SERIES 351 EQUIPMENT

SECTION 3

OPERATION

GENERAL

The 351 Series recorder/reproducers are available for full (single) track, half track or two track stereophonic operation. All operating controls are located on the tape transport with the exception of the record control which is on the front panel of the electronic assembly. When the remote control unit is furnished, duplicate tape motion controls, a RECORD button and RECORD INDICATOR light and a TAPE MOTION indicator light are mounted on the remote unit.

The equipment can handle the NAB 10-1/2 inch diameter tape reels or the EIA 5 and 7-inch reels. Provision is made for selection of proper tape tensioning at the REEL SIZE switch on the tape transport for the LARGE or SMALL size reels.

Either of two capstan drive motor speeds can be selected at the LOW-HIGH TAPE SPEED switch which is also on the tape transport.

On the front panel of the electronic assembly are facilities for setting RECORD LEVEL and (reproduce) PLAYBACK LEVEL, selecting LOW SPEED or HIGH SPEED EQUALIZATION, selecting three input arrangements by means of the INPUT TRANSFER SWITCH, and switching the vu meter at the METER and OUTPUT switch so that (reproduce) PLAYBACK, RECORD, BIAS and ERASE LEVEL(S) can be read. A phone jack (PHONES) for monitoring, a RECORD button, a RECORD INDICATOR light, and a POWER OFF-ON switch are also mounted on the electronic assembly front panel.

Another MONITOR AMPLIFIER phone jack and a line termination (LINE TERM) OFF-ON switch are located on the back of the amplifier-chassis.

SUMMARY OF CONTROLS, SWITCHES AND INDICATORS

Item	Schematic Reference Symbol	Location	Function
POWER OFF-ON SWITCH	S-5	Electronic Assembly front panel	Controls power to the electronic and mechanical assemblies. When power is on capstan will rotate if tape is properly threaded or the safety switch de-activated. The v-u meter lamps light when power is on, and are unaffected by the safety switch, remaining lighted till the power is turned off. For stereophonic 351-2 operation POWER switches of both electronic assemblies must be in the ON position.

Item	Schematic Reference Symbol	Location	Function
TAPE SPEED	S503	Tape Transport control cluster	Determines speed of the capstan drive motor by high or low speed winding. Used in conjunction with EQUALIZATION switch S2.
EQUALIZATION LOW SPEED HIGH SPEED	S2	Electronic Assembly front panel	Used to select appropriate equalization circuitry for tape speed chosen.
REEL SIZE LARGE SMALL SWITCH	S504	Tape Transport	Adjusts tape tensioning circuitry for the reel size used. The switch is closed when (LARGE position) NAB 10-1/2 inch reels are used. In the SMALL position the switch is open, connecting resistance R502 with the torque motors, thereby reducing holdback tension.
METER AND OUTPUT SWITCH	S3	Electronic Assembly front panel	Provides a means for switching the meter to read indications of record input, erase and bias, and reproduce output. In the reproduce (PLAYBACK) position, the meter indicates the signal level at the secondary of the output transformer. In the RECORD position the meter indication shows a flat amplifier reading of the input signal.
RECORD LEVEL	R9	Electronic Assembly front panel	Adjusts record level.
PLAYBACK LEVEL	R36	Electronic Assembly front panel	Adjusts reproduce level.
VU METER	M1	Electronic Assembly front panel	Provides a means for visually monitoring record input level, reproduce level, and bias and erase.

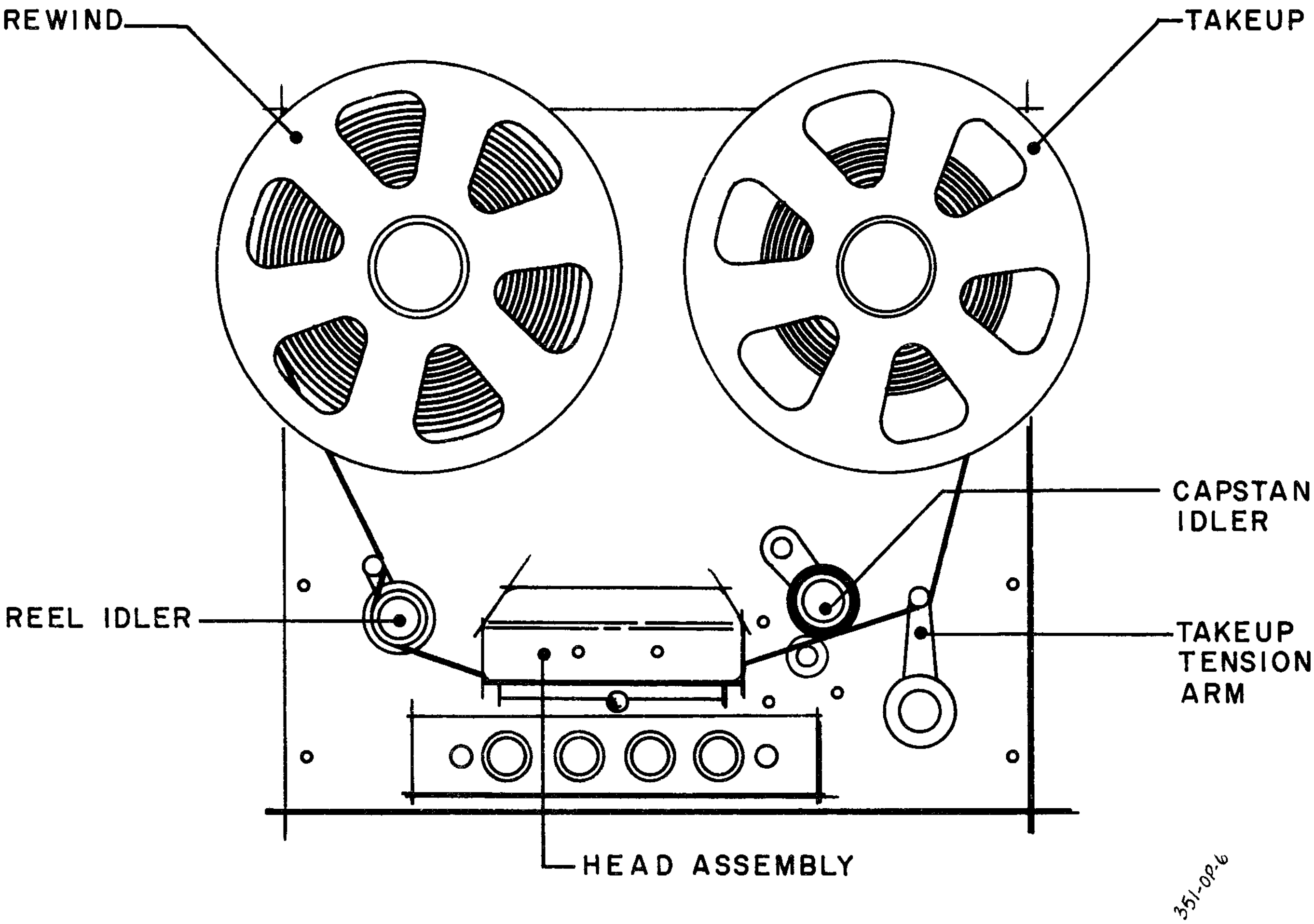
Item	Schematic Reference Symbol	Location	Function
INPUT TRANSFER SWITCH	S1	Electronic Assembly front panel	Provides a means for selecting the appropriate input circuitry to record with a microphone or from a balanced or unbalanced line.
LINE TERM OFF ON	S4	Electronic Assembly back panel	Controls output termination of the reproduce amplifier. In the ON position a 560 ohm resistor is across the output. In the OFF position, the resistor is out of the circuit and the amplifier must then feed a 600 ohm device.
PLAY button	S505	Tape Transport Control Cluster	Controls tape motion in the reproduce (PLAY) and record modes. Interlocked with rewind and fast forward modes.
RECORD button	S6	Electronic Assembly front panel	Controls the record relay in the electronic assembly. Power is connected to the bias oscillator when this button is depressed. PLAY button must be depressed to put the tape in motion before the record button is used.
REWIND button	S507	Tape Transport Control Cluster	Controls the rewind relay. Full a-c power is connected directly to the rewind (supply) motor when this button is depressed, and resistance R504 is placed in the a-c circuit to the take-up motor.
FAST FORWARD button	S506	Tape Transport Control Cluster	Controls the fast forward relay. Connects full a-c power to the take-up motor and places resistance R504 in the a-c circuit to the rewind motor when this button is depressed.
STOP button	S502	Tape Transport Control Cluster	When this button is depressed, the brake solenoids and all relays are deenergized.

OPERATING TECHNIQUES

Threading the Tape

Thread the tape as shown in the illustration. Unwind and inspect all new factory wound reels of tape by running them through in the FAST FORWARD mode.

New tapes are usually looped to the hub in such a manner that the tape will not come free of the reel at the end. This will prevent the safety switch (S501) from disengaging the capstan idler from the capstan which results in a flat being worn on the capstan idler wheel. (Any adhesive material accumulation on the reel hub may also keep the tape from coming free at the end of the reel, and should therefore be removed with solvent.)



TAPE THREADING PATH

Power

Power is supplied through power switch 4S5, which must be turned on to operate the electronic and mechanical assemblies. The mechanical assembly and electronic assembly are individually fused by the 3 ampere control circuit fuse 5F2 and the 1/2 ampere electronic fuse 5F1.

Speed switches

There are two switches associated with operating speed. The tape speed switch S503 determines the speed of the capstan drive motor, and the equalization switch 4S2 changes the equalization in the amplifiers appropriately.

Tape Motion

The tape motion is controlled by means of four pushbuttons labelled REWIND, FAST FWD, STOP and PLAY.

PLAY OR RECORD

The tape is set into play motion at the speed selected by the tape speed switch when the PLAY button S505 is depressed. The tape must be completely stopped before starting in this mode. To change from play to the record mode with the tape in motion, press the record button 4S6 on the electronic assembly.

STOP

To stop the tape while it is moving in any mode, press the STOP button S502. The equipment will stop automatically if the tape breaks or runs off either reel.

FAST FORWARD

The equipment can be started in fast forward or switched to fast forward from any of the operating modes by simply depressing the fast forward button S506.

REWIND

The equipment can be started in rewind or switched to rewind from any of the operating modes by simply depressing the rewind button S507.

NOTE

In using either the fast forward or rewind mode, it is desirable to remove the tape from direct contact with the heads by opening the gate of the head assembly. This will reduce wear on the heads and prevent the oxide coating on the tape from depositing on the heads and impairing their performance.

Editing and Cueing

Indexing the tape as in editing or cueing, or when approaching the end of the reel, is simplified by holding down a combination of buttons. Tape motion can be reduced to a slow creep by holding down the fast forward and rewind buttons simultaneously, and then alternating between the two to control tape direction. When the desired point is reached, the STOP button must be held down until the other buttons are released.

CAUTION

Never press the STOP and PLAY buttons in rapid sequence when the tape is traveling at high speed in the rewind or fast forward modes. This will almost invariably break the tape since it does not allow sufficient time for the tape to stop before the Capstan Idler locks it to the Capstan.

Reproduce (Playback)

To reproduce a previously recorded tape, turn the METER and OUTPUT SWITCH 4S3, to the extreme left position designated PLAYBACK LEVEL, then start the tape in motion as indicated under PLAY. A PLAYBACK LEVEL Control 4R36 has been provided on the front panel to adjust the tape level to plus 8 vu output (zero on the vu meter).

Record

To record a new program on previously recorded tape, or on blank tape, turn the METER and OUTPUT SWITCH 4S3 to the second position from the left which is designated RECORD LEVEL. Turn the RECORD LEVEL CONTROL 4R9 clockwise until the level reads 0 (zero) on the vu meter on the most intense program peaks. The program can be audibly monitored through either the phone jack (PHONES) 4J6, Monitor 5J4, or the line out connector (LINE OUTPUT) 5J5 before the tape is in motion. This direct monitor feature allows the program to be set up through the machine without actually recording during the set up period.

NOTE

For correct meter calibration it is important that the line out be properly terminated in a nominal 600 ohms either external to the machine or by the use of the line out termination switch (LINE TERM) 5S4.

When the program level is properly set, open the head gate and start the tape in motion as indicated under PLAY. Then push the RECORD BUTTON 4S6 and close the head gate. This procedure results in minimum transients during the start of recording. The record indicator 4I1 next to the record button will now glow and the equipment is recording.

The erase position of the METER and OUTPUT SWITCH provides for metering of erase current. The erase current is not critical and has been factory adjusted to read approximately -1/2 on the vu meter for half track and stereophonic heads and +1 for full track heads. Both the erase and bias current will vary directly with line voltage. The bias current is more critical and is factory set to read zero at 117 volt line voltage, using an average tape. It should read between -1/2 and +1/2 for the optimum high frequency response at 7-1/2 and 3-3/4 inch tape speeds using a median tape. For the flatest possible response with a given tape, the bias can be reset as described in Section 5 ALIGNMENT AND PERFORMANCE CHECKS. Note the bias current reading for this particular tape and log it for future reference.

The bias is adjusted by means of the Bias Control R460, located on the electronic chassis. The meter calibration for bias measurement can be checked as indicated in SECTION 5.

CAUTION

While in the record mode during stereophonic operation always bring the tape motion to a stop before depressing either the FAST FORWARD or REWIND buttons.

Half Track Operation

The tape is threaded and operated as described under TAPE THREADING and TAPE MOTION. However, only the upper half of the tape will be used on the half track equipment. To utilize the lower half of the tape, the full reel on the takeup turntable should be removed, turned over and placed on the tape supply turntable upside down. Place an empty reel on the takeup turntable. Repeat the operation as performed on the first track.

Remote Control

For remote operation, remove the dummy plug P502P from the receptacle J502S on the control box of the tape transport and connect the remote control cable from J502S to the remote control unit (see INSTALLATION -- REMOTE CONTROL).

Notes on Stereophonic Operation

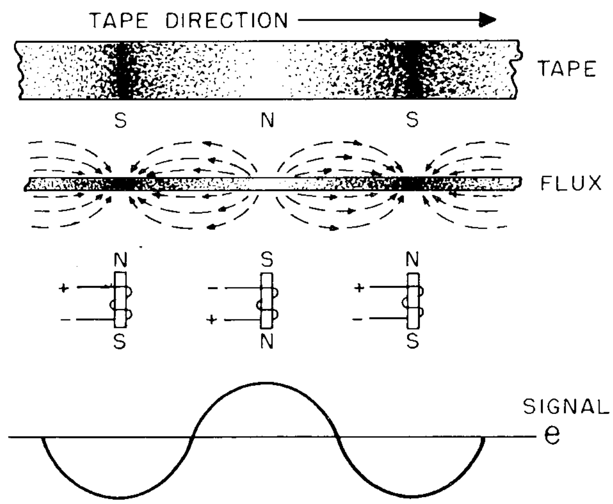
Because the stereophonic equipment has a separate erase feature, permitting either track to be erased independently of the other, it is necessary to depress the RECORD buttons on each amplifier to place both amplifiers in the record mode.

When using the remote control unit the single RECORD button will energize both electronics (concurrent record feature).

THEORY OF MAGNETIC TAPE RECORDING

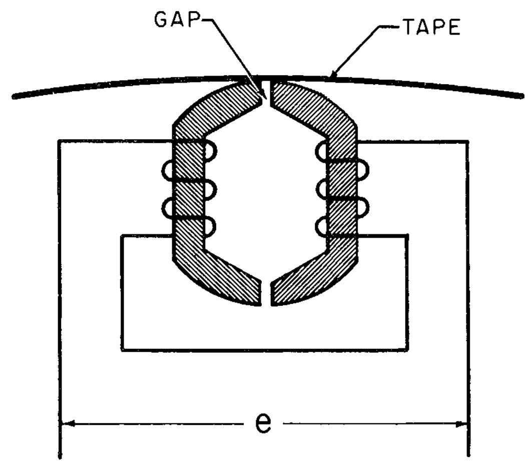
If a material capable of being magnetized is placed in the proximity of a magnetic field the molecules of that material will be oriented according to the direction of the field. Any of several methods may be used to produce a magnetic field, but of most interest in magnetic recording is the field produced by a current flowing through a coil of wire. The current itself may be derived from a transducer such as a microphone which converts the mechanical energy of sound to electric current.

Magnetic recording tape consists of finely divided iron-oxide particles deposited upon a plastic backing. During the recording process this tape is moved through a magnetic field in which the magnetizing force is alternating , and the iron oxide particles are aligned according to the instantaneous direction and magnitude of the field.



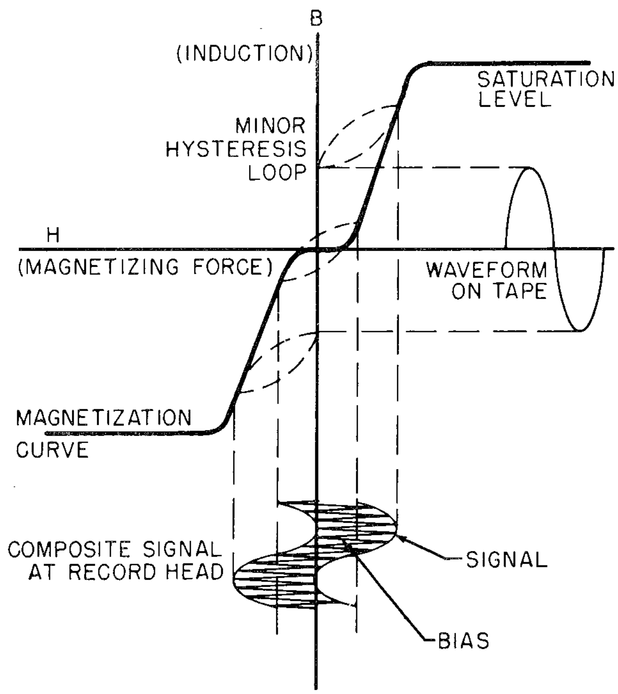
MAGNETIZATION OF TAPE

The magnetic field is produced in the gap of a recording head (which is essentially an electromagnet), over which the recording tape passes. The head consists of an incomplete ring of highly permeable material inserted in a coil of wire. The discontinuity in the ring forms the gap, and the ring itself is the core of the electromagnet. The recording head and its gap thus constitute a series magnetic circuit.



RECORD HEAD

The magnetization curve of the iron oxide used as the recording medium is similar to that shown as the heavy line in the illustration below.



RECORDING MEDIUM MAGNETIZATION CURVE

At points near the origin the curve is extremely non-linear and, without some corrective factor, the signal recorded on the tape would not be directly proportional to the signal applied to the head, resulting in a high degree of distortion when the tape was reproduced. This distortion is greatly reduced by mixing a high frequency, constant amplitude, bias signal with the actual signal being recorded, so that operation is obtained on the linear portion of the curve. This may be likened to applying a d-c bias to a tube to force it to work on the linear portion of its curve. The bias signal is generally selected to be at least five times the highest frequency to be recorded so that no beating will occur between the bias frequency and the harmonics of the recorded signal.

While the tape is in the recording gap the bias causes the magnetization characteristics of the iron oxide to follow the dashed line loops known as the "minor hysteresis loops." As the tape leaves the gap the influence of the magnetic field created by the bias is reduced to zero and the tape assumes a permanent state of magnetization (known as "remanent induction") determined by the gap flux at that time.

After the recording process there exists on the tape a flux pattern which is proportional in magnitude and direction to the signal recorded. If the tape is then moved past a reproduce head -- which is similar in construction to the record head -- the magnetic flux on the moving tape will induce a voltage in the coil of the reproduce head. This induced voltage is proportional to the number of turns of wire on the head and the rate of change of flux. This is expressed by the equation $E = N (d\phi/dt)$

Where

E = induced voltage
N = number of turns of wire
$d\phi/dt$ = rate of change of flux

It is desirable that the gap in the reproduce head be as small as possible so it will intercept less than one wave length of the signal on the tape at the highest frequency to be reproduced. However, as the gap is made smaller the induced voltage decreases, so there is a practical limitation in decreasing the gap and still maintaining an adequate signal-to-noise ratio.

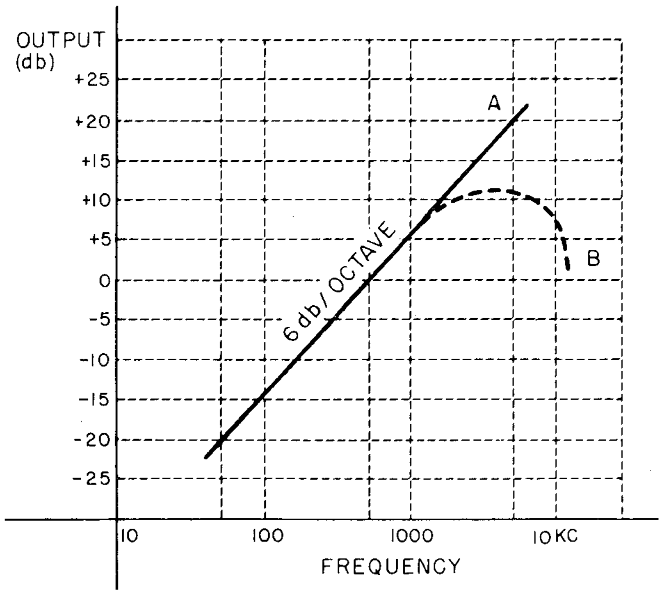
The voltage induced in the reproduce head during reproduction is computed by the equation

$$E = B_M \, V \, \mathrm{SIN} \, \pi \omega / \lambda$$

Where

E = induced voltage
B_M = maximum flux density of the recording material
V = velocity of tape over the head
ω = width of the gap
λ = wavelength of the signal on the tape

From this equation it can be seen that the voltage across the coil increases directly as the velocity increases and as the wavelength decreases (frequency increases). If the tape velocity and gap width are assumed to be constant, the output voltage from the head is directly proportional to the frequency as long as the wavelength on the tape is large compared to the gap width. This results in an output vs. frequency characteristic such as is shown in curve A of the figure below.



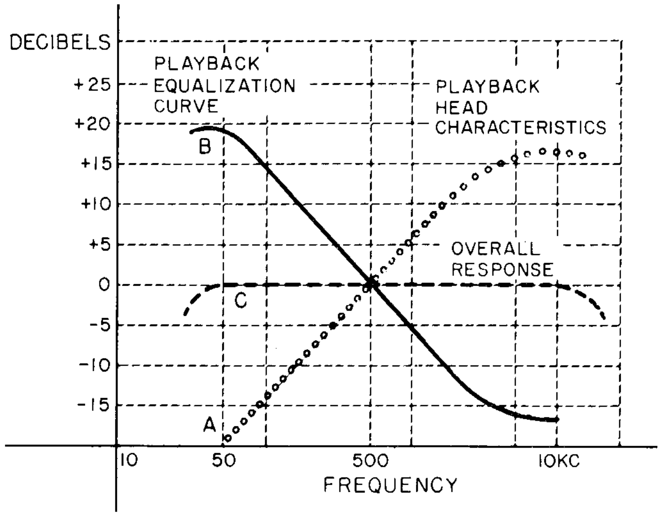
REPRODUCE HEAD CHARACTERISTICS

The voltage does not continue to rise indefinitely. As electrical losses in the core material increase and as the wavelength on the tape approaches the same dimensions as the reproduce head gap, the actual output resembles curve B in the same figure.

In order to provide an over-all frequency response that is flat (see the figure below) an equalization circuit consisting of a series resistance and capacitance is inserted in one of the early stages of the reproduce amplifier. This equalizing circuit has a high-frequency droop characteristic (curve B) which is the inverse of the reproduce head characteristic curve A of the above figure. In order to extend the high frequency response, additional equalization is included in the record amplifier in the form of a high frequency boost circuit designed to compensate for the droop in record and reproduce head characteristics caused by core losses, self-demagnetization of the tape at the short wave lengths and the wave length approaching the gap dimensions.

Disregarding the response of the associated amplifiers, the physical aspects of maintaining constant tape speed and good head-to-tape contact, and core losses in the head -- all of which can be placed at a high performance level by good engineering design -- there are certain inherent properties which define the frequency limits in recording and reproducing information on a specific magnetic tape recorder-reproducer. While these properties can be varied to meet differing requirements, the over-all result represents a compromise arrangement in which frequency response, signal-to-noise, and distortion are interrelated.

In this respect the high frequency response is primarily limited by the dimension of the reproduce head gap, and the frequency at which that head resonates with the capacity in the circuit.



ACHIEVING FLAT OVERALL RESPONSE

During the recording process the tape assumes a permanent state of magnetization as it leaves the head gap, thus the record head gap width is relatively uncritical. However, in the reproduce mode the magnetic flux on the moving tape must induce a voltage differential across the reproduce head coil if a current is to flow in that coil. This induced voltage is attained as the flux travels through each branch of the head core, forced into that path by the high reluctance of the head gap. Therefore, an instantaneous difference in the magnitude of the moving flux must exist across the head gap to cause the flux to travel through the core and magnetically induce a voltage difference in the head winding.

When the recorded frequency rises to a degree where the reproduce head gap intercepts a complete wavelength of the signal (as it appears on the tape) there can be no difference in flux magnitude across the gap, and head output will reduce to zero. This cancellation effect will occur at multiples of the represented frequency, and for all practicable purposes the output is useless.

There are two means of counter-acting this "gap effect" -- either the reproduce head gap width can be reduced or the record-reproduce tape speed can be increased. There are limitations in reducing the gap width and retaining adequate signal level and realistic manufacturing tolerances; as these limitations are reached any further extension of high frequency requirements must be accompanied by corresponding increases in record-reproduce tape speed. (In instrumentation applications it is also possible to record at a high tape speed and reproduce at a low tape speed, thus providing a signal expansion characteristic. For example, a 10 kc signal recorded at 7-1/2 ips, will reproduce as a 5 kc signal if the reproduce tape speed is 3-3/4 ips. This procedure of course cannot be used in standard audio applications where music or voice is recorded, and will result in the loss of the low frequency components of the signal.) Increasing the record-reproduce tape speed lengthens the wavelength of the signal as it appears on the tape, with the result that higher frequency wavelengths do not approach the gap dimension. (It also decreases the "self-demagnetizing" effect which occurs as the opposite poles of individual magnetic fields on the tape come closer and closer together.)

The resonant frequency of the inductance of the head coil and the capacitance -- either actual or distributed -- of its circuit must normally be either outside the pass band of the system (so the drop in output following the point of resonance will not adversely effect the frequency response) or so placed at the extreme upper limit so that the increased output at the moment of resonance actually provides an extended response. When good engineering design has reduced circuit capacitance to an irreducible minimum, the only means of placing head resonance at a higher frequency is to reduce the inductance of the head coil by reducing the number of turns of wire. This adversely affects the output over the entire frequency range, and will particularly influence the low frequency limit.

Low frequency response if primarily determined by the relationship of the required signal-to-noise ratio, the characteristic curve of the reproduce head, the distortion which can be tolerated, and the bandwidth which must be recorded.

As previously explained the output of a reproduce head rises directly with frequency at an approximate 6 db per octave rate. Stated conversely, the reproduce head output drops directly with frequency at an approximate 6 db per octave rate. The low frequency limit is determined by how far this decreasing output can be tolerated while maintaining an adequate signal-to-noise ratio. Thus, the noise generated by the associated electronic assemblies will have a definite effect on low frequency response. Increasing the record level to offset this decreasing output will eventually result in an increase in distortion.

Bandwidth is a determining factor in low frequency response because the 6 db per octave dropoff in reproduce head output normally starts at the highest frequency which must be reproduced, and is constant regardless of tape speed. Thus as the upper frequency requirement is extended, the lower frequency limit -- dictated by the required signal-to-noise ratio rises inexorably with it, octave for octave. A general rule is that the maximum bandwidth which can be effectively reproduced by any magnetic tape device is approximately ten octaves.

It should now be apparent that compromises are necessary in designing a magnetic tape recorded for a given purpose. If a high frequency requirement is imposed, then low frequency, signal-to-noise, or distortion must be limited (or perhaps a modulating-demodulating system employed which will effectively compress the bandpass requirements). Conversely, a low frequency requisite limits the high frequency response which can be obtained.