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USE OF CAPSTAN SERVO SYSTEMS IN AUDIO RECORDERS FOR MULTIMEDIA SYNCHRONIZATION

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The versatility of a dc capstan servo simplifies synchronization of audio recorders to each other, to video tape recorders or to sprocketed film equipment. Several systems will be described, including pilot tone resolving, video lock and film lock, all of which use pulse counting techniques. A system which uses an address code can offer further advantages. The SMPTE code and how one system uses it to synchronize as many as six tape transports will be described.

Timing accuracy is vital in synchronizing audio tape recorders to each other or to video recorders or film equipment. To produce acceptable "lip syncing" of picture information to audio, the two systems must coincide throughout the program to an accuracy of plus or minus one frame (±33 ms) or better. This would require a tape recorder with a timing accuracy of 0.0037% for a 15-minute program. This accuracy dictates the use of a control track plus a suitable capstan servo system to force the tape to run at the required speed to maintain the correct positional accuracy between the picture frame and the control track. It should be noted that it is not sufficient to run the tape at a constant speed. Tape is an elastic medium which can change length with temperature, humidity and tension. It is necessary to run the tape at whatever speed is needed to make the timing identical to that of the source media, the machine with which you desire to synchronize. One method of accomplishing this is to compare a signal from the source media with audio control track, and vary the speed of the audio recorder to make these signals equal in frequency.

BASIC CAPSTAN SERVO

Figure 1A shows a block diagram of a typical capstan servo system. This servo is a Type II System, commonly known as a position servo. It obtains this name from the fact that it forces the feedback signal to have a specific phase or position relationship to the reference signal. Thus the average frequency or velocity error is zero. The phase comparator produces an error signal proportional to the phase difference between the reference and feedback signals. This error signal is often a rectangular wave with the positive-going edge representing reference or "where you wish to be" and the negative edge representing feedback or "where you are". This phase error signal is filtered to produce a dc signal which is amplified to control the current or voltage in a dc motor. With the feedback signal switch connected to the tachometer, the motor will rotate at an angular velocity that produces a tachometer frequency exactly equal to the reference frequency with some average phase relationship that varies to control the motor. The amount of phase variation seen depends upon the open loop gain of the system and the magnitude of the disturbing torques that are seen by the motor. Figure 2 shows two dc motors used by Ampex in audio recorders. The smaller motor is used for 1/4 and 1/2-inch wide tape, while the larger motor is used for 1-inch to 2-inch tape widths.

SYNCHRONIZING TO VIDEO

To give an example of how the capstan servo system can be used for synchronization, let us assume that we wish to lock to a helical scan video tape recorder. A typical helical VTR will operate at approximately 9.6 in/s with the speed being determined by the master composite sync generator, while the audio recorder will run at 15 in/s. The reference frequency to the audio servo must come from the video recorder but it does not have to come from a control track on the video machine. It can be derived from the same signal that controls the speed of the video tape recorder. If we assume that the tachometer signal from the audio servo needs to be 2400 Hz for a 15-in/s tape speed, we must obtain an identical frequency from the video tape recorder. By stripping the 15,734-Hz horizontal sync signal from the composite video sync signal, multiplying it by 2 and dividing by 13, we can produce a 2420-Hz signal to operate the audio servo at 15.1 in/s. This is an adequate compromise, since we are not interested in speed per se but in synchronism. When the original recording is made, the 2420-Hz signal is fed to reference input of the servo and is also recorded as a control track. During this recording process, the feedback input to the servo is connected to the capstan tachometer. Upon subsequent reproduction, the feedback input will be connected to the control track reproduce head. The servo action will force the frequency of the control track to be identical to the reference frequency which also controls the speed of the VTR. As long as the control track is faithfully reproduced, the audio recorder and VTR will maintain perfect synchronism, despite the fact that the tape speeds are quite different.

PHASE LOCK LOOP

In the example above, hypothesize that composite sync is not available but a 59.94 Hz vertical drive signal proportional to VTR speed is available. It is necessary to convert this signal to 2400 Hz to feed the servo reference. The phase lock loop shown in Figure 1B will convert a lower frequency into a higher frequency while holding phase relationship between the two. The phase lock loop shown in Figure 1B is very similar to the servo of Figure 1A. It is also a Type II System, the II referring to the number of poles of the loop transfer function located at the origin. Like the servo, it uses a phase comparator, filter and amplifier. In place of a motor, the amplifier drives a voltage-controlled oscillator. Instead of obtaining the feedback input to the phase comparator from the tachometer, it is obtained by dividing the output frequency by the appropriate number to make reference and feedback frequencies identical. With a 59.94 Hz reference input and a division of 40, the output frequency of the phase lock loop will be 2398 Hz. This in turn is used for making the original control track recording and is fed to the reference input of the capstan servo, producing a tape speed slightly less than 15 in/s. Upon reproduction, the control track frequency will be forced by the servo action to equal the 2398 Hz which is still obtained from the 59.94 Hz by the phase lock loop.

SYNCHRONIZING WITH 60 HZ CONTROL TRACK

There are many instances where neither high frequency reference sources nor control tracks are available for the capstan servo. Resolving a 60-Hz pilot tone signal is a familiar example used for synchronizing audio tape recorders to film equipment. This consists of synchronizing a 60 Hz control track to the ac power line, since film transports are synchronous to the power line. If these frequencies were to be fed directly to the servo phase comparator inputs, the bandwidth of the capstan servo would be limited to approximately 6 Hz. This is derived from a rule of thumb that states that the bandwidth of a stable position servo cannot exceed 1/10 of the sample rate. A high bandwidth is normally desirable in a capstan servo system because it allows freedom from torque disturbances that otherwise would require large inertias. Figure 3 is a simplified block diagram of the system used on the Ampex AG-440 tape recorder to resolve a 60-Hz control track. Figure 4A shows the recorder equipped with the synchronizer system and Figure 4B shows the front panel of the synchronizer chassis. The capstan servo is identical to the one previously described except the reference and tachometer frequencies are 4800 for a 15-in/s tape speed. The phase lock loop is also the same as shown in Figure 1B except it converts a 60-Hz reference to a 9600-Hz output. The major difference in the system is that the control track is fed to the feedback input of the phase lock loop instead of to the feedback input servo. It does this through an electronic switch operated by a control track detector. If the control track is not present or is at some frequency lower than 60 Hz, the phase lock loop will be connected to the divider so that the 60-Hz reference input will be translated to 9600 Hz and the capstan will run at a constant 15 in/s. When the control track gets within a few cycles of 60 Hz, the control track detector switches the feedback input of the phase lock loop to the control track. The output of the phase lock loop will now adjust itself to produce a frequency that will cause the capstan to rotate at whatever speed is needed to produce a control track frequency equal to the 60-Hz reference frequency. The reference frequency can be obtained from several sources. When synchronizing to film equipment, which use synchronous ac motors, the reference would be the power line that drives these motors. When synchronizing to video equipment that uses composite sync, the synchronizer strips the 59.94 Hz vertical drive from the composite sync signal and uses it for the reference. The internal crystal oscillator, with appropriate division, can also be selected as reference.

LIP SYNC REQUIREMENTS

Several methods of synchronizing tape to other media have been discussed but no mention has been made of how to locate the initial sync position. Some form of manual lip syncing is required. Quite often this is done by varying the speed of the tape until lip syncing is achieved. Figure 3 shows how an internal variable frequency oscillator is connected to the servo reference to vary the speed of the tape. Sometimes click tracks are used as an aid in locating the sync position. The techniques can be cumbersome. Obviously, the next area of sophistication should incorporate a method that automatically searches for the sync position between media.

The systems described so far utilize pulse count techniques. For the system to be in lock, a pulse from the reference must be followed by a pulse from the tape. By extending these pulse count techniques, it is possible to "know" the position of the tape and source media at any time. For example, if the tape is started from an initial start mark and the control track pulses are counted, this total count represents an accurate location of the tape position relative to the start mark. The tape can be stopped, restarted, and run at various speeds. As long as control track pulses information is not lost, the total count represents the tape position, If the source media has a control track, it is also possible to keep count of its position relative to its start mark. It is then possible to control the speed of the audio recorder to make these counts equal. If the source is a film projector without a control track, all that is needed to keep track of position is a tachometer connected to the drive shaft. As long as the film remains in the sprockets, this tachometer is an accurate position detector.

FILM LOCK SYSTEM

Figure 5 is a simplified block diagram of the Ampex film lock accessory which utilizes these principles to lock an Ampex MM-1000 audio recorder to a film system. Figure 6A shows this accessory installed in a 16-track recorder while Figure 6B shows the control panel for the system. In addition to seeking frame coincidence in the forward direction, the tape recorder will follow the projector or film recorders in a reverse movement and re-establish lock in the subsequent forward movement. As long as the projector does not stop too quickly, the tape recorder will stop in frame coincidence with the projector. In the lower right-hand corner of the block diagram is the identical capstan servo shown in Figure 1A. The nominal reference and feedback frequencies are 2400 Hz for 15 in/s and 4800 Hz for 30 in/s. The line lock oscillator in the left of the block is identical to Figure 1B except it translates the 60-Hz input to 259.1 kHz and has a division ratio of 4320. The tachometer that is mechanically coupled to the projector will produce a 2400-Hz squarewave when the projector runs at 24 frames per second. It also determines whether the projector is running forward or reverse.

Instead of using two separate counters to keep track of film and tape position, one up/down counter is used. This counter has a capacity of 256 frames and sync position is set to be a count of 128.00 frames. When the projector and tape recorder are both traveling forward, each control track pulse will add one count or 0.01 frames to the counter. Each projector pulse will subtract one count or 0.01 frames from the counter. Therefore, the output of the counter will be an indication of the relative tape-to-film position within an accurancy of 1/100 of a film frame (416 microseconds). In reverse, the inputs to the counter are reversed so that the film adds and the tape subtracts.

Upon initial start, the operator cues both film and tape to visible start marks. He presses the FILM LOCK ON button on the film lock control panel (Figure 6B), which stops the capstan motor (if running), deactivates transport controls, engages the capstan pinch roller, applies power to the take-up and rewind motors and releases the brakes. The tape is now stationary, locked to the capstan, and ready to react to projector movement. The operator will also press a RESET COUNTER button which inserts the sync count of 128.00 frames into the counter. If the projector now starts in the forward direction, the stop command is removed from the capstan when the counter reads four frames behind sync (124.00). The capstan control logic instructs the programmable divider to produce a frequency of 2541 Hz to the servo so that the tape tries to speed up to 15.9 in/s to catch up with the film. If the counter indicates that the tape has pulled ahead of the film, the reference frequency is reduced to 2254 Hz so that the film can catch up. In this manner, the tape recorder searches for the sync position. If the tape should fall behind the film by more than 6 frames, the search speed is increased to 25.3 in/s, to produce a correction rate of 16-1/2 frames per second. A 100-frame error would be corrected in a little over 6 seconds. When the film speed stabalizes and the tape recorder remains in a 1/10 frame wide window for 300 milliseconds, the search mode will terminate. Lip sync has been established. The capstan servo reverts to its 2400-Hz line-locked reference with the 2400-Hz control track as its feedback input and operates in a manner similar to the previously described synchronizers. The up/down counter no longer controls the speed but continues to monitor the tape-to-film position and display this on the control panel.

If it is desired to move the position of the tape relative to the film after sync has been established, a variable speed mode of operation can be initiated. This connects a variable frequency oscillator to the servo reference input. Since the search mode used for initial lock is not active, changing the tape speed will change the tape to film position. When the desired position is found, the operator terminates the variable speed mode and the reference returns to normal. The tape and film are again in synchronism but at a new position. Throughout this operation, the counter keeps track of the film-to-tape position but takes no aciton.

If the operator likes the new position, he may press a button to reset the counter to sync count. This is equivalent to a physical movement of the original start mark. If the operator wishes to return to the original sync position instead of using the new position, he can press a button that reactivates the search operation. The tape will automatically seek the original sync count.

Like starting, stopping the system is initiated only by the projector. When the projector begins to stop, the tachometer pulses decrease in frequency. The dc output of the projector discriminator drops, giving the capstan control logic a "slow down" command. The programmable divider lowers the reference frequency to produce a 3-3/4-in/s tape speed. The tape recorder will normally decelerate faster than the projector and fall behind the projector so that the tape is still moving when the projector comes to a stop. The tape will continue to move at 3-3/4 in/s until the counter registers 3 frames from sync. The programmable divider is then changed to produce a 1-7/8-in/s tape speed. When the counter registers 1/10 frame from the sync count, the capstan servo is given a stop command which normally stops the tape in 3/32 inches of tape travel

When the projector starts up in the reverse direction, the direction and motion sensor in the projector tachometer generates a reverse command which performs the electronic switching necessary to permit reverse movement of the tape. The search mode of operation is not activated in reverse and no attempt is made to achieve frame coincidence. As shown in Figure 5, the reverse switching connects the projector tachometer pulses directly to the reference input of the capstan servo. Therefore, if the projector travels in reverse at some speed greater than 24 frames per second, the tape recorder will also operate backwards at the increased speed. However, the reverse speed of the tape recorder is limited to 60 in/s. Stopping from a reverse movement uses the same techniques as a forward stop, slowing to 3-3/4 in/s, then 1-7/8 in/s, and stopping the capstan when frame coincidence is achieved. The mechanical brakes are never used in making a film lock stop.

The same equipment described above can be used to lock the audio recorder to a video recorder. The signal now obtained from the projector tachometer would be obtained from a prerecorded 2400-Hz cue track on the video recorder. The forward and reverse commands can be obtained from the control logic of the VTR. The servo reference can be locked to the horizontal drive signal. As long as the reverse speed of the VTR can be limited so as not to exceed the capabilities of the film lock system, the two recorders will remain in synchronism through forward and reverse movements. However, the system would have several limitations. The audio recorder could not follow a high speed forward and reverse movement of the VTR without losing synchronism. The film lock system starts and stops under capstan control to ensure that control track information will not be lost during the start/stop process. If the video recorder should lose head-to-tape contact during the start or stop, errors in the information can be accumulated. This would limit the number of start/stop cycles that could be made before synchronism was lost. It would be possible to avoid these problems if the control track contained address information.

EDITING AND ASSEMBLY USING ADDRESS CODE

The systems described thus far were designed to automatically maintain synchronism between transports; such a feature is especially useful in adding sound to the primary media, and in keeping the sound in synchronism during editing. But in some editing situations, *maintaining* synchronism is only half the task. Teleproduction people have found that in order to edit and assemble video taped programs quickly, it is necessary to have a means of automatically accessing program segments at random and rehearsing and modifying the splices between them. To *rehearse* a splice between two segments of tape, each on a different transport, it is necessary to synchronize the transports and switch from one playback head to the other at the splice point. To *modify* the splice point, it is necessary to synchronize a point on one tape with a randomly selected point on the other tape. For a machine to perform these functions automatically and reliably, it is necessary that the tapes contain a machine readable address code.

THE SMPTE ADDRESS CODE

The television industry uses an address code standardized by the Society of Motion Picture and Television Engineers (SMPTE). In domestic television, there are thirty picture frames to the second, and the SMPTE standard is to number each one of them, in order, with a complete "time-of-day" code. For example, if one frame is numbered one hour, 50 minutes 59 seconds and 28 frames (1:50:59:28), the frame preceding it would be numbered 1:50:59:27 and the one following it would be numbered 1:50:59:29. Since there are thirty frames to the second, (and sixty seconds to the minute), the next frame would be numbered 1:51:00:00.

The SMPTE address code is essentially a 1200-Hz squarewave, phase modulated to encode digital data. Specifically, the encoding scheme is the bi-phase mark, also known as Manchester I. A circuit designed to decode the SMPTE address code would generate a clock pulse with each transition of the 1200-Hz squarewave, thereby generating a 2400-Hz clock rate. The space between two adjacent clock pulses is a "bit". The bi-phase mark scheme is to write the digital data between the clock pulses by reversing the phase: A phase reversal between clock pulses makes the bit a digital "one" and the absence of a phase reversal makes it a "zero". In

Figure 7, signal (A) is a totally unmodulated 1200-Hz squarewave and therefore all the "bits" are "zeros". Signal (C) has one phase reversal between clocks; therefore all but one of the bits are zeros.

The SMPTE standard specifies that each decimal digit of the address code shall be recorded serially in binary coded decimal, with the least significant bit first. [Binary coded decimal (BCD) is the scheme for representing a decimal number (0 through 9) with four binary bits (one and zeros) with the weights of 1, 2, 4 and 8 respectively. Thus, to record the decimal number 3 in BCD, serially, with the least significant bit first, one would record 1100 (1 x 1 + 1 x 2 + 0 x 4 + 0 x 8 = 3). The number eight would be 0001 (0 x 1 + 0 x 2 + 0 x 4 + 1 x 8).]

Since there are 2400 bits per second, and thirty frames per second, there are 80 bits per frame. Data to be recorded in those 80 bits belongs to one of three major categories: Sync group, address and spares.

The sync group occupies sixteen bits and is comprised of two zeros, twelve ones and then a zero and a one. The decoding circuitry determines the direction of tape travel by sensing the value of the second bit just after the group of twelve ones. If it is a one, the tape is traveling forward; if it is a zero, the tape is traveling backwards.

The address nominally occupies 32 bits, since the time-of-day number has eight decimal digits, and decimal digits are normally represented by four bits. But in the time-of-day address, not all digits require four bits to be represented, since some digits are limited in value. For example, the seconds digits have a maximum of 50; therefore, only seven rather than eight bits are needed. The extra bits are put to use by being assigned certain significances, as shown in Figure 8.

Of the 80 bits per frame, 16 are occupied by the sync group and 32 by the address; the remaining 32 are assigned as spares, subject to dedication by the user. They can be used to label the recording with a date, or take number, or any combination of data up to eight decimal digits.

The Ampex address code generator (Figure 9) can generate spare digits dialed-up on the thumbwheel switch or fed to a rear connector. The Ampex address code reader (Figure 10) can display the spare digits as well as the address code.

Returning to the idea of using address codes to facilitate editing and assembly of taped video programs, the advantage of using time-of-day codes rather than some other sequential numbering system is that it is easy for people to think in terms of and work with time-of-day numbers when editing. For example, determining the time duration of a segment becomes a matter of subtracting the beginning address from the end address.

THE RA-4000 SYSTEM

To further appreciate the convenience of using the time-of-day numbering system in particular, as well as the convenience of using an address code/random access controller in general, consider the RA-4000 System (Figure 11).

The RA-4000 system was designed for teleproductions studios for rapidly editing and assembling taped TV programs. Editing is here defined as selecting a tape and deciding which part of it is to be in the final tape; these parts are called segments. Assembling is defined as the process of putting all of the segments together in the right order. Or, in other words, editing is deciding where to splice and assembling is doing it. Consider this scenario:

A producer wants to edit one scene which was recorded at different angles with two cameras. It would be convenient if he could observe both tapes being played back simultaneously and in synchronism on adjacent monitors so that he could select segments from each one. To do that easily, he needs a system that can automatically cue both transports simultaneously and put them into synchronous playback, and do it all again any time the producer wants another look. The RA-4000 system performs that function each time the "Rehearse" button on the Programmer is pressed (Figure 12C). The Programmer (shown in Figure 12A) is the nucleus of the RA-4000 system. A central time multiplexed controller, the Programmer looks at the address code playback from each transport, determines what it has to do to reach its destination (what direction and how fast) and tells the transport to do it. The only thing the producer has to do is tell the Programmer what the destination is. In this case, it's the address of the beginning of the take. In Programmer language, the beginning of a take is called the entry point, and the end is the exit point. (Since both cameras were recording simultaneously, the entry point addresses will be identical).

Now the producer can sit back and watch the take as many times as he needs to make up his mind. The Programmer display contains an address code reader, so he can identify the splice points by their addresses. At 30 frames per second, the reader will be incrementing too quickly for him to read accurately, but pressing the "From Address" button will capture the instantaneous address and display it on the accumulator readout (Figure 12B).

When he is finished editing, he'll have a list of segments defined in terms of entry and exit points. Now he is ready to do an assembly.

Earlier, assembling was defined as putting segments together in the right order. Assume we wish to splice a segment that is on transport A with a segment that is on transport B. In RA-4000 language, that is an A/B roll. It is an "A/B" because it involves the synchronous playback to transports A and B. It is a "Roll" because as the exit point of the first segment is neared, the Programmer will automatically "Roll" the other transport and get it up into sync so that the entrance of the second segment will be reached precisely when the exit of the first segment is reached. Meanwhile, transport C is in Record, and the first and second segments are being dubbed-down in turn; a switching command from the Programmer at the right moment makes the splice. That describes how the RA-4000 automatically assembles the first two segments on transport C. As the A/B Roll graphic display depicts, a third segment from transport A can be spliced to the exit of the second segment by punching in a new entrance address for transport A and recueing it after the playback of the first segment has been completed and while the second is still in process. In turn, a fourth segment, from transport B, can be spliced to the exit of the third segment by punching in a new entrance address for transport B and re-cueing it while the third segment is in process, et cetera.

To summarize, transport C is continuously in Record and accumulating segments from transports A and B, which are alternately being cued and run-up to the entrance point of the next segment as the exit point of the previous segment is neared on the other transport.

Another feature of the Programmer is that entrance addresses needn't match. The Programmer will synchronize the playback of six transports so that all six entry point addresses occur simultaneously, even if they are all different. It's like making six clocks run synchronously even though they are each set for local times at different points around the world. This feature comes in handy for locking special effects recorded wild to the primary tape, or in fact any time overdubbing requires that an extra transport be added. This feature of the RA-4000 system stems from the fact that rather than synchronizing the transports on the Master/Slave principle, each transport is synchronized to its own time-of-day clock. To run-up a transport, that is, to put it into synchronous Play, the Programmer presets the time-of-day counter with the entrance address (less the cue-up time) and begins incrementing the counter when it puts the transport into Play. The cue-up time is the amount of time allotted for a transport to get into synchronism; normally, four seconds is selected. With this detail information, it is now possible to present a clearer description of an A/B roll: Assume that the A/B roll is already in process and that transport A is nearing its exit address. Transport B has already been cued to a point four seconds less than its entrance address, and its time-of-day counter is preset to the same number. Four seconds before transport A reaches its exit address, transport B is put into Play and its counter begins to be incremented. By the time transport A reaches its exit address four seconds later, transport B should be in synchronous Play.

To cue-up a transport, the Programmer compares the entry point to the present tape address and commands the transport to go into the appropriate fast mode. As the tape address nears the entry point, the Programmer begins dynamically braking the transport by reversing the command momentarily; the tape is normally parked to an accuracy of three frames (about 1/10 second of playing time) with no overshoots.

The Programmer is a time-multiplexed controller. Even if six transports are connected to it, it will control all of them simultaneously. Actually, it isn't really operating on all six at any one instant, but in its 1.28 millisecond cycle it services each and every one.

Besides transports A, B and C, the Programmer can handle three more transports (A' B' and C') at the same time. In the A/B Roll mode, the Programmer locks A' to A, B' to B, and C' to C. Thus, each could well contain the multitrack audio for its respective video.

RA-4000/AUDITEC/MM-1000 SYSTEM

The Programmer is a powerful tool which can do some very helpful things even in a strictly audio media. With the proper interface it can control virtually any transport; for the MM-1000, the proper interface is the "Auditec". Figure 13 shows an MM-1000 with Auditec. Since the Programmer can synchronize up to six MM-1000 transports simultaneously, and since each MM-1000 can be fitted with as many as 24 channels of electronics the number of channels available for sweetening and special effects is for all practical purposes limitless.

The entire interface between the Auditec and the Programmer is through one cable. Through this cable, the Programmer sends the transport FF, RW, Play and Stop commands, and the capstan control signals. The Auditec sends the Programmer signals defining speed, frame rate and transport type so that the Programmer can anticipate its dynamics and interpret the address code properly.

The Auditec also sends the Programmer the "servo locked" signal. When the Programmer has run-up a transport and has determined that the address code playback is in synchronism with the time-of-day counter, the Programmer releases control of the capstan to the local tape servo in the Auditec. When the tape servo stabilizes, it sends the "servo locked" signal to the Programmer. At this point the Programmer determines "all's well" and completely severs control of the transport. The address code playback is now used as a control track by the local transport servo, which locks the frame decoded from the sync group to composite sync; the address information itself is no longer used. Had the local servo not stabilized and sent a negative "servo-locked" signal, the Programmer would, upon sensing the failure, stop all transports.

When the Auditec/MM-1000 is not being used as part of the RA-4000 system, it can be used independently, as a capstan or tape servo, using composite sync as the reference.

Figure 14 is a simplified block diagram of the Auditec/MM-1000. When it is operated independently of the Programmer as a capstan servo transport, switch S2 is in the Tach position and the frequency of the tachometer signal is simply compared with reference generated by the Phase Lock Loop (PLL). This configuration is similar to the "Basic Capstan Servo System" illustrated in Figure 1A.

When the Auditec/MM-1000 is operated independently of the Programmer as a tape servo, switches S1 and S2 are in the positions shown. The address track frequency is compared with the reference. An error results in a dc voltage which drives the Voltage Controlled Oscillator (VCO) off center frequency. That frequency is then compared with the tachometer signal to drive the MDA. Notice that while going from phase detector to VCO to phase detector the information goes through a frequency-to-dc conversion, then a dc-to-frequency conversion and then another frequency-to-dc conversion. Such a configuration ensures a smooth run-up.

Recall that the run-up is when the Programmer controls the capstan to get the tape into synchronism. During that time, switch S1 is in position B. When the Programmer calculates to its satisfaction that the tape is very close to being in synchronism (30% of a frame – about 10 milliseconds), it puts switch S1 back to position A and gives Auditec a chance to control the capstan. Meanwhile, Auditec should have prepared for the change of command by generating the right dc error signal with its sample-and-hold phase detector, so that the voltage at A (from the phase detector) will be very nearly equal to the voltage at B (from the Programmer) when the transition occurs.

SUMMARY

The foregoing discussion has covered not just one synchronizing method, but rather a complete family of products for synchronization. Since no single product can fill the needs of all users, the key problem is to decide which type of equipment is required for a specific application.

The most economical system is the basic tape lock resolver system with variable speed, which permits lip syncing to film or video in the forward direction during normal reproduce. Common applications are transferring audio from tape to sprocketed magnetic film for editing, locking multichannel audio recorders to video tape recorders, and providing a very crude lock between two or more audio machines.

The film lock system, which is completely self-contained to permit ease of operation, adds automatic synchronization during repeated starts, stops, and fast wind operations. The system was developed to provide film and recording studios with the equivalent of five three-channel magnetic film machines interlocked with a projector for film scoring and dubdown with picture but without compromising any of the normal recording studio techniques. Other applications include synchronization of audio with video and multi-machine lock for more than 16 tracks of audio.

The time code based control system is primarily intended for random access editing of audio and video tapes. To provide truly random access, such a system must include not only automatic synchronization in the reproduce mode, but also the ability to automatically search for a desired cue point. At the present time, there are very few installations capable of true random access of both video and audio.

In addition to random access editing, time code can also be used to synchronize two machines or to provide a convenient index for search purposes.

The acceptance of time code techniques for motion picture production has been slowed by two technical problems. The first difficulty is the lack of recording capability on the film cameras currently in use. Unlike a videotape recorder which has cue track facilities for recording time code, a film camera must be modified to record an optical track for the code. The second problem is the 30 frames per second rate of the SMPTE code. Film production requires a 24 frame per second rate to provide frame by frame lock. Thus a new code and new code reading equipment would be desirable.

How does a user go about choosing one of the above systems to fill his needs? The actual choice of system type must be preceded by two steps. First, determine the exact functions that must be performed by the sytem. Second, determine the amount of money available to fill this need. Once these steps are completed, there will usually be only one system that fits the need. (Unfortunately, not all applications and budgets can be accommodated by present-day systems.) The authors hope that this paper will serve as a reference to aid the user in analyzing his specific application in this way.

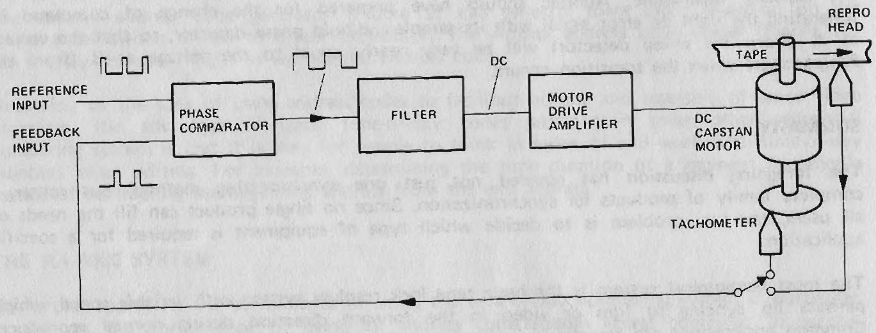

Figure 1A. Basic Capstan Servo System, Block Diagram

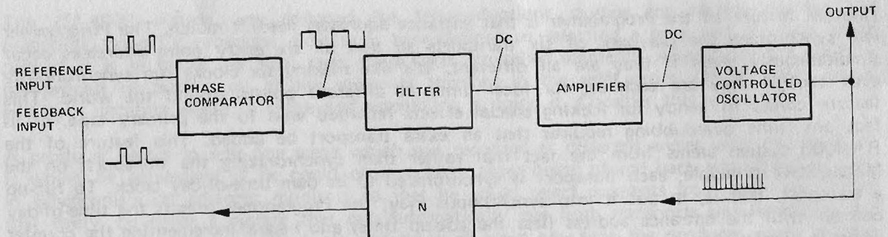

Figure 1B. Basic Phase Lock Loop, Block Diagram

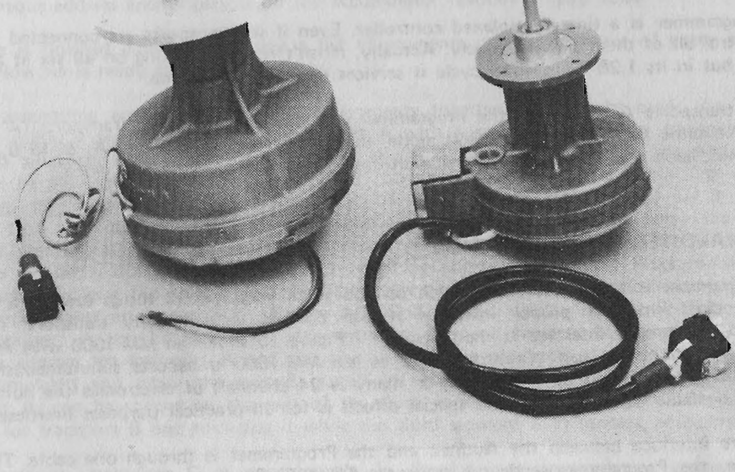

Figure 2. DC Capstan Motors Used On Ampex Audio Recorders

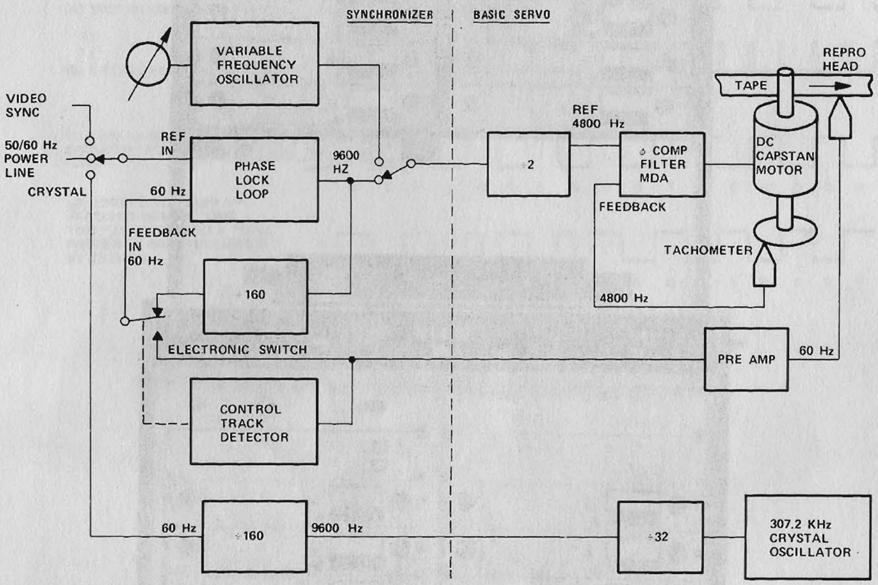

Figure 3. 50/60 Hz Synchronizer, Block Diagram

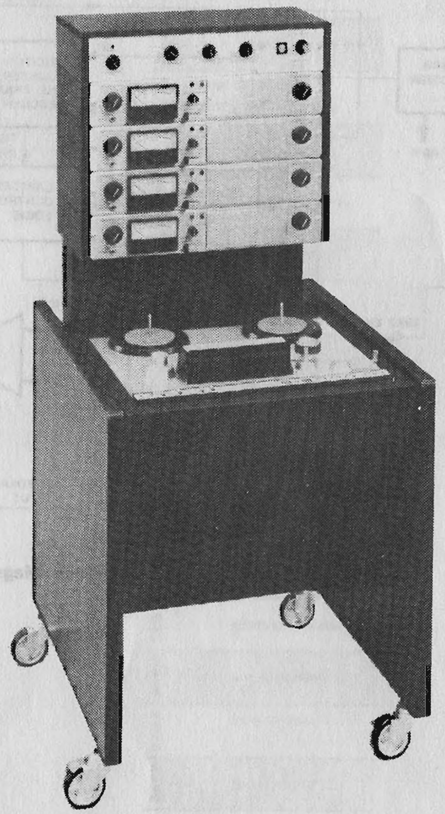

Figure 4A. A 4-Channel Tape Recorder Equipped With A 50/60 Hz Synchronizer

Figure 4B. Front Panel Of Synchronizer

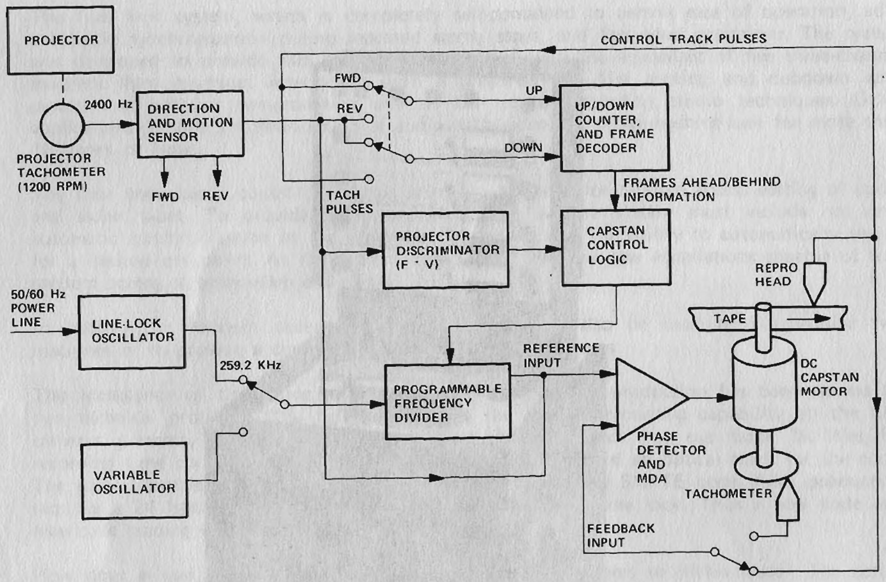

Figure 5. Film Lock System, Block Diagram

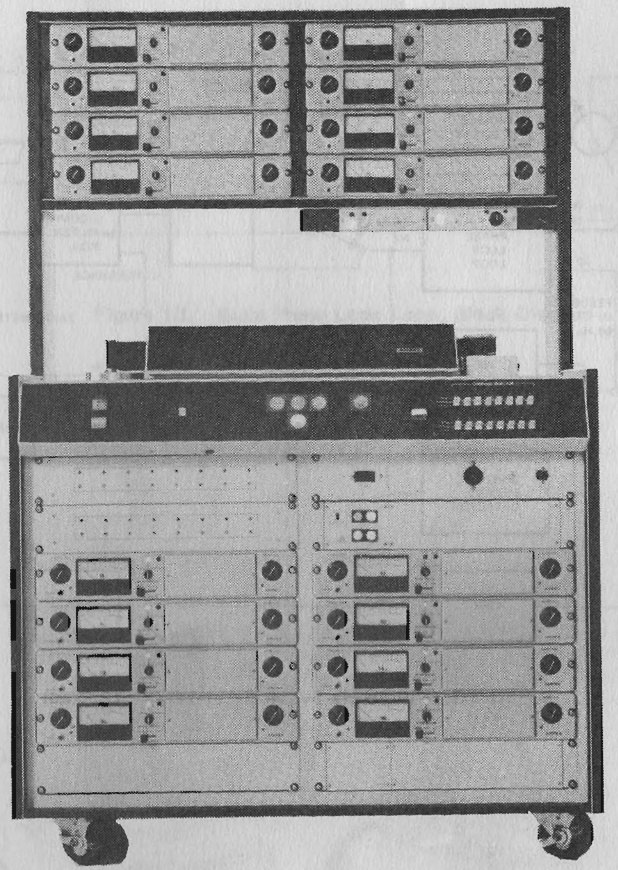

Figure 6A. A 16-Channel Tape Recorder Equipped With Film Lock

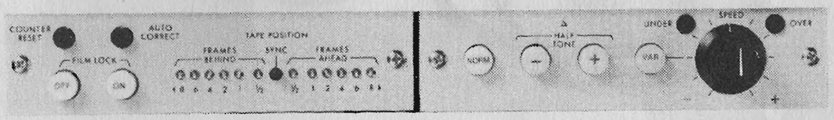

Figure 6B. Control Panel For Film Lock

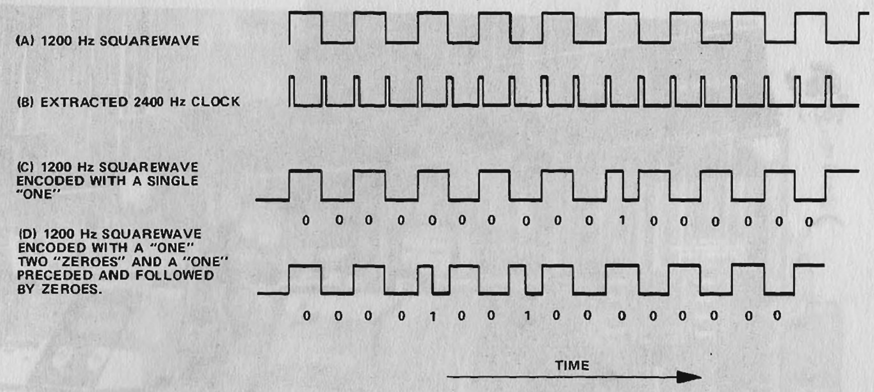

Figure 7. Bi-Phase Mark Coding.

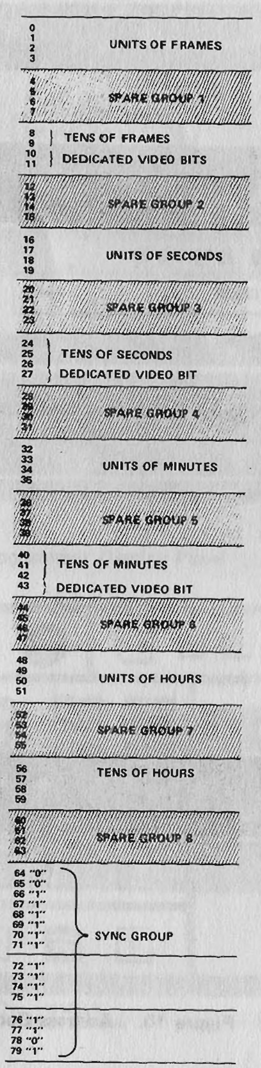

Figure 8. SMPTE Code Format

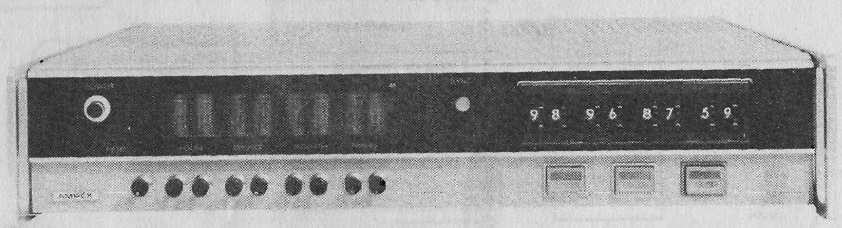

Figure 9. Adress Code Generator

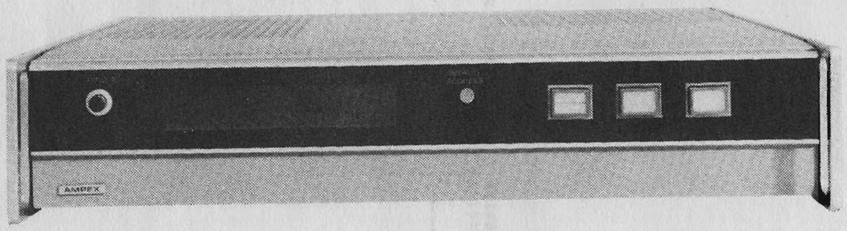

Figure 10. Address Code Reader

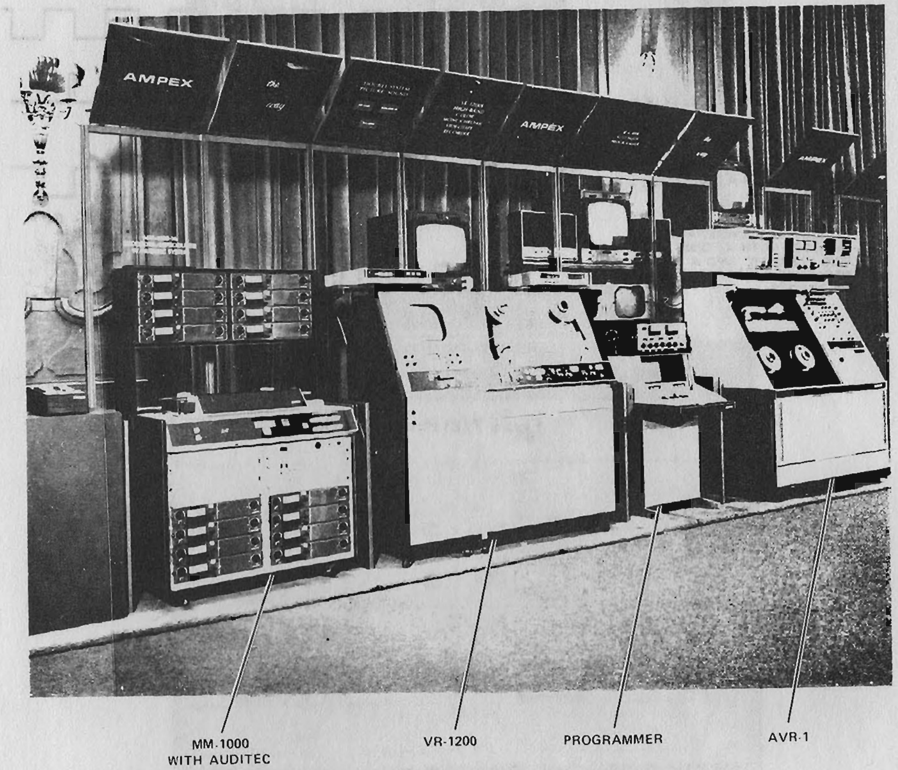

Figure 11. An RA-4000 System

Figure 12A. Programmer

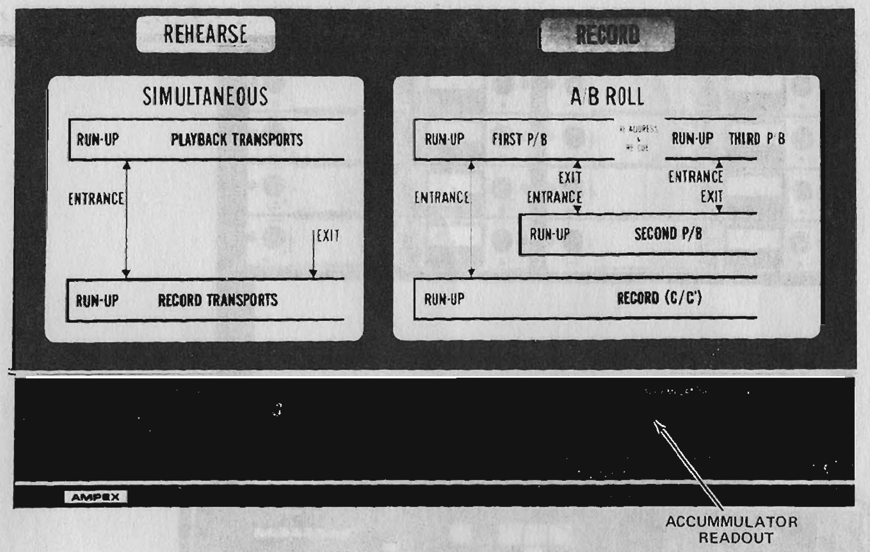

Figure 12B. Programmer Display Panel

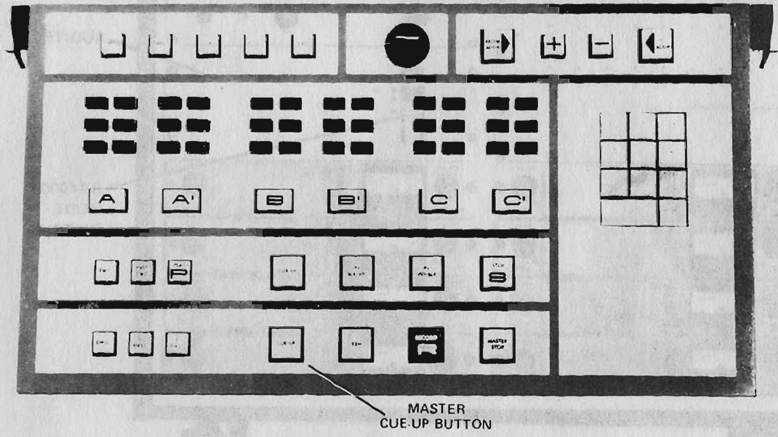

Figure 12C Programmer Control Panel

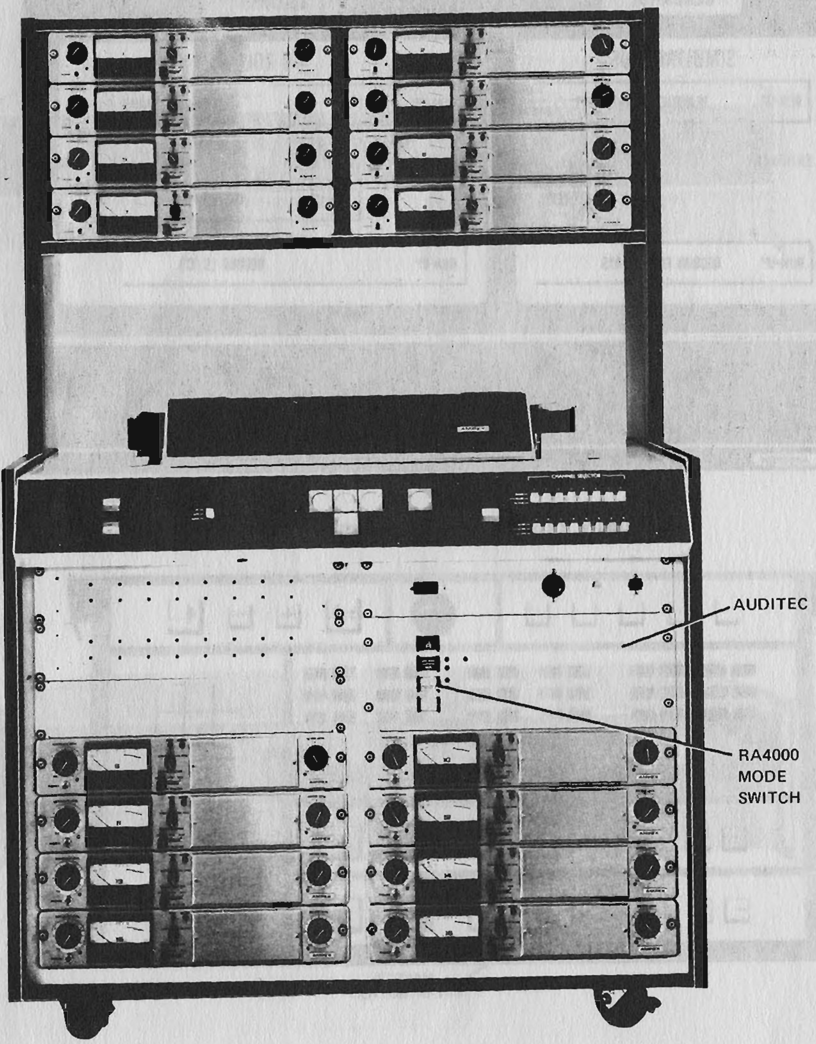

Figure 13. MM-1000 With Auditec

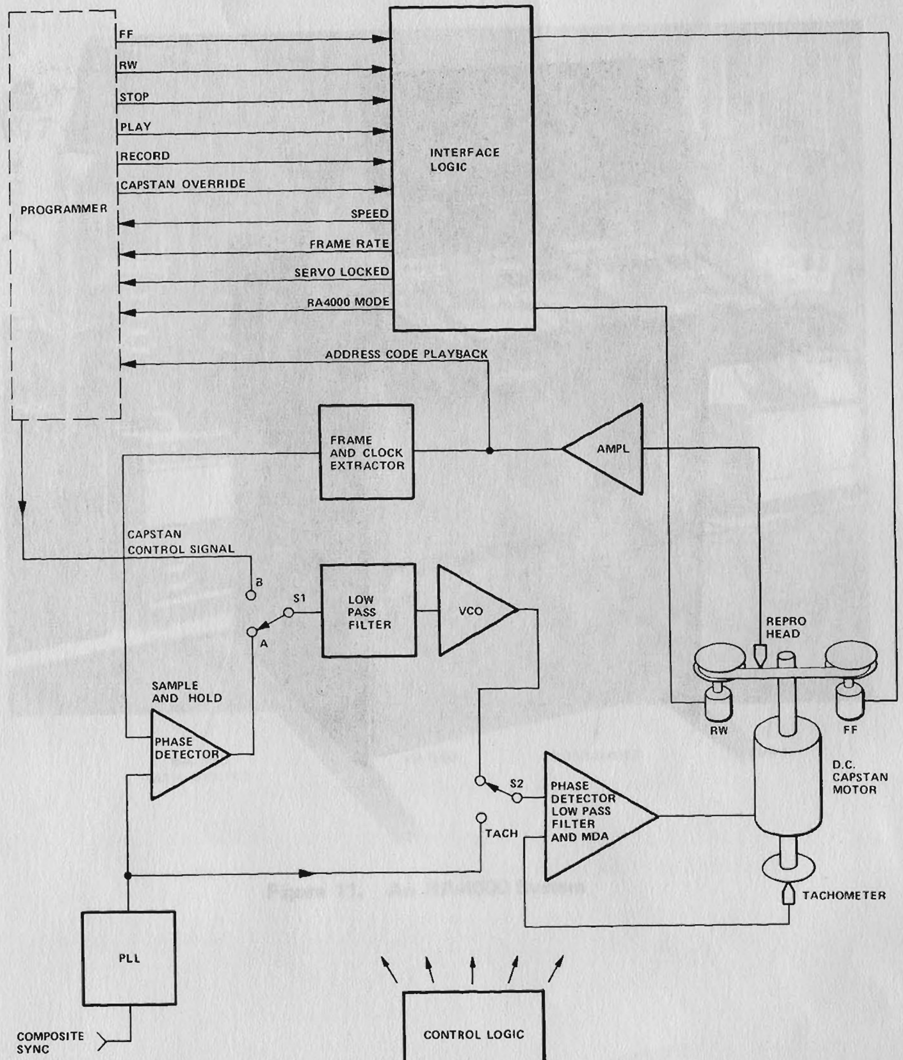

Figure 14. Auditec/MM-1000 Simplified Block Diagram