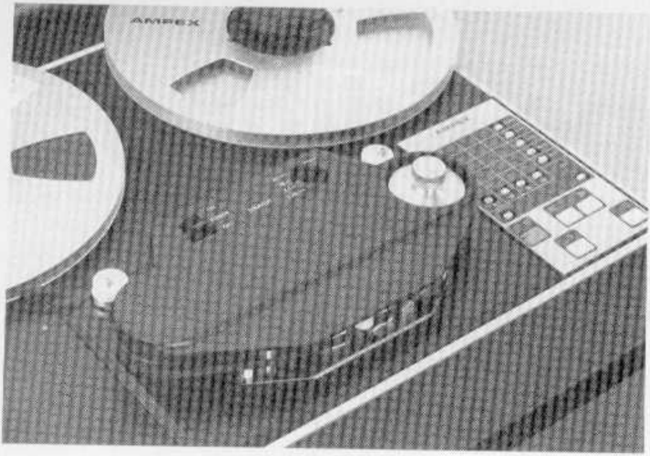
"So if the capstan is told to accelerate at this fixed rate, you do not want the reel to accelerate at that rate. It senses the extra large error in reel servos and controls the rate of acceleration of the capstan so the capstan will never accelerate faster than the reel can.

"You also have the opposite extreme where if you have a very tiny hub, or if you wound tape right on the spindle, the reel would be going much faster than the voltages in the reel servo would allow. So the capstan servo also senses that the voltages on the reels have risen to a high level and slows down the capstan. So if you have a very small reel on one end, as you are rewinding it actually does slow down."

MECHANICAL ACTION

One of the most impressive things about this new machine is its mechanically smooth and quiet operation. My next questions had to do with these aspects.

"We should talk about the guiding and the acoustic quietness of the machine. The tape lifters on the machine are conventional type solenoid operated lifters, but they are damped. So when you operate, you don't get any clunk



A closeup of the ATR-100 deck.

at all from the machine. In fact, the lifters are adjustable in the setup—so set them so you just don't get the clunk.

The capstan noise factor is down because the rpm of the motor is down. Note that the size of the capstan itself is about 2⅜ inches in diameter. It happens that one revolution of the capstan is exactly 7½ inches of tape. We wanted it to be intervals of time, 30 in/sec being four revolutions per second. The size of the capstan is significant for many other reasons. One is the area of the capstan's circumference. Because with the small diameter on most machines, you're very subject to run-out effects from the capstan. A run-out is when (as the shaft rotates) it is not really rotating around the center.

"It may be slightly bent so the effect of the driving radius to the tape varies. The shaft simply can't be made or supported in its bearing perfectly. That run-out translates directly to flutter. It becomes a velocity error around the tape. The larger you make the capstan radius, maintaining the same number for the run-out, say 1/1000 inch, the more you proportionately reduce your flutter."

Next month we will conclude this discussion, beginning with the four speed operation of the recorder. ■

LARRY ZIDE

The Making of the Ampex ATR-100, Part 2

In this concluding segment, the Ampex engineers discuss the four tape speeds, the development of the electronics for superior headroom and phase coherence, timing accuracy for radio broadcasts, and finally future machines to come from this technology.

THE ROUNDTABLE consisted of Robert P. Harshberger, Jr., staff engineer who did the motors and control systems; Alastair M. Heaslett, senior staff engineer whose responsibility included the signal electronics; and Roger R. Sleger, senior engineer who created the mechanical systems (and whose name we misspelled in the picture captions in part one). Also present, and in whose office we sat, was Frank Santucci, the audio product manager for the project and its marketing.

The ATR-100 is a four speed tape machine, but in practice only two speeds at a time can be selected. The other two speeds are available and require circuit board changes to achieve. What I wanted to know was why this method had been selected rather than making it a simple four speed front panel selection alone.

"Mechanically, with the type of servos we are using, four speed operation was easy to implement. However, it must be realized that for every speed you have you must also have a full set of equalizers for both play and record. So, to have a four speed operation from the front panel you would need two more complete sets of equalizers. This, of course, would raise the price significantly.

"It was the considered opinion of both engineering and marketing that few potential users need four speed operation. Rather, most people tend to work at one dominant speed with another as secondary. In the broadcast field the primary speed is 7½ in/sec and sometimes 15 in/sec, with an equal amount at 3¾ in/sec. In the recording field, the dominant speed in Europe is 15 in/sec, and in the U.S. 30 in/sec, with 15 in/sec as a secondary speed.

"All that is required to change to any other speed not already set up is more a jumper on each audio board. For each channel there are two jumpers which select the respective two speeds at which the machine will operate. You only have to reposition those on each channel. Then, of course, you will have to readjust equalization for the speeds you want to use. Incidentally, the machine will only operate at the two speeds selected on the boards. Setting the front panel speed switch to another speed will cause the machine to refuse to function.

"There is no jumpering required for the servos. The audio signal boards control the speed at which the servos will run.

THE ELECTRONICS DESIGN

My basic question to the group was what was done to the electronic design to get the ATR-100 to be so much better than the 440-C model.

"The short quick answer is that the electronics are designed with margins that accommodate the existing tapes. These tapes may be two or three generations old. The improvements of tape performance over the last five years have been such that these margins have been eroded to the extent that the headroom to electronic saturation above the tape operating level has got to the point where there's not much left anymore.

"In general, however, the ATR-100 improvements have consisted of just attention to detail in each individual element of the signal paths and ensuring that there is enough headroom for today's and tomorrow's tapes.

"Let's put some numbers on headroom. In the reproduce electronics of the ATR-100, the headroom approaches 40 dB and for the record electronics, there is the capability of driving the record head with a signal that is 30-35 dB above operating level (or what we assume as operating level today before any intrinsic internal clipping occurs).

"This headroom is not fully apparent if you take an ATR-100 and drive it to see what happens. Under that condition we would be talking about 20-25 dB of headroom—with modern tapes. That used to be a pretty good number and still is. The 440 had that number when applied to the tapes of its day, but modern tapes have considerably eroded it.

"There are other factors that give the electronics their present qualities. We've made sure the system is linear from a distortion viewpoint, all the way to the overload point. From a purely design view, that meant circuits with output stages that are symmetrical.

"In short, it was an effort to ensure that there would be enough margin for today's tapes, while adding a bit more to provide for a few more years of tape development.

PHASE COHERENCE

Intertrack phase relationships on most multi-track machines are pretty poor. Ampex made a special effort to achieve a high degree of intertrack phase coherence on the ATR-100. I wanted to know how this had been achieved.

"Intertrack phase coherence is affected by many factors. In part one we talked about the design and construction of the tape heads. With our heads, mechanical gap scatter is so small as to be difficult to measure even with visible light.

"The precision with which the head and the rest of the machine is aligned mechanically is also important.

"Now if a machine is set up without paying attention to these details, you will end up with a system that has intertrack gap scatter. If phase differences were caused by differing track head impedances, you could still do some correction by careful alignment of the heads. This is, of course, a mechanical correction for an electrical problem.

"Where the ATR-100 is different from other machines is that a great deal of attention has been given to making sure that the performance of the two channels, or any pair of channels, is as identical as possible to each other. Once these electrical differences are worked out, you are left with the mechanical ones. And these can be readily corrected.

"It is fundamental to the process of magnetic recording that there will be phase non-linearity in the channel. The direct effect of this is that if you put a pulse into the system, and reproduce it, and the apparent amplitude response to the system is flat over any desirable frequency range, the pulse comes out the other end distorted. The form of the distortion is not important, but the fact is that the pulse is not faithfully reproduced. One could ask if the amplitude response is flat, why doesn't the pulse response come flat?

"The answer is because the process has nonlinear phase things happening in it due to the process of magnetic recording. Having said that, now we can go back and say why the ATR is different. There have been attempts in the past on professional machines to put appropriate phase equalization circuits into the electronics with the aim of producing a machine which will reproduce pulses correctly as they are recorded: The drawback to these systems has been that the phase equalization has been accomplished principally during reproducing. The factors which influence the nonlinearity in terms of phase recording are intimately bound up with the particular record head (what was its physical gap length, what was the coating thickness of the tape, how did the user choose to bias the tape?) and a lot of other similar factors. Of course, on that particular machine you could adjust this phase equalizer and indeed come out with a very good replica of a square wave coming off the tape.

"The problem was that the recording that you produced is not compatible in the sense that now you take this recording and play it on another machine which is equalized to reproduce the sine wave response correctly, but it would not possess these good phase characteristics. In a similar sense, if you took a recording that was made on another machine, and play it on this machine which had the phase equalization present, it might help the phase response, but it might make it worse because it just depends on the particular set of circumstances under which that machine was aligned.

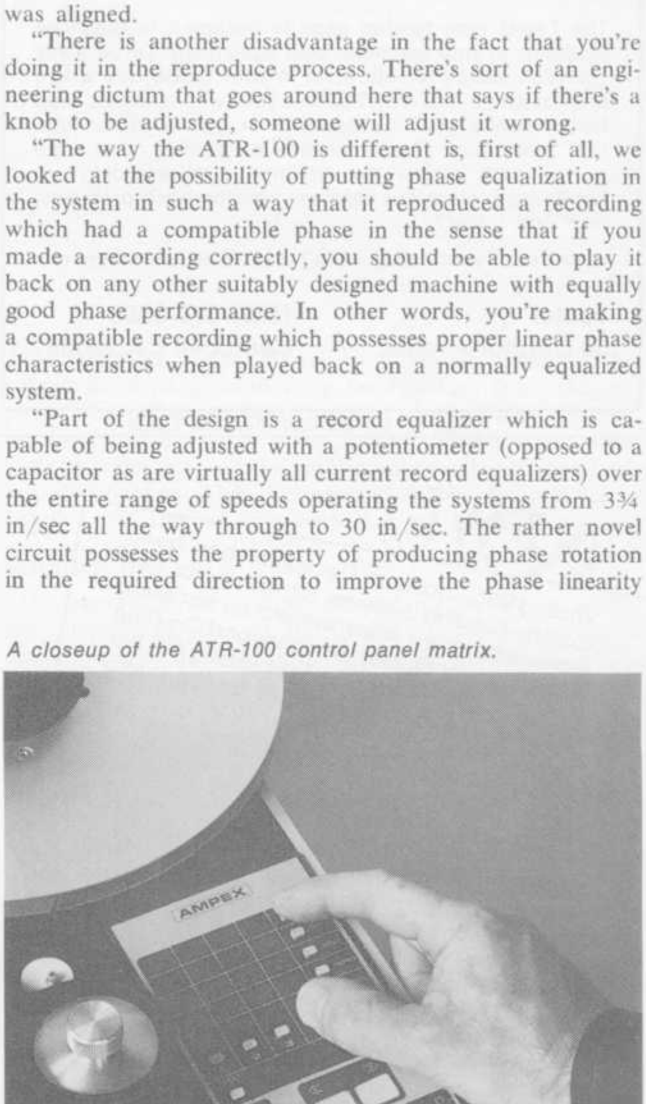
The Ampex ATR-100.

"There is another disadvantage in the fact that you're doing it in the reproduce process. There's sort of an engineering dictum that goes around here that says if there's a knob to be adjusted, someone will adjust it wrong.

"The way the ATR-100 is different is, first of all, we looked at the possibility of putting phase equalization in the system in such a way that it reproduced a recording which had a compatible phase in the sense that if you made a recording correctly, you should be able to play it back on any other suitably designed machine with equally good phase performance. In other words, you're making a compatible recording which possesses proper linear phase characteristics when played back on a normally equalized system.

"Part of the design is a record equalizer which is capable of being adjusted with a potentiometer (opposed to a capacitor as are virtually all current record equalizers) over the entire range of speeds operating the systems from 3¾ in/sec all the way through to 30 in/sec. The rather novel circuit possesses the property of producing phase rotation in the required direction to improve the phase linearity

A closeup of the ATR-100 control panel matrix.



I had the rare privilege of a short interview with Alexander M. Poniatoff, founder of Ampex, still active in the company although in his eighties. He posed for my camera, seated at his desk.

recording. The nice part of it is that the user is totally unaware of the fact that while he is adjusting his record equalizer to produce a flat amplitude response, he is also adjusting the phase equalization of the system so that the overall phase linearities of the system are considerably better than if the classical kind of record equalizer were used. If you adjust the record amplitude response of the system for a particular type of tape, you produce the correct phase response. By having the phase correction on the record side, the result is a tape that is more phase linear and you can benefit from it on any machine on which it is played."

TIMING ACCURACY

The ATR-100 is well suited to the needs of broadcasting. In this field, timing consistency and accuracy is important, and it was toward this that we talked.

"Let's look at the worst possible case—a one hour program recorded on one machine and played on another. Under such conditions the total error in one hour would be less than two seconds. More likely, it will be under one second. If, in fact the recording is made today, and played back on the same machine tomorrow, the maximum error will be less than one second."

ONE AND TWO INCH MACHINES

The present configuration of the ATR-100 is as a quarter- or half-inch only machine. In an attempt to look into the future, I asked about the probability of machines using the new technology for the larger format. The question was fielded by Frank Santucci.

"It must be understood that any larger format is a totally different machine from the ATR-100. The tape handling is different; the control system is different. If we were to start the design today, it would be at least three years before the machine saw the light of production day. Of course, we are looking at one and two inch machines with the performance characteristics of the ATR-100. But there are practical problems. Two inch ferrite heads are a whole new ball game at the very least.

"Of course, Ampex is looking at this project, but it certainly has a long way to go down the pike before it sees production."

It is easy to become impressed with the product after an interview such as this. But the specifications of the ATR-100 really tell the full story. It's all the story that has to be told. ■