MAGNETIC TAPE RECORDER

Of Broadcast Quality

HAROLD LINDSAY* And MYRON STOLAROFF*

Design details of a new high-fidelity instrument for exacting applications.

MAJOR EMPHASIS in designing the Ampex magnetic-tape recorder has been on the production of unsurpassed recordings with reliability and continuity of performance to satisfy the most rigid professional standards. Production model 200A, shown in *Fig.* 1, has the following capabilities:

a. *Full coverage of the audible spectrum* (±1 db from 30 to 15,000 cps).
b. *Low distortion.* From input to output terminals the system shows 4 per cent intermodulation distortion at peak meter reading—with harmonic distortion not exceeding 5 per cent 10 db above peak meter reading.
c. *Great dynamic range.* The over-all unweighted noise level of the system (measured flat from 30 to 15,000 cps) is 60 db below full modulation, or 5 per cent harmonic distortion.

The significance of the above statements is that reproduction on this system is, for all practical purposes, substantially perfect. The use of separate recording and playback heads and amplifiers allows essentially instantaneous monitoring and makes possible extremely critical comparisons between recordings and original programs—comparisons which cannot be readily made with other systems. Such a comparison—where the output of the recorder is directly compared with the material being recorded—has been given the term "A-B Test." The incoming signal is fed into the recorder. The monitoring amplifier is then bridged alternately across the recorder input and output terminals.

When live programs are recorded—using the best possible input equipment—and when monitoring with the highest-quality amplifier and speaker systems, critical listeners have not been able to determine which is the original program and which the reproduction. Comparable results with other methods of recording can generally be obtained only under carefully-controlled laboratory conditions.

Overload Characteristic

Another advantage of tape recording results from the gentle overload characteristic. Unlike other methods of recording, tape distortion increases gradually as the signal level is increased to the point of saturation. Because of this, severe transient overloads do not cause breakup and therefore do not spoil the program. This feature allows considerable latitude in setting up for recording and eliminates the necessity for rigid monitoring of the input signal.

Other outstanding features of magnetic-tape recording—such as permanency of record without deterioration, simplicity of editing, and re-use of the medium, have been amply covered in previous literature.

Recorder Details

The electronic system consists of four plug-in chassis units: the power supply, a relay chassis for controlling all operations, the recording amplifier, and the playback amplifier. The input of the recording amplifier and the output of the playback amplifier are 150 or 600 ohms. The whole chassis assembly is resiliently mounted.

The power supply consists of a 360-volt plate-voltage source for the erase, bias, and playback output tubes, and a regulated 300-volt supply for the recording and playback amplifiers, the oscillator, and erase and bias screens.

Fig. 1. Author Lindsay takes some measurements on the Ampex tape recorder.

*Engineers, Ampex Electric Corp., San Carlos, Calif.

In addition, there is a d-c filament supply for the playback amplifier, a 36-volt a-c output to provide—through a selenium rectifier—24 volts d-c for all relays and selenoids, and filament supply for all tubes.

The essential problem in the recording amplifier is to convert the signal voltage into proportional current in the head. This is accomplished by the circuit shown in *Fig* 2. A 6AC7 was chosen for the output tube because of its high mutual conductance. The current output of this tube is further increased by a transformer. The secondary current is fed back through the cathode of the output tube. This assures that the current through the recording head is proportional to the signal voltage and is free of distortion. Ample undistorted recording current is provided for any of the commonly-available tapes under any desirable mode of operation.

The design of erase and bias circuits is extremely critical from the standpoint of achieving the lowest possible tape noise. With a properly-designed system, the residual tape noise caused by erase and bias currents will be below that of the playback amplifier. It has been found that the quietest erasure can be made by placing the entire roll of tape in a powerful gradually-decreasing 60-cycle field. The erase and bias currents in the recorder should not measurably increase the noise level of the tape above that obtained by this type of tank erasure. This result is achieved

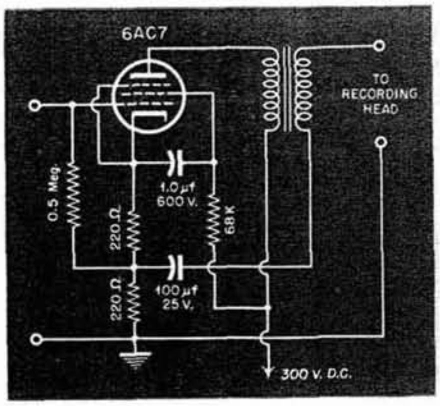

Fig. 2. Circuit of the output stage of the recording amplifier. Current feedback arrangement shown here contributes to proportionality of head current.

by proper design of heads and excellent current waveforms.

The actual setting of the bias is not critical as the same undistorted output is obtained (4 per cent intermodulation distortion) over a wide variation in bias current once a definite minimum value is exceeded. Over-all sensitivity is reduced with higher bias, as it takes greater recording current to supply the same output, but since the recording amplifier has ample capacity this is of no consequence. The bias is normally set slightly above that value giving maximum output for constant recording input and thus is conveniently set by ear. At lower tape speeds the bias setting becomes more critical, as high values of bias reduce the high-frequency response.

There is one bias setting which, at first, seems very attractive. It usually occurs at a value of bias just below the current giving maximum response, and results in a dip in the over-all intermodulation distortion. The setting is quite critical, but, for the same limiting distortion, 8-db higher output can be obtained. Because of this apparent increase in dynamic range, the bias was always adjusted to this value during the early stages of this development. However, it has since been discovered that this setting results in a poor overload characteristic. When A-B tests were made it was found that, at the point where differences between program and reproduction could be detected, the output level was higher with the higher bias current in spite of the fact that the critical setting resulted in 8-db higher measured dynamic range. Therefore, the dip setting was abandoned.

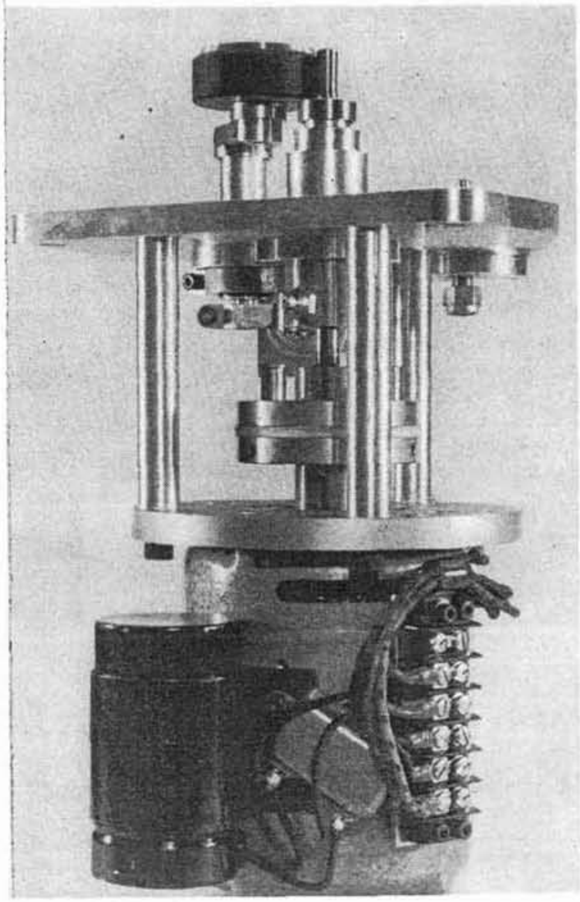

Fig. 3. View of units suspended from top plate shows rewind assembly, left rear, capstan drive, center, and takeup assembly, right rear. Brakes can be seen below both turntable drives.

Playback Noise

The main problem on playback is to obtain best signal-to-noise ratio. The maximum signal obtainable from a given design of playback head is limited by capacitive loading of the head at high frequencies. Therefore, the maximum number of turns is placed on the head for which loading does not occur within the desired frequency range. Because of the tremendous amplification required for the low frequencies, great care has been taken to eliminate hum pickup. The playback head is contained in two mu-metal shield cans with a copper can in between, and the entire head placed in a cast-iron head housing. Matching caps cover the front of the playback head when the head gate is closed into the playing position. Direct current is used on tube filaments to eliminate hum from this source.

Wide-range frequency response is not a problem at 30 inches per sec., as 15,000-cps response is readily obtained at lower speeds. However, considerable equalization is necessary to achieve flat response because the voltage induced in the playback head is proportional to frequency and because of demagnetization effects in the tape at shorter wavelengths. For maximum signal-to-noise ratio, the recording current must be equalized to provide equal probability of overload at all frequencies. The exact nature of this equalization requires careful study as the energy distribution of program material may vary widely with different types of pick-ups. This problem has now been studied for a considerable time and it has been found that the low-frequency end can be boosted 5 db at 50 cps with a 50-microsecond pre-emphasis on the high end without overload under a wide variety of program material. The playback amplifier is equalized to provide flat over-all response.

Tape Types

Several varieties of tape are now available in this country. In general, the lower-force tapes have proved most satisfactory for broadcast applications because they are easier to erase and more quiet, and have lower modulation noise. Tapes in this category are made by Audio Devices, Inc., and Minnesota Mining & Mfg. Co. (Type RR). Type RR is outstanding because of its uniform coating which results in low modulation noise and extremely uniform magnetic properties and output. In the latter property, this tape surpasses samples obtained from Germany where this method of recording saw its early development.

Higher coercive-force tapes, such as Minnesota Type A or Type B, have 10-db higher output for the same distortion but also have greater modulation noise and are difficult to maintain quiet. A great deal of research is being conducted to improve tape characteristics further and promising results have already been obtained. They indicate that the dynamic range of the medium will continually improve.

Tape Speed

Use of the 30-in. speed warrants some justification. Very excellent results have been obtained at half this speed. In fact, it is possible to obtain flat response to 15,000 cps with the same intermodulation distortion and unweighted noise level as quoted for the 30-in. speed. To obtain 15,000-cps response requires 15-db additional gain at 10,000 cycles in the playback amplifier, which brings up the hiss level and harmonic distortion accordingly. The measured noise level is not increased because the noise in the system consists primarily of low-frequency components and at 30 inches per sec. the hiss level is more than 15 db below the components which produce the noise reading. While it is still impossible to distinguish recorded material from the original in A-B tests at 15 inches per sec., the higher hiss can be detected on the reproduction during quiet passages when monitoring at original orchestra level.

Because of the higher noise level and harmonic distortions, it is not practical to make re-recordings at the lower speed as these deficiencies are doubled in the copy. Therefore, for the highest-quality recordings which can be re-recorded without detectable deterioration, 30 inches per sec. is indicated as the best choice.

Further advantages of the higher speed are as follows:

a. *Extremely low hiss level.* Although the measured noise level is the same as at 15 inches per sec., because of the ear characteristic at low levels, the noise background actually heard on programs is predominantly tube and tape hiss. Therefore, at 30 inches the "listening" dynamic range is considerably greater.

b. *Ease of editing.* At 30 inches, it is possible to remove syllables from words or clicks and pops from a recording without disturbing the actual program. This would be difficult or impossible at lower speeds.

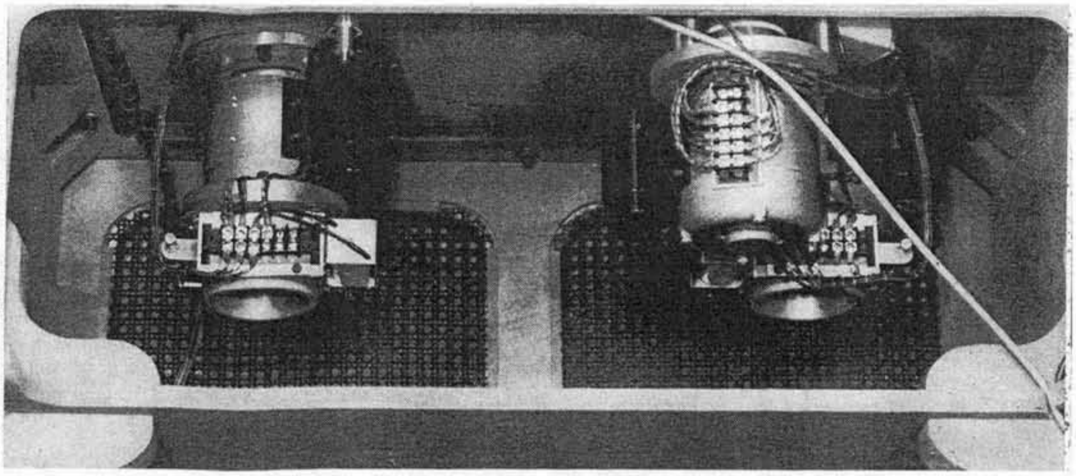

Fig. 4. Capstan drive includes resilient coupling, above motor, and crank-actuated idler which presses tape against driving shaft, above top plate. Assembly is adjustable for tape alignment.

c. *Uniformity of frequency response.* At extremely short wavelengths the response of tape varies considerably between rolls and even within a single roll. At 30 inches, the shortest wavelength used is still long enough not to exhibit these inconsistencies. This is proved by the fact that all available tapes, though varying greatly in magnetic properties, give exactly the same frequency response with no change in equalization at 30 inches per sec.

d. *Independence of bias setting.* As explained above, the bias setting is not critical and at 30 inches high values of bias do not affect the high-frequency response. At shorter wavelengths the bias tends to erase high frequencies and it is necessary to set the bias more critically.

e. *Greater stability of motion.* The 30-inch speed contributes greatly to the achievement of a steady tape motion, resulting in undetectable wow and flutter content even in the most susceptible program material.

f. *Head alignment less critical.* In order for recordings made on one machine to play back on another without losing high-frequency response, all the gaps of recording and playback heads must be very critically aligned perpendicular to the tape. The higher the speed the less critical is this adjustment. At 30 inches, there is little danger of heads becoming misaligned as they wear.

Mechanical Features

A synchronous drive with very positive tape coupling characteristics gives playback time reproducible to 0.5 sec. per half hour of program time. This permits, in broadcast operations, the use of machines in close synchronism in pairs, to afford complete program protection.

That the handling of the necessarily substantial quantities of tape required for high-quality performance might be sufficiently convenient to satisfy practical requirements, very high rewind and fast-forward modes of operation have been provided. These speeds have been made as great as possible without exceeding the maximum safe operating tension for the tape during acceleration and without reaching temperatures when passing over tape guides that would cause thermoplastic deformation of the tape.

Total rewind time for 36 minutes of program material is approximately 1 minute, 45 sec. This same rate of speed is available as the fast-forward mode of operation and is particularly useful where it is required to pick up selections within a program. During these high-speed functions the tape will, at times in its transport from one reel to another, acquire velocities of about 760 inches per sec. Stopping the tape, reels, turnables, etc., when traveling at these speeds requires very effective and consistent brakes. They are capable of making a stop from maximum reeling speed in 5 sec., or from normal playing speed in 0.2 sec.

The drive system consists of a removable supply and take-up reel, each mounted on a turntable carried on the vertically-extending shafts of the rewind and takeup drive assemblies; a capstan-drive assembly with its tape-locking idler; a reel idler; and compensating tension arms.

On the German Magnetophon, tape was reeled onto plain hubs without side flanges and was thus removed from the equipment as a solidly-packed self-supporting roll. In the design of the Ampex machine it was necessary to take into account the fact that the reels were to hold over 50 per cent more tape than Magnetophon reels and would consequently be much less safe to handle as self-supporting rolls. Accordingly, tape is handled on reels consisting of a plastic hub (4-in. diam. by 3/8-in. thick) mounted on a single 14-in. diam. (0.050-in. thick) aluminum flange — providing, when wound to within 3/8 in. of full diameter, storage space for 5400 ft. of 0.002-in. thick recording tape—36 min. of continuous program time.

In operation on the recorder, these reels are placed on turntables carrying a central extended centering-spindle and three equally-spaced drive pins. The centering spindle is somewhat longer than the drive pins to facilitate centering and positioning of the reel. The hub carries three equally-spaced 5/8-in. diam. holes, each centered with respect to a corresponding flange-drive-pin (3/16) hole. A radially-placed tape-measure slot 3/32-in. wide connects each of the 5/8-in. diam. hub holes with the hub periphery.

In threading, the tape is held between thumb and index finger to form a short narrow loop, the short end of which is next to the hub, and inserted through a hub slot and over a drive pin to form a hitch. This threading hitch is rapidly done and is self-freeing on runout.

While this type of reel does not require a hold-down device, editing knobs are provided. They slip on the portion of the spindle projecting through the reel hub and are pin-keyed to the hub for manual reeling of tape in editing and threading.

Drives and Brakes

The rewind, or supply-reel assembly, located to the left rear of the top plate of the recorder, is illustrated in *Fig.* 3. It consists of a specially-designed vertically-mounted ballbearing two-phase capacitor-type induction motor with double shaft extensions and flanged end bells. Electrical design of the motor is such that the maximum torque is developed at or near zero speed to effect a uniform tape tension throughout the reel. The upper flange serves as a means of attachment to the supporting structure while the lower flange carries the brake assembly.

Brakes are spring-applied and solenoid-released external-band-and-drum type, the drum being carried on the lower motor shaft extension. The brake design has been worked out to effect a differential braking ratio of approximately 2:1, using the self-energizing effect of band wrap. Rewind and take-up assemblies (which are substantially identical otherwise) are arranged so their brakes are self-energizing in opposite directions of rotation and in such order that regardless of which direction the tape is traveling, the reel supplying the tape will always receive the stronger braking action.

Obviously the brakes must operate in unison and this is assured by the solenoid control, which when combined with the differential action, provides a braking system allowing rapid stops without tape being broken or snarled from the throwing of slack loops. The spring-energized brakes offer considerable advantage here over the use of dynamic braking. Reels are not too free to turn but offer some resistance to the removal of tape. This is particularly important when the machines are used in remote operation where, at rest, the tape will not lose tension and stall the machine through operation of the tape-runout switch associated with the takeup tension arm.

The function of the capstan-drive assembly shown in *Fig.* 4 is to maintain constancy of tape speed during recording and playback operations. This is effected by the use of a synchronous motor driving, through a mechanical filter system, a precision-ground capstan shaft. This runs in precision bronze sleeve bearings, grooved and graphited and provided with a generous lubricating system. A close-coupled non-slip drive from capstan to tape is obtained by clamping the tape between a rubber-tired ball-bearing idler and the capstan surface. The idler is carried on the end of a bell-crank arm and is solenoid operated.

Including synchronous motor, capstan shaft and housing, capstan idler with bearings and linkages, solenoid, motor capacitor, and terminal strip, the complete assembly is mounted on a common base plate. This is suspended on the under side of the main top plate with spring-loaded spherical-cone joints arranged for critical adjustment of tape tracking.

On either side of the centrally-located head housing are the tension arms. The one on the left is associated with the reel idler while the right-hand arm is combined with a cutoff switch. The spring-loaded tension arms serve to momentarily equalize sudden changes in tension during starting or stopping and the lesser fluctuations resulting from the passage of a splice. They also preserve tension on the tape while the equipment is at rest.

Maintenance

Ease of servicing and maintenance has been provided in the arrangement of the functionally-styled front-access-type console. Further, the general design facilitates simple removal of units for replacement by spares. All chassis units are withdrawn from their plug-in connections and replaced by the combined action of a special leadscrew and crank. The complete head housing is also of plug-in design—held in place by a pair of crank-operated screws.

Fig. 5. Closeup of chassis units shows plug-in arrangement with leadscrew and crank for insertion and removal. Entire base plate is shock and vibration-mounted.