WS No. 19 Mark III

MAGNETIC TAPE RECORDERS

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Distribution—Class 353. Code No 2

INTRODUCTION

1. Although the principles of magnetic recording were outlined as early as 1888 and a simple machine applying them was devised by the end of the 19th century, it was not until the nineteen-thirties that recordings made on steel wire (and later on steel tape) came into commercial use, chiefly by broadcasting authorities. During the second world war thin plastic tape, coated with ferric oxide powder, replaced steel tape, and in the last decade magnetic tape has become the most widely used medium for recording sound (and even television programmes) in commercial broadcasting services and domestic circles.

2. The principle, however, remains essentially the same. The recording is made by passing a length of magnetic material across the poles of an electromagnet to the windings of which signal currents are applied. Whenever the magnetized material is again passed over the poles, currents are generated in the windings of the electromagnet which correspond to the original signal current.

3. Magnetic recordings may be erased by submitting the magnetic material to an intense magnetic field. The material may then be used again.

4. Standardization of tape width and speeds, direction of tape travel, methods of reeling and the dimensions of magnetic tracks, permit in most cases the interchangeability of recordings.

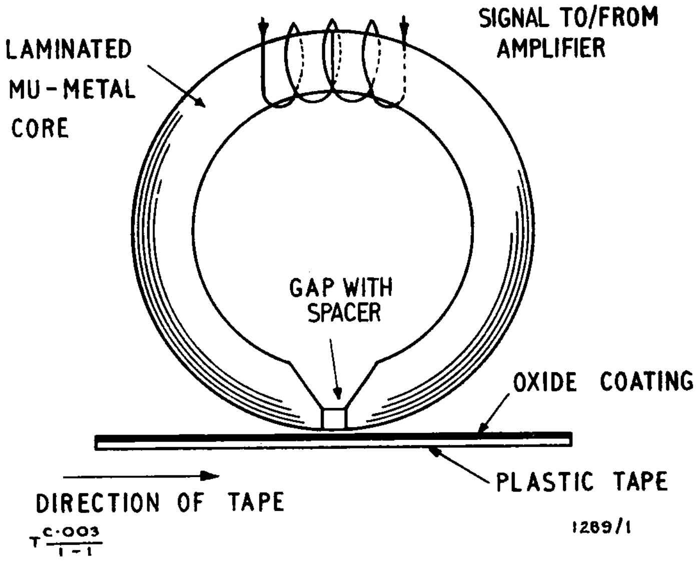

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Fig 1—Record/playback head—schematic diagram

MAIN COMPONENTS

5. Although the design of recorders can vary considerably, all have certain features in common. These may be grouped according to the main components in the following manner.

Magnetic tape

6. The magnetic tape consists of countless microscopic particles of ferric oxide powder evenly distributed in a binding substance to form a coating on the surface of a plastic ribbon or base. The manufacturing processes are strictly controlled to ensure uniformity of coating thickness and magnetic particle size throughout the length of tape, to minimize unwanted effects in reproduction such as amplitude variation and noise.

7. The tape, a ¼ in. in width, is accommodated on plastic or aluminium reels (similar to 8 mm motion picture type reels) of appropriate diameter depending on the length of tape required. A 7 in. diameter reel will accommodate 1200 ft of standard thickness tape and provides a (single track) playing time of 30 min at a tape velocity of 7½ in./sec.

Record/playback heads

8. A schematic diagram in plan of a record/playback head is shown in Fig 1. A laminated core made from a material that offers high permeability at low flux density, usually mu-metal, accommodates a winding. Laminations are kept as thin as practicable to reduce eddy current losses and hence improve high frequency response. Both core and winding are made in two halves, with the coil wound in a hum-bucking arrangement. The two surfaces of the core forming the gap are ground and then butted together with a non-magnetic spacer having a thickness of approximately 0·0005 in. Beryllium copper is normally used for this purpose.

9. The requirements of record and playback heads are very similar. Because of this, and for reasons of economy, a single or combined head is often used. This compromise, however, results in somewhat inferior performance. A further advantage of the use of separate heads is to permit monitoring of the recorded tape during recording, an essential requirement for studio equipment.

Erase head

10. Thorough erasure of the tape is necessary before it passes over the recording head. This may be done by saturation of the magnetic medium with a direct current or permanent magnet, but the method usually adopted is by h.f. current, using a similar head to that for recording but with a wider gap width (0·010 to 0·020 in.).

Tape transport mechanism

11. The tape drive mechanism draws the tape from one reel, feeds it past the magnetic heads at a constant velocity and then re-winds the tape on to another reel. In addition to this, facilities for fast forward wind and fast rewind of the tape are usually incorporated. These permit rapid location of a particular part of the recording and fast rewinding for subsequent replay or storage.

Recording and playback amplifiers

12. Two amplifiers are required, one to amplify the input signal (eg from microphone) to a suitable level for recording, the other to amplify the output from the magnetic head on playback to provide sufficient power to drive a loudspeaker or other reproducer. With the aid of switching to effect circuit changes, a common amplifier may be used, thus reducing the overall number of components required. This is not possible, however, when monitoring facilities of the recorded tape are required.

High frequency bias oscillator

13. An oscillator operating at a frequency between 40 and 90kc/s provides the necessary erase and bias currents required during recording.

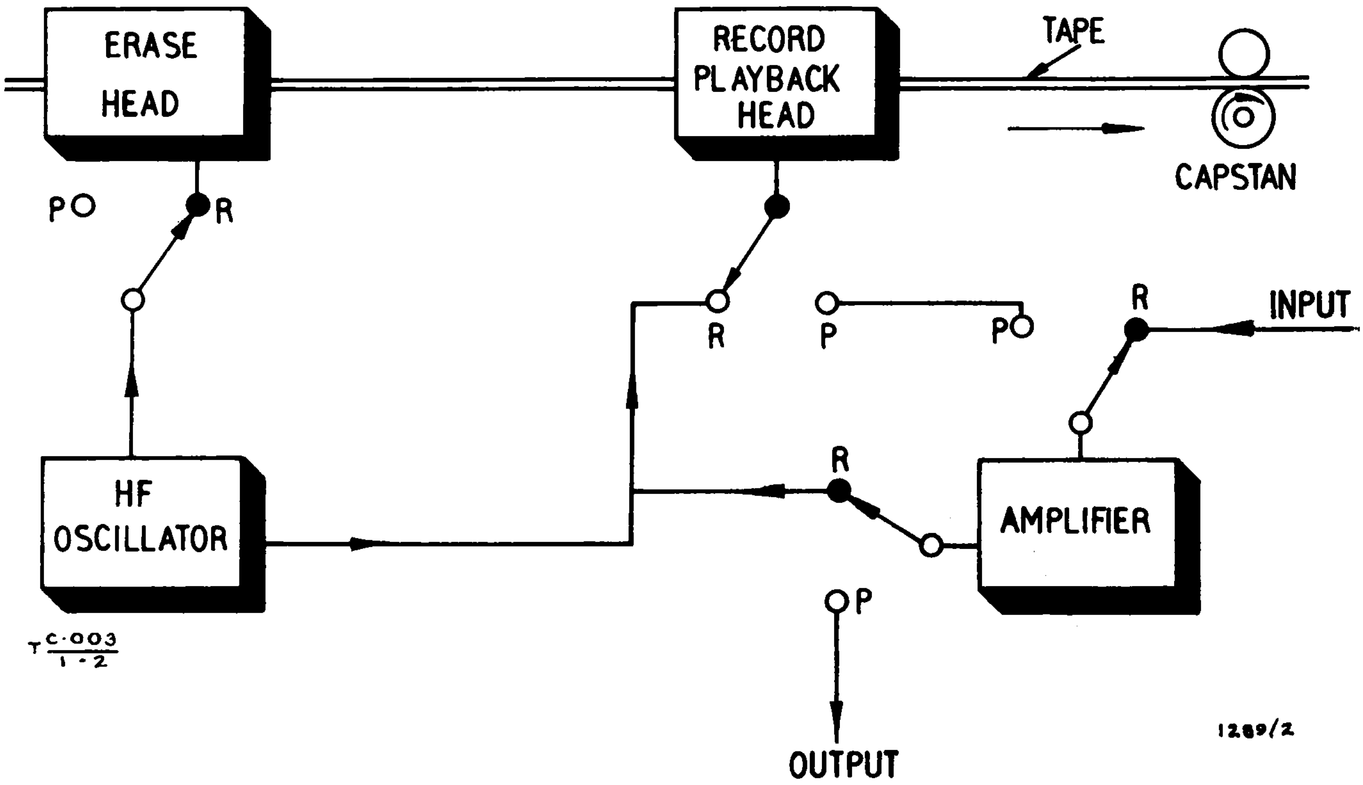

Fig 2—Simplified block diagram

PRINCIPLE OF OPERATION

14. Fig 2 shows a simplified block diagram of the main components of a typical recorder having a combined record/playback head and a common amplifier. The switching is shown in the record position.

15. During recording the magnetic tape is drawn past the erase head to remove any trace of previous magnetization, and then past the record/playback head where the bias and amplified signal currents in the coil generate magnetic fields which are impressed on the tape in the form of a magnetic pattern. On playback the bias and erase currents are switched off and the voltage induced in the record/playback head by the magnetized tape is applied to the amplifier input, the output from the amplifier being switched to the load.

MAGNETIZATION PROCESS

16. During recording the portion of the tape under the influence of the magnetizing field (H) in the gap will become magnetized and have a corresponding flux density (B) governed by the signal current. The 'magnetic record' stored is dependent on the remanence (Br) of the tape medium. The relationship between flux density and remanence is shown in Fig 3.

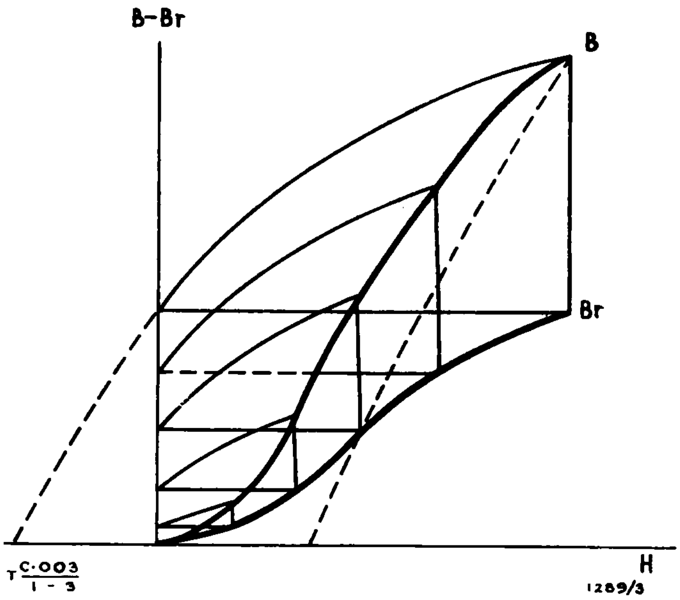

Fig 3—Relationship between B and Br

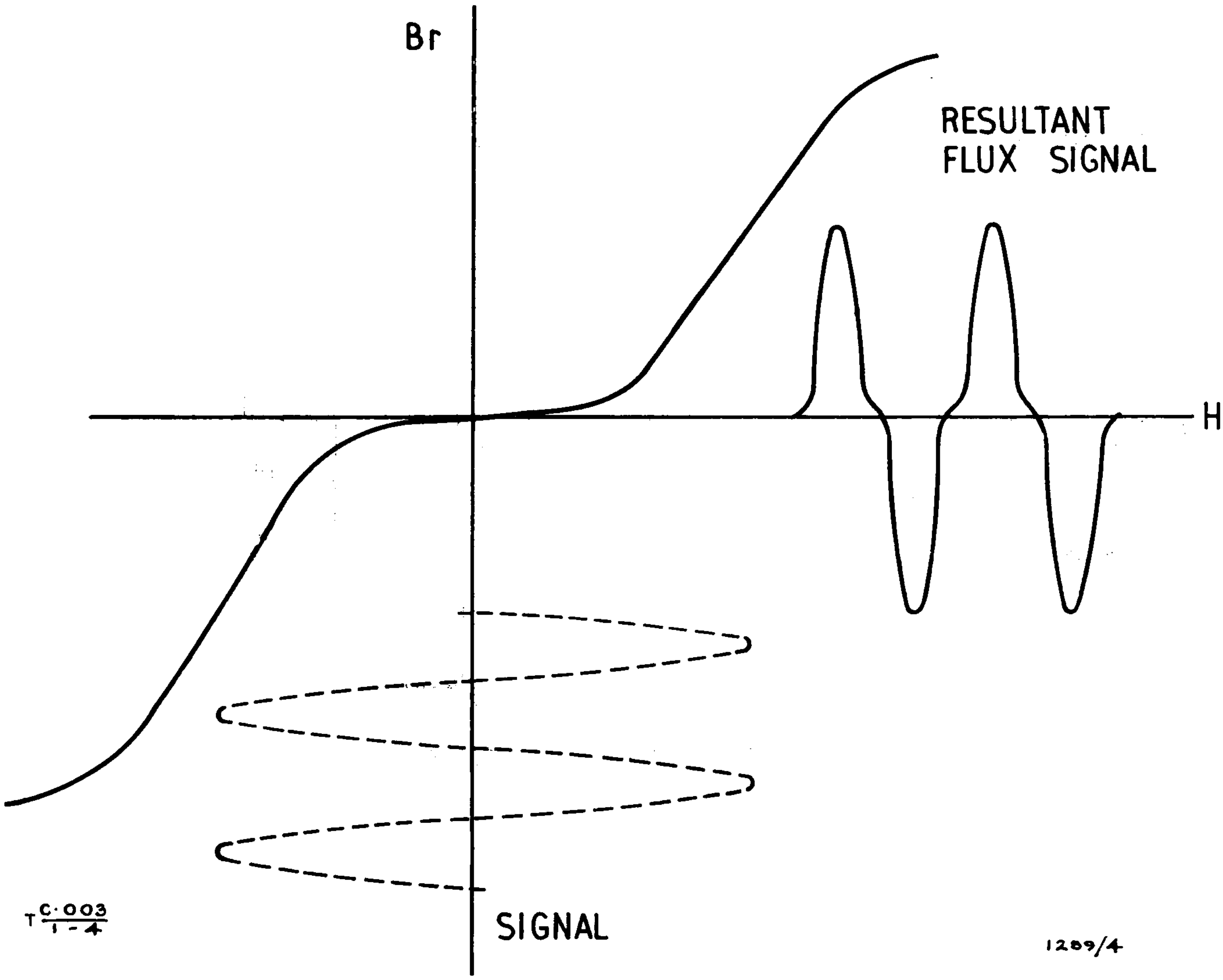

Fig 4—Resultant flux signal

17. Consider the tape to be passing over the gap at a constant velocity and a signal applied to the magnetic head. Then assuming the field does not vary perceptibly during the time taken for a magnetic particle of the tape to traverse the gap, there is a definite relationship between the magnetic field produced by the current in the recording head and the remanent magnetism imparted to the tape. Fig 4 shows the resultant flux signal produced by the application of a sinusoidal input. Severe distortion of the applied signal results due to the non-linearity of the lower region of the Br-H curve, especially under weak signal conditions.

High frequency bias

18. To minimize the effect of non-linearity in the tape magnetic characteristic, bias in the form of an h.f. current (usually between 40 and 90kc/s) is combined with the signal to be recorded. The action of this bias current in moving the operating point on to the substantially straight part of the Br-H curve is shown in simplified form in Fig 5. As a result the tape acquires a pattern of magnetization, the audio component of which corresponds quite closely to the waveform of the audio signal. Moreover, weak signals now operate upon a more steeply sloping portion of the Br-H curve, hence output obtained from weak signals on replay is greatly increased.

19. Fig 6 shows in simplified form the relationship between bias current, distortion and playback signal strength. It will be seen that an increase in bias produces a decrease in distortion and an increase in playback signal strength until the point where saturation occurs resulting in reduced output and increased distortion. Higher values of bias produce a relatively greater attenuation of the upper audio frequencies.

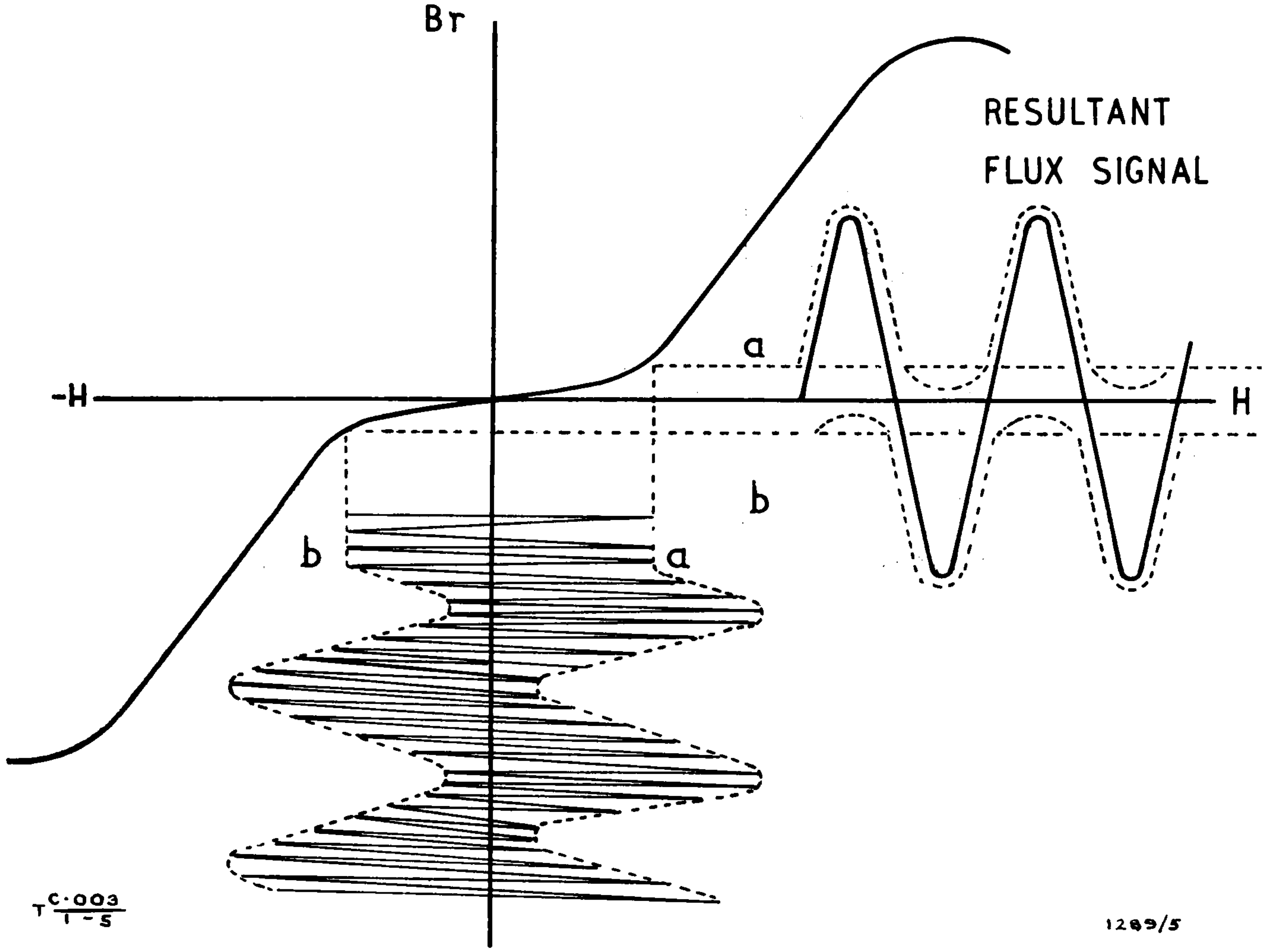

Fig 5—Action of h.f. bias

20. The frequency of the bias current is as a general rule at least five times the highest audio signal frequency being recorded. This is necessary to avoid unwanted beat notes arising between bias frequency and audio signal harmonics.

Erasure

21. One of the main features of magnetic recording tape is that after it has been recorded, the recording may be erased and the tape re-used an unlimited number of times.

22. The erasure takes place when the tape passes over the wide gap of the erasing head. Here a strong field is produced by an h.f. alternating current (usually 40 to 90kc/s and from the same source as the bias current). The tape in passing over the head reaches magnetic saturation when opposite the centre of the gap, when past the gap the magnetizing field gradually dies away over a number of cycles so leaving the tape demagnetized. Fig 7 shows the variations of flux density from saturation to zero. The corresponding variations of field strength plotted against time are shown in Fig 8.

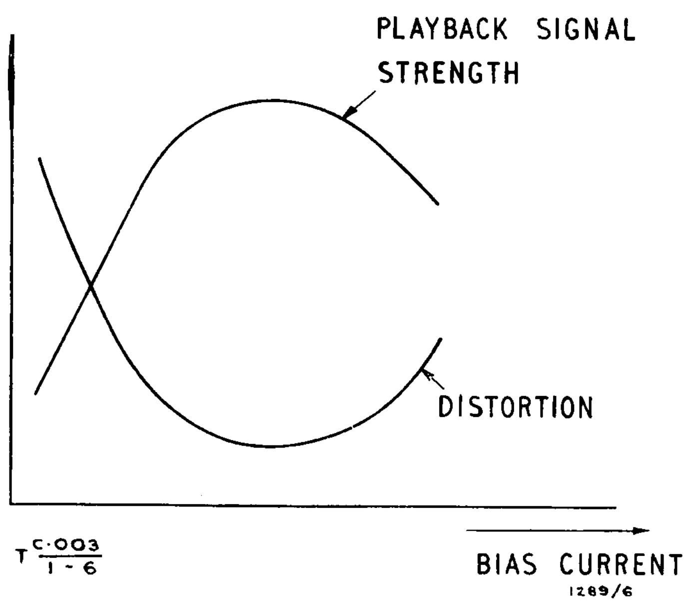

Fig 6—Effect of bias level on signal strength and distortion

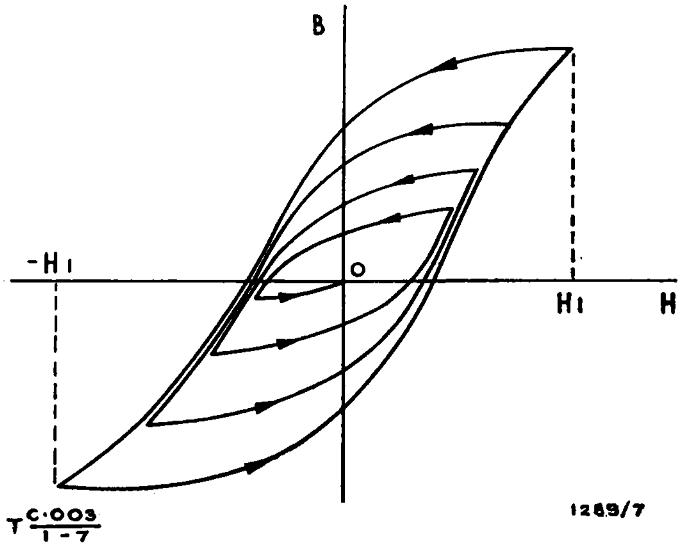

Fig 7—Variation of B-H curve during erase

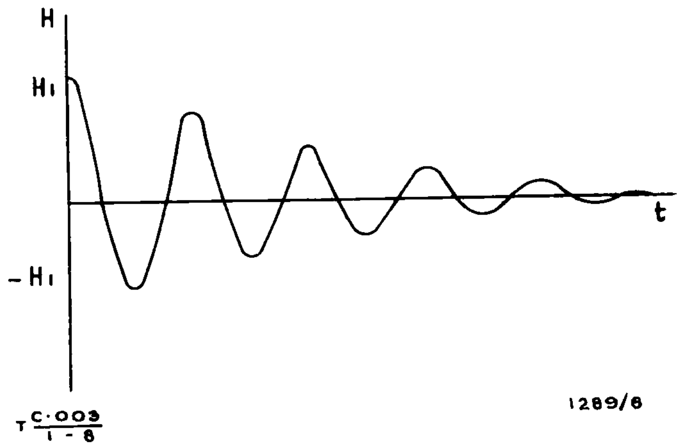

Fig 8—Variation of field strength during erase

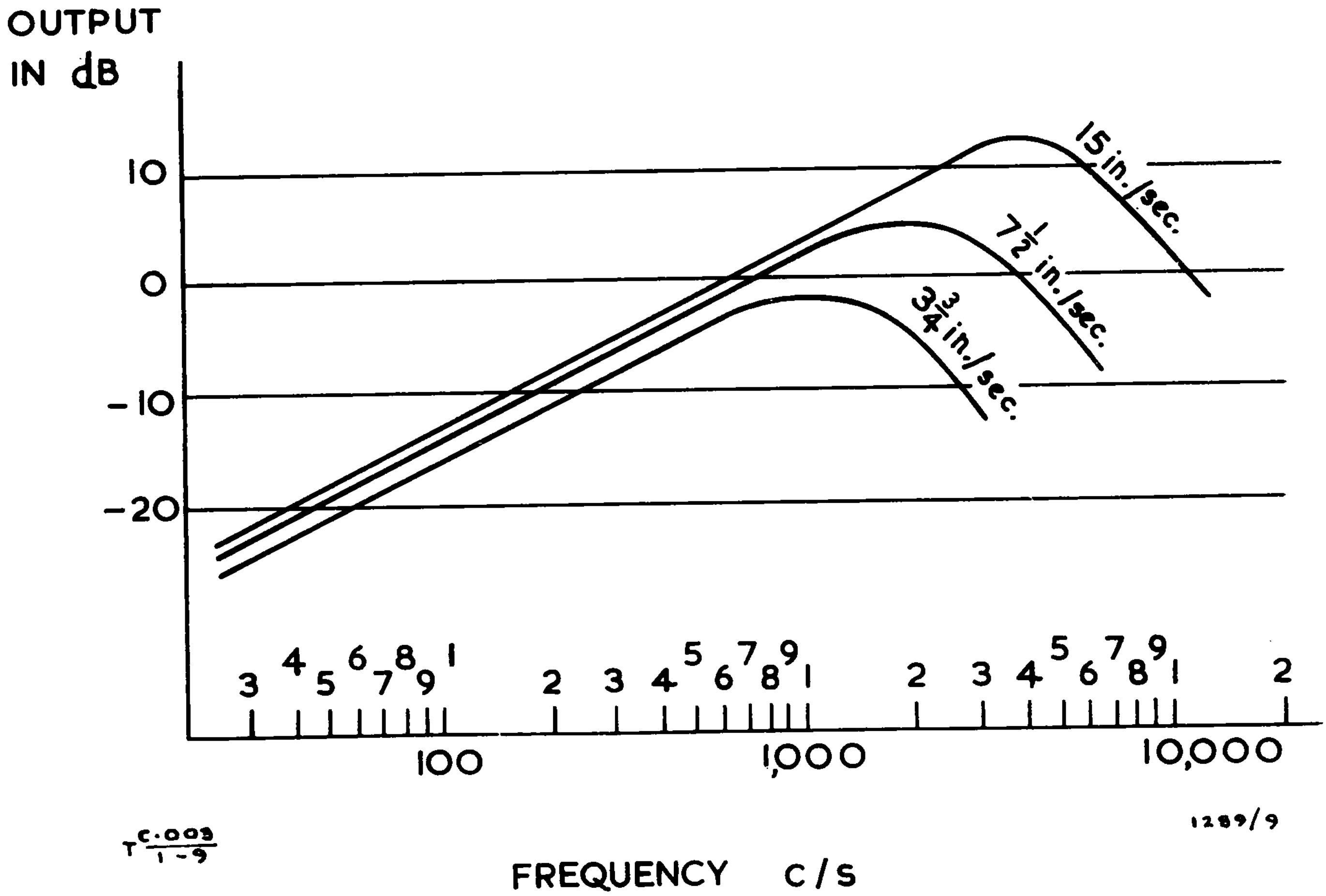

Fig 9—Frequency response—effect of tape speed

Frequency response

23. As with other recording systems, frequency response is inherently non-linear. The head is fed from a high impedance source and the resultant constant current characteristic of the magnetic recording produces a voltage output from the playback head which rises with frequency at a rate of 6dB per octave, since this voltage is directly proportional to flux density and frequency. This constant rise in response is only true for the lower and middle frequencies. At the higher frequencies, gap width losses, demagnetization losses, core losses and tape-head contact losses cause the response to fall off at about 12dB per octave.

24. The wavelength pattern on the tape for a given recorded frequency will depend on tape velocity. As the recorded wavelength approaches the gap width, the response falls off reducing to zero when they are equal. For this reason the gap width is made as small as practicable. Narrowing of the gap width, however, introduces problems due to 'fringing' effects, short circuiting by the oxide particles and also a reduction in output at the middle and lower frequencies.

25. Since both gap and demagnetization losses are dependent on the recorded wavelength rather than the signal frequency, the h.f. response is directly affected by the running speed of the tape. As a result, almost twice the frequency may be recorded at twice the tape speed. The effect of tape speed on frequency response is shown in Fig 9.

26. The corrections for frequency response and variation in this response for different tape speeds, are introduced in the record and playback amplifiers.

TAPE DRIVE MECHANISM

Tape drive

27. The most common method employed is based on the capstan principle. The tape is pressed against the capstan by a rubber pinch roller, the roller usually being wider than the tape and so rides against the capstan also, the friction between capstan and roller, and between tape and roller being sufficient to prevent slip. Tape speed is thus dependent on the speed and diameter of the capstan since $V = n\pi d$ where V is the tape speed, n speed of the capstan d the diameter of the capstan.

28. After being drawn from the feed reel by the capstan the tape is wound on the take up reel. Since the roll of tape on the reel gradually increases, the rotational speed of the reel must correspondingly decrease. This is achieved by some method of slip coupling or resistance control.

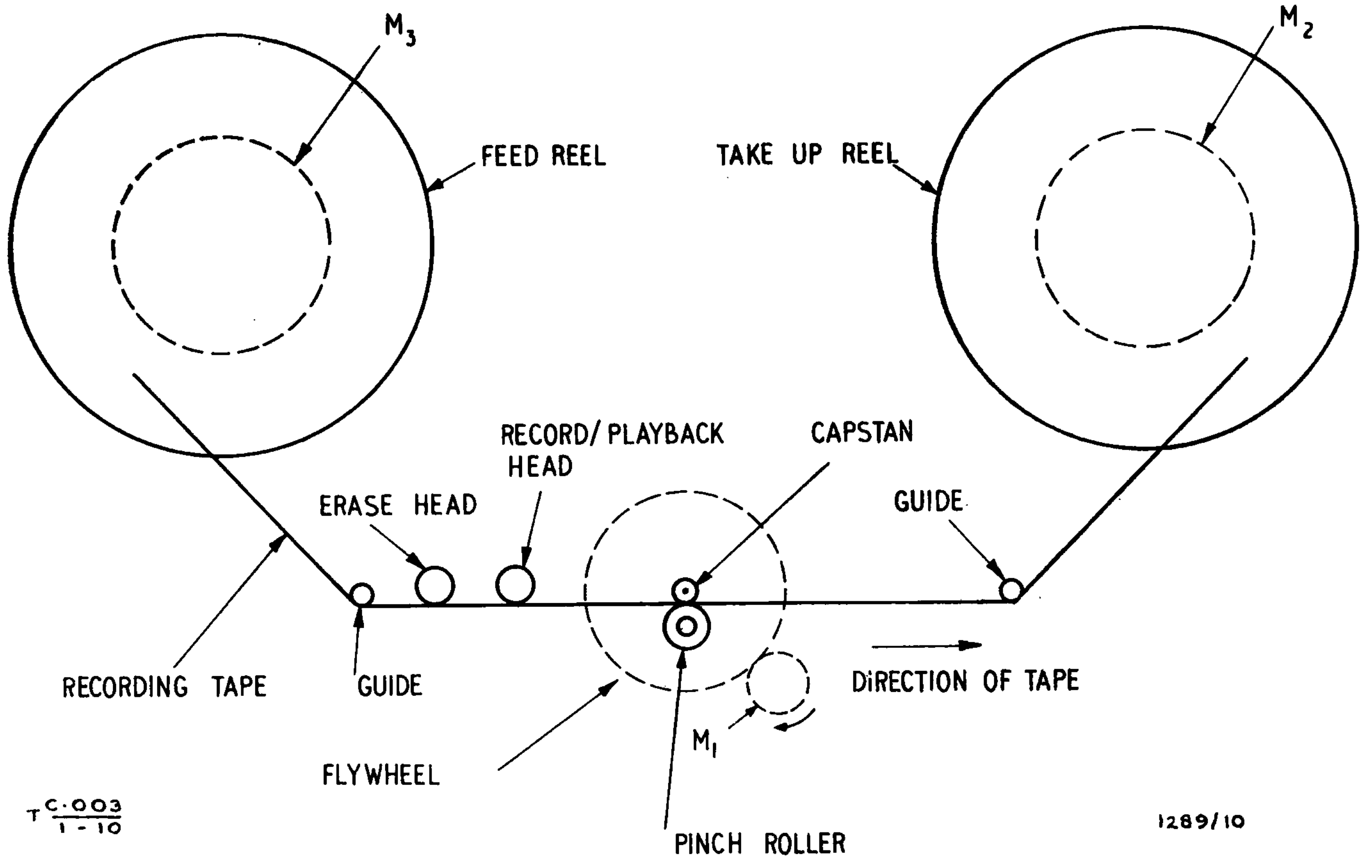

Fig 10—Typical tape drive system

29. During fast forward wind and fast rewind of the tape, the rubber pinch roller is withdrawn from the capstan, and positive drive applied to the appropriate reel. To prevent tape spill at the end of these operations a suitable method of braking (electrical or mechanical) is incorporated in the switching system.

30. There are several methods of driving the capstan and reels. A simple system using three electric motors is shown in Fig 10. Motor M1 drives flywheel and capstan, motor M2 drives the take-up reel during recording, playback and fast forward wind, and motor M3 is brought into operation on rewind. Systems using two or even one motor are mechanically more complex and employ cord or wheel drives or a combination of both to distribute the power.

Alternative speeds

31. Most recorders have tape speed changing facilities. When a reduction in the response at the higher audio frequencies is permissible, (eg when recording speech) slower speeds may be used to increase playing time. The increment between speeds is a factor of two, these having been standardized at 15, $7\frac{1}{2}$, $3\frac{3}{4}$, $1\frac{7}{8}$ and $\frac{15}{16}$ in./sec. The choice of speeds available of any one instrument is normally limited to two or three.

32. A common method of effecting tape speed changes is to use a motor having a stepped drive spindle. Fig 11 shows the principle of this type of drive. To change speed the rubber idler wheel is raised (or lowered) into position and then

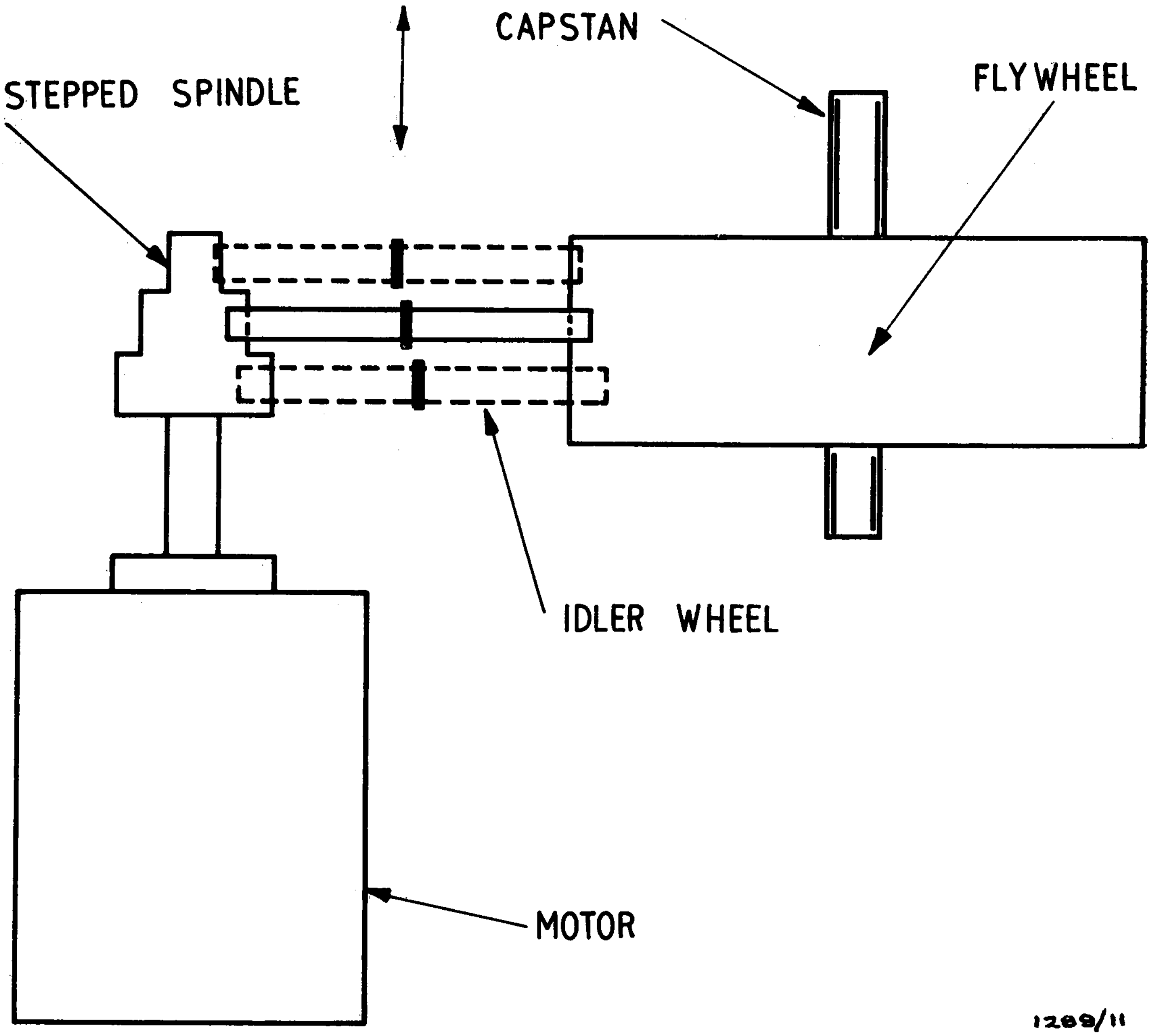

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Fig 11—Method of changing tape speed

pressed by the spring loading on its spindle against the flywheel and the appropriate step on the motor spindle. The speed of the capstan (N_2) is given by: $N_2 = \frac{d1}{d2} N_1$ where N_1 and d1 are the speed and diameter of the motor spindle and d2 the diameter of the flywheel.

Wow and flutter

33. Fluctuations in tape speed, during either record or playback, produce corresponding fluctuations in the frequency of the reproduced signal. This form of distortion, aptly referred to as 'wow' and 'flutter' is normally expressed as a percentage change in tape velocity, 'wow' describing fluctuations below 20c/s and 'flutter' those above. Ideally total fluctuations should be less than 0·1% but most portable machines necessitate lower standards and a total wow or flutter of 0·25% is about average.

Dual track recording

34. To double the length of playing time per reel, the recording can be limited to half the width of the tape. Most portable instruments adopt this system. Standardization requires that the top track be used when the tape is moving from left to right though machines using the bottom track with tape moving from right to left produce interchangeable recordings.

35. Whilst the reduction of track width does not affect the frequency response the output voltage is less, so the signal-to-noise ratio suffers. Track dimensions for a half-track tape are given in Fig 12. Machines using four track recording, with particular application to stereophonic reproduction, are now quite common.

Two way recorders

36. This type of recorder enables the direction of the tape to be reversed, thus obviating the need for turning over and exchanging reels when changing from one track to another. Track 1 (upper) is recorded in the usual way with the tape running from left to right, track 2 (lower) is recorded in the opposite direction. Apart from being mechanically more complex, these recorders require two sets of magnetic heads.

AMPLIFIERS

37. As explained previously, it is possible to combine the record and playback amplifier. A common amplifier, having from three to four stages, is modified by switching to fulfil both functions. Also included as part of the amplifying equipment are the recording level indicator, high frequency oscillator and power supply circuit.

38. In order to obtain an overall frequency response which is substantially flat, amplification must be corrected to compensate for the 6dB per octave rise in the recording characteristic and the subsequent fall mentioned in para 23-26 above. The frequency at which high frequency equalization commences is dependent on tape speed as shown in Fig 9.

Recording amplifier

39. This amplifies the input signal and feeds it to the recording head. High frequency bias is introduced in the output to the head via a suitable network or to a separate or tapped winding on the recording head.

40. The design of input circuits varies with the facilities provided. For use with low impedance microphones an input transformer is either incorporated in the amplifier or supplied as a separate item. To accommodate signals of high input level the first stage is usually by-passed. On some recorders, provision is also made for a 600Ω balanced input, in which case an impedance matching transformer having a centre tapped primary is included.

41. The output from the amplifier to the magnetic head winding may be either direct or through a transformer depending on the impedance of the winding.

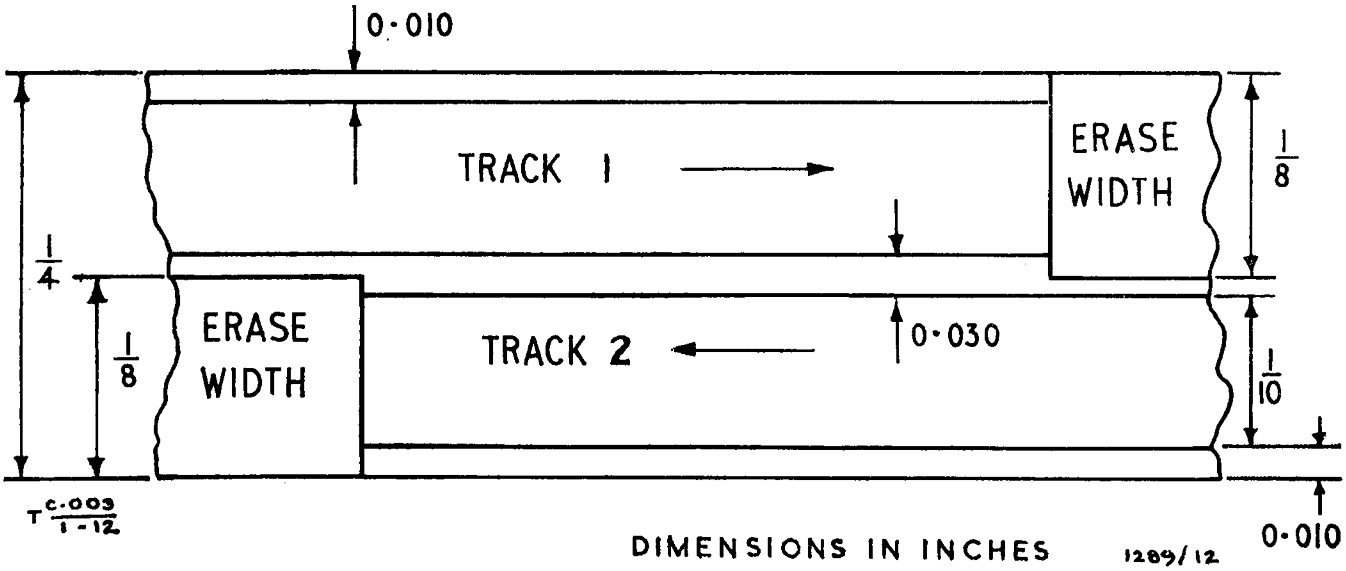

Fig 12—Dual track dimensions

42. In general, the response of the recording amplifier is flat except at the higher audio frequencies, where a lift in response is introduced to compensate for gap and demagnetizing losses. By compensating for these losses in the recording amplifier a higher signal-to-noise ratio is obtained, since compensation during playback would result in an increase in both signal and noise. However, to avoid overloading the amount of compensation that may be applied during recording is limited. The frequency characteristic of a typical recording amplifier is shown in Fig 13.

Playback amplifier

43. This amplifies the voltages generated in the winding of the magnetic head on playback and corrects for the recording characteristic. Suitable equalizing circuits included in the amplifier, compensate for the 6dB rise and the subsequent fall which begins at about 2500c/s for a tape speed of 7½ in./sec. Fig 14 shows (*a*) tape output without correction, (*b*) ideal response of playback amplifier, (*c*) compensated response. Switching to effect the necessary changes in equalizing for other tape speeds may be coupled to the tape speed changing mechanism.

44. The final stages of the amplifier are usually provided with a gain control and one or more tone controls giving manual variation of bass and treble response.

Recording level indicator

45. The purpose of such indicators is to avoid magnetic overloading of the tape and consequent distortion during playback. The most common type is a 'magic eye', whose luminous segments converge upon the application of a signal, full modulation being indicated by complete closure of the segments. On more expensive equipments, level indicators often take the form of a valve voltmeter, this being arranged to have its peak readings sustained giving a sharp rise and a slow fall characteristic.

H.F. oscillator

46. The high frequency erasing and bias currents used in recording are usually provided by the same oscillator. The power required for erasing being in the order of 3W at a frequency between 40 and 90kc/s. The power required for bias being considerably less than this.

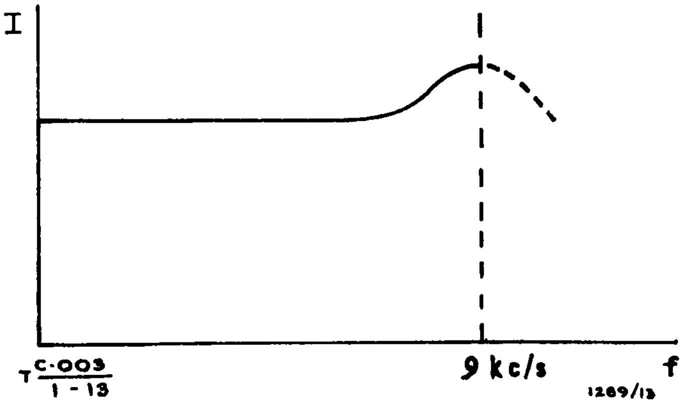

Fig 13—Recording amplifier—typical response characteristic

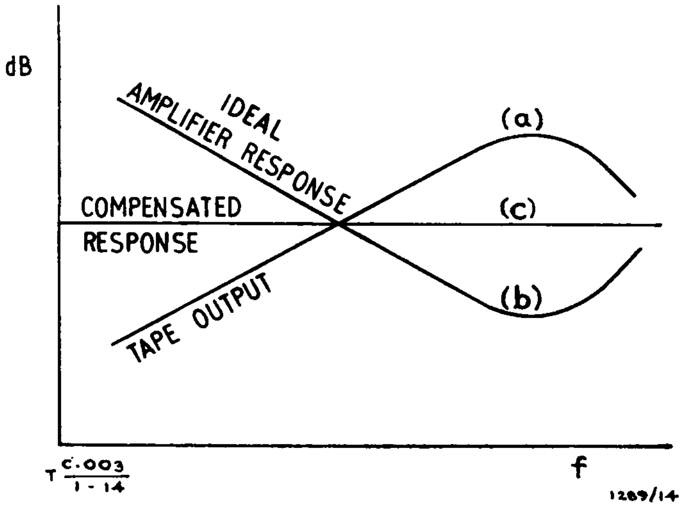

Fig 14—Playback amplifier—correction of tape response

47. To avoid even harmonic distortion in the recording process, the oscillator waveform must be symmetrical. By careful design of the oscillator stage, even harmonics, which give rise to an asymmetrical waveform, are kept to a minimum. The distortion produced by an asymmetrical waveform is similar to that caused by the presence of a d.c. component or a permanently magnetized head which apart from increasing the distortion also reduces the signal-to-noise ratio. To further minimize these unwanted effects the more elaborate equipments employ push-pull oscillators.

48. The majority of recorders have preset controls for the adjustment of oscillator output level and frequency. These should on no account be altered without the necessary test equipment and instructions.

Power supplies

49. In mains-operated types a conventional power supply provides l.t. and h.t. voltages. Mains transformers are tapped to cater for different supply voltages and the tappings may be used (in auto-transformer fashion) to provide appropriate motor supply voltages. Power consumption is in the region of 100W.

OPERATION

50. Recorders are relatively simple to operate once familiarity with the controls has been achieved. However, care must always be exercised to prevent unwanted erasure of the recording by inadvertent switching to record. Magnetized objects must be kept well away from heads or tapes. Operating instructions are provided as part of the equipment of each recorder.

Playing time

51. Reel diameters, tape speeds and tape thicknesses, now standardized, determine the playing time. Table 1 gives playing times for the different reel sizes, types of tapes and speeds for complete transit of the tape in one direction. For dual track recording these times are double. In each case the next larger reel size has twice the length of tape

Reel diameter (in.)	*Type of tape*	*Length (ft)*	*Playing time (single track) (min)*		
			$7\frac{1}{2}$ *in./sec.*	$3\frac{3}{4}$ *in./sec.*	$1\frac{7}{8}$ *in./sec.*
3	S	150	3·75	7·5	15
	L	225	5·5	11	22
	D	300	7·5	15	30
4	S	300	7·5	15	30
	L	450	11	22·5	45
	D	600	15	30	60
5	S	600	15	30	60
	L	900	22·5	45	90
	D	1200	30	60	120
7	S	1200	30	60	120
	L	1800	45	90	180
	D	2400	60	120	240

Type of tape: S = standard tape, L = long play tape, D = double play tape

Table 1—Playing time

and hence playing time. 'Long play tape' and 'double play tape' increase the playing time by factors of 1·5 and 2 respectively.

Tape splicing

52. A suitable method of splicing the magnetic tape is by the use of transparent adhesive tape applied to the uncoated side as shown in Fig 15. To ensure that the splicing does not produce a noise on playback and assist in making a good butt joint, the two ends to be joined should first be overlapped, shiny side up, and trimmed to an angle of approximately 45 deg. It is also permissible to splice tape by overlapping the trimmed ends for about half an inch and applying cement directly to the overlapped portion.

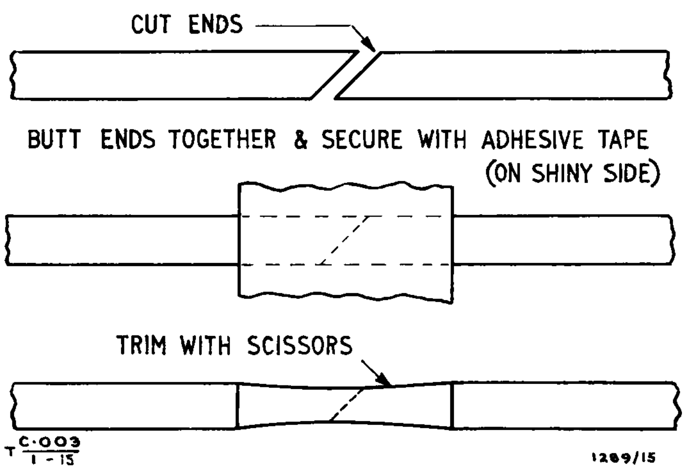

Fig 15—Method of tape splicing

Editing

53. Recordings may be edited by cutting out parts of the tape or joining others together by means of splicing. It should be noted however, that with twin track recording only one of the tracks may be edited, the remaining track may of course be subsequently used for recording in the normal way.

Cueing

54. Scales or counters are included in the equipments to give an indication of the amount of tape used or still available, and also to allow for the location of a desired portion of the recording. For more accurate cueing small pieces of coloured adhesive tape (less than tape width) may be secured to the tape, these being observed as the tape passes over the tape guides or through the head assembly.

Faults

55. Some of the more common operational faults, not necessarily due to defects in the recorder, are detailed in Table 2.

Fault	*Possible cause*
Recorder will not start	Mains lead or plug faulty. Batteries exhausted, fuse blown
Playback level too low	Insufficient gain during recording. Ensure adequate modulation by observing recording level indicator during record. Felt pressure pads (where fitted) dusty or worn. Clean by brushing
Recording very faint and woolly	Tape wrongly loaded. Dull surface should face the heads. If not, rewind tape with 180 deg twist. Dust or tape coating on head. Remove with brush or rag moistened with cleaning fluid. **Do not** attempt to clean with a metal object
Recording distorted on loud passages	Recording level too high or microphone too near sound source. Defective indicator
Recording satisfactory but erasure incomplete	Mains voltage low. Check supply and position of voltage selector. Dust or tape coating on erase head. Clean as above. Gross over-recording. Erase a second time
Hum recorded on tape	Microphone too close to recorder or other hum field. Microphone cable screening faulty
Playback lifeless, slow and low-pitched	Recording made at faster speed
Playback shrill and hurried	Recording made at slower speed
Wow and flutter	Feed or take up reel warped. Dirt or accummulation of tape coating on capstan or pressure roller. Flat on capstan or on one or more drive rollers. Tape stretched by careless handling
Tape loops or spills when recorder is stopped	Oil on brakes. Brakes out of adjustment or worn

Table 2—Common operational faults

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