CHAPTER 17

REPRODUCTION FROM RECORDS

By F. Langford-Smith, B.Sc., B.E.

SECTION 1: INTRODUCTION TO DISC RECORDING

(i) Methods used in sound recording (ii) Principles of lateral recording (iii) Frequency range (iv) Surface noise and dynamic range (v) Processing (vi) Turntables and driving mechanism (vii) Automatic record changers.

(i) Methods used in sound recording

There are many methods which have been used for sound recording, but these may be arranged in the following principal groups :

1. **Magnetic recording** includes magnetic wire and magnetic tape. See Refs. 258 (Chapter 29), 272, 316, 318.

2. **Sound on film** finds its principal application in cinema films. The Philips-Miller engraved film system is used to a limited extent for broadcast transcription. Film is also used for embossed lateral recording for some special applications. The high cost of the film precludes the use of this medium in most other fields. See Ref. 258.

3. **Mechanical groove recording** is used in various forms including
   (a) the cylinder (e.g. dictaphone)
   (b) the disc, which is the only type of recording considered in this chapter.

Two methods of recording are used with discs :

1. **Vertical recording** (" hill and dale "), which has had only a limited field of application, and appears unlikely to be used extensively in the future.

2. **Lateral recording** which is the method used most generally, and is the subject of this chapter.

Lateral recording is used with five types of discs—
- (a) The 78 r.p.m. " shellac " pressings,
- (b) The 33-1/3 r.p.m. fine groove, otherwise known as microgroove or long-playing (LP) records,
- (c) The 45 r.p.m. fine groove records,
- (d) Lacquer discs used for direct playback—see Sect. 8,
- (e) Discs used principally for broadcast transcription recording, usually operated at 33-1/3 r.p.m.—see Sect. 9.

The nominal speed of rotation is interpreted for recording as follows :

Supply frequency	50 c/s	60 c/s (R.M.A.)
78 r.p.m. nominal	77.92	78.26 r.p.m. (R.M.A.)
33-1/3 r.p.m. nominal	33-1/3	33-1/3 r.p.m. (R.M.A.)
Tolerance in speed of rotation	± 0.5%	± 0.3% (N.A.B.)

The speed is usually checked by means of a **stroboscope** illuminated by a lamp supplied from a.c. mains. The usual arrangement is :

Supply frequency	50 c/s	60 c/s (N.A.B.)
Number of bars on stroboscope	77	92 for 78 r.p.m.
	180	216 for 33-1/3 r.p.m.

At either 78.26 or 33-1/3 r.p.m. not more than 21 dots per minute in either direction may drift past a reference point (N.A.B. for recording).

See Reference 89 for a " Glossary of disk-recording terms." See Reference 105 for a " Bibliography of disc recording " (1921 to 1947).

See References 2, 87, 237 and 260 for American Recording Standards. See Sect. 2 for current English and American practice.

(ii) Principles of lateral recording

In lateral recording the groove forms a spiral either from the outside to the inside (as with all commercial " home " recordings) or from the inside to the outside (as with some transcription discs). The groove undulates horizontally from side to side of the mean path so as to deflect the stylus (needle) and armature of the pickup in accordance with the recorded sound (Fig. 17.1). The undulation of the groove is called " modulation " and the movement to one side of the mean path at any instant is called the amplitude of the modulation. The stylus is wedged in the groove by the effective vertical pressure due to the weight of the pickup, and moves radially about the pivot of the armature (Fig. 17.2).

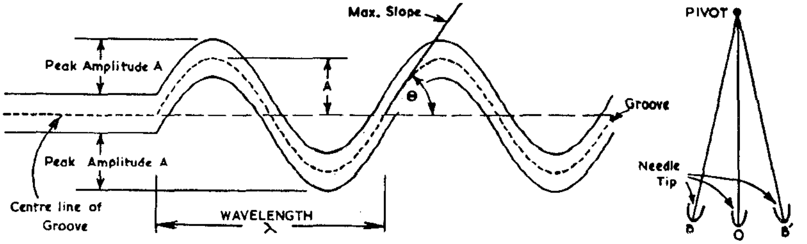


Fig. 17.1. *Unmodulated (left) and modulated (right) groove of lateral recording.*
Fig. 17.2. *Motion of stylus tip with lateral recording.*

If the recorded sound is of sine-wave form, the maximum transverse velocity of the stylus tip will occur at O and zero velocity will occur at B and B′, the two extremities of travel. This is an example of simple harmonic motion (see Chapter 6 Sect. 4). The maximum transverse velocity is $2\pi fA$ where f is the frequency in c/s and A is the peak amplitude. The r.m.s. transverse velocity is given by $1.41\ \pi fA$.

The **recorded level** may be specified in terms of r.m.s. velocities at 1000 c/s, or in decibels with a reference level 0 db = 1 cm/sec. lateral r.m.s. stylus velocity. The following tables are based on this usage.

(A) 78 r.p.m.—Cross-over frequency = 500 c/s

Level	**Velocity r.m.s.**	**Peak amplitude***	**Comments**
+ 10 db	3.16 cm/sec	0.56 mil	R.M.A. Frequency Test Record No. 1(A)
+ 16 db	6.31 cm/sec	1.1 mils	R.M.A. Frequency Test Record No. 1(B) max. velocity (1000 c/s).
+ 18 db	7.94 cm/sec	1.4 mils	
+ 22 db	12.6 cm/sec	2.2 mils	
+ 26.8 db	22 cm/sec	3.8 mils	Max. instantaneous programme peak.

* Over constant amplitude portion.

(B) 78 r.p.m.—Cross-over frequency = 250 c/s

Level	Velocity r.m.s.	Peak amplitude*	Comments
+ 10 db	3.16 cm/sec	1.1 mils	
+ 12 db	3.98 cm/sec	1.4 mils	
+ 15 db	5.62 cm/sec	2.0 mils	Normal maximum level
+ 18 db	7.94 cm/sec	2.8 mils	

N.B. 1 mil = 0.001 inch.

(C) 45 r.p.m.

Level	Velocity r.m.s.	Comments
+ 14.3 db	5.2 cm/sec	RCA Test record 12-5-31 (1000 c/s)
+ 22.9 db	14.0 cm/sec	Max. instantaneous programme peak.
+ 25.1 db	18.0 cm/sec	Max. level on R.C.A. Test Record 12-5-37.

(D) 33-1/3 r.p.m. (LP)

Level	Velocity r.m.s.	
+ 7.5 db	2.4 cm/sec	Columbia Test record RD-103 (1000 c/s).
+ 22.9 db	14.0 cm/sec	Max. instantaneous programme peak.

There are two basic methods of recording sounds of different frequencies—constant velocity and constant amplitude. " **Constant velocity** " refers to the maximum transverse velocity of the stylus tip at the zero axis, this being held constant as the frequency changes. A diagrammatic representation of constant velocity recording for two frequencies is given in Fig. 17.3.

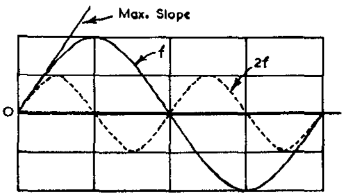


FIG. 17.3

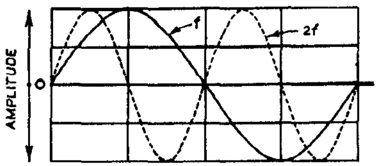


FIG. 17.4

Fig. 17.3. *Diagram of constant velocity recording for two frequencies f and 2f.*
Fig. 17.4. *Diagram of constant amplitude recording for two frequencies f and 2f.*

It may be shown that constant velocity recording has the following characteristics for constant power at all frequencies—

1. The peak amplitude is inversely proportional to the frequency.
2. The maximum slope of the curve is the same for all frequencies.

In the general case when the power is changing, the maximum velocity at any frequency is proportional to the peak amplitude. With an " ideal " electro-magnetic pickup, which inherently follows a constant velocity characteristic, the output voltage for sine waveform is proportional to the maximum velocity at all frequencies.

Constant velocity recording is not suitable for use over a very wide frequency ratio, owing to the large variation in peak amplitudes. For example, over a range of 8 octaves the ratio of maximum to minimum amplitude is 256 to 1.

" **Constant amplitude** " recording indicates that the maximum amplitude is held constant when the frequency changes, for constant power output (Fig. 17.4). It may be shown that the maximum slope is proportional to the frequency.

Constant amplitude recording is very suitable for low frequencies, but is not satisfactory with large amplitudes at the highest audio frequencies because the transverse velocity of the needle tip becomes excessive, leading to distortion in recording and in reproducing. On the other hand, constant velocity recording is satisfactory over a

*Over constant amplitude portion.

limited frequency range of medium or high frequencies. Therefore most recording systems employ an approximation to constant amplitude recording at low frequencies and an approximation to constant velocity recording for at least part of the medium and higher frequency range (see Sect. 5).

It may be shown (Ref. 146) that the minimum radius of curvature at the peak of the curve is given by

$$\rho = 0.025\lambda^2/A \qquad (1)$$

where ρ = radius of curvature in inches
λ = wavelength of sine-wave curve in inches
and A = peak amplitude of curve in inches.

Equation (1) may also be put into the form

$$A = 0.025\ \lambda^2/\rho. \qquad (2)$$

Any stylus is unable to fit accurately an undulation in the groove with a radius of curvature at the point of contact less than its own radius of curvature. We may therefore apply eqn. (2), taking ρ as the radius of curvature of the stylus, to give the maximum amplitude (called the **critical amplitude**) for correct operation,

$$A_{crit} = 0.025\ \lambda^2/\rho \qquad (3)$$

where ρ = radius of curvature of stylus, in inches.

But since the r.m.s. transverse velocity is equal to 1.41 $\pi f A$ we can determine the critical velocity in cm/sec,

$$\text{Critical velocity r.m.s.} = 11.3\ fA_{crit}\ \text{cm/sec} \qquad (4)$$

where A_{crit} = critical amplitude in inches.

(iii) Frequency range

The maximum recorded frequency in commercial shellac records manufactured prior to 1940 was of the order of 6000 c/s. At the present time most new recordings are recorded up to at least 8000 c/s, while many manufacturers record up to 10 000 or 15 000 c/s. Recordings up to ultrasonic frequencies (20 000 c/s) have been made, and are claimed to provide improved fidelity even though the higher frequencies are inaudible (Refs. 195, 271).

The lowest recorded frequency is of the order of 30 c/s, although some record manufacturers do not publish their recording characteristics below 50 c/s.

(iv) Surface noise and dynamic range

Surface noise (needle scratch) is unavoidable with any method of disc recording, but the maximum signal-to-noise ratio may be made quite high. The maximum dynamic range will be greater than the measured signal-to-noise ratio on account of the nature of the noise, which approaches the characteristics of random noise if there are no resonances anywhere in the equipment—see Chapter 14 Sect. 7(v).

Surface noise is not really objectionable if it is reasonably low in level and if it can be described as " silky." This latter criterion can only be attained when the pickup and loudspeaker both have smooth response throughout the whole frequency range. If the pickup has a prominent resonance within the audible frequency range—even if correctly equalized—the noise will not be " silky " and will tend to become objectionable.

In all cases the high frequency range of the equipment should be limited by a suitable filter giving a choice of cut-off frequencies. Filters with very rapid cut-off characteristics are undesirable on account of distortion effects, but a combination of a " roll-off " characteristic and a filter with an ultimate attenuation of at least 12 db/octave appears to be satisfactory. Any other method of achieving a " rounded " cut-off characteristic would probably also be satisfactory.

The maximum signal to noise ratio of **shellac pressings** varies considerably. The older shellac pressings had a maximum signal to noise ratio* of the order of 30 or 35 db. The most recent English shellac pressings have a maximum signal to noise ratio* of 50 db (Ref. 88) for a new record. The best of recent American 78 r.p.m. shellac recordings have a maximum signal to noise ratio* of 45 or 46 db when new

*Measured with flat frequency response.

(Refs. 255, 254). The average post-war shellac record, taking into account all the various types of records on the market, both English and American, has a maximum signal to noise ratio* of about 38 db (Ref. 256).

A new vinyl fine groove record can have an average surface noise, measured on a system whose response is flat on a velocity basis from 500 to 10 000 c/s, about 56 db below the peak recording level; if measured on a system whose response is the inverse of the recording characteristic, the surface noise is approximately 62 db below peak recording level. The B.B.C. " D Channel " recording has a weighted signal to noise ratio greater than 60 db (Ref. 297).

The surface noise increases with the use of the record. After 100 playings with a 2 ounce pickup some shellac records showed negligible increase in noise level while others showed 5 db increase, the average being about 2.5 db (Ref. 181). After 200 playings of a fine groove vinyl record (LP) the surface noise increased by 2 db (Ref. 308).

The cost factor limits the use of **polyethylene** (Ref. 181) which has a scratch level even lower than that of vinyl. See also Sect. 9(ii) for the measurement of noise in accordance with NAB standards for transcription records.

(v) Processing

The processing of shellac pressings is described in Refs. 7, 10 and 25. The processing of vinyl (LP) records is described in Ref. 308.

(vi) Turntables and driving mechanism

Turntables should be strongly constructed, free from flexing, and should run true. The typical home-type turntable and motor is unsatisfactory for good fidelity on account of insufficient motor power, insufficient flywheel action and insufficient mechanical rigidity; it suffers from rumble, wow and (with some pickups) hum due to the proximity of the motor. The motor should be as far as possible from an electromagnetic pickup. Motor and turntable vibrations are transmitted through the mounting board and pickup arm to the pickup head and are finally reproduced in the loudspeaker as rumble. Steel turntables may be used without bad effects with crystal pickups and high level moving iron types, except that in the latter case the turntable should be solid, without perforations. Steel turntables are unsatisfactory with some low-level pickups, particularly moving coil types.

Either rim or centre drive may be used, and first class products using both methods are available. In the moderate price class, it seems that (for the same price) the rim drive is generally the more satisfactory arrangement.

The specification for a motor and turntable unit should include—

1. Type of motor.
2. Voltage and frequency range.
3. Power consumption.
4. Torque to brake the turntable from the nominal speed to a lower speed (e.g. 78 to 77 r.p.m.), the torque being expressed in oz-ins and the applied voltage and frequency to be stated.
5. Turntable diameter.
6. Form of automatic stop.

(vii) Automatic record changers

With most record changers it is important to adjust the vertical angle between the stylus and the record so that the deviation from normal is the same (although opposite in direction) at both the top and bottom of a stack of records.

Care should be taken to minimize the impact of the stylus on to the record surface when the arm is released by the changer mechanism.

There are three types of trip mechanisms, one being the velocity trip in which the changer mechanism is triggered by a sudden change in groove pitch. This system has

*Measured with flat frequency response.

the advantage of not requiring adjustments for different inside diameters. It has the disadvantage of requiring, in most designs, that the stylus, cartridge and arm operate a spring tension as they move inwards. This presses the stylus against the outside wall of the grooves and tends to produce differential wear as well as other undesirable effects.

The second type of trip mechanism operates when the stylus reaches a specific inside diameter, and the eccentricity of the inside groove has no effect. The disadvantage of this arrangement is that there are large differences in the inside diameters of the various types of records, so that an adjustable (preferably continuously-variable) control is required. This method is used in 45 r.p.m. record changers, where there is no eccentric inside groove.

The third type is the eccentric groove.

Difficulty is often experienced in an attempt to incorporate automatic record changers in high fidelity equipment owing to rumble and, in some cases, hum pickup. In addition, some high fidelity pickups are unsuitable for use on any automatic record changers. The choice of a pickup for use with an automatic record changer is necessarily a compromise, and many high fidelity enthusiasts prefer to use a good quality turntable with manual operation.

Automatic record changers for 45 r.p.m.

The R.C.A. record changer is described in Ref. 263. The tripping mechanism requires an extremely small lateral force from the pickup arm, since the work of putting the mechanism into cycle is supplied by the moving turntable.

SECTION 2 : DISCS AND STYLI

(i) General information on discs (ii) Dimensions of records and grooves (iii) Styli (iv) Pinch effect (v) Radius compensation (vi) Record and stylus wear.

(i) General information on dics

Shellac discs are used only with 78 r.p.m. standard groove records. The material is hard, and has no appreciable elastic deformation under pressure.

Vinyl* is used for all forms of fine groove discs, and has appreciable elastic deformation under pressure. As a consequence, high peak accelerations are reduced as compared with the same recording in shellac. For the effects of elastic deformation see Ref. 212. Vinyl has the defect that it becomes electrified and collects a considerable amount of dust. The effect of dust collection on vinyl records through electrostatic attraction may be avoided by the use of a liquid anti-static agent which may be sprayed or wiped on to the surface of the record.

(ii) Dimensions of records and grooves

(A) 78 r.p.m.

The usual nominal sizes of shellac pressings are 10 in. and 12 in. diameter. Dimensions and tolerances as recommended by the American Radio Manufacturers' Association and as used by English and American manufacturers are tabulated opposite.

European continental records do not differ in any significant respect from English practice. The outside diameters are 25 cm (9.85 in.) and 30 cm. (11.8 in.) and the hole diameter is 0.284 inch.

On the basis of these dimensions, the ratio of maximum to minimum R.M.A. groove diameter is 3.07 to 1 for a 12 inch record, providing a groove speed from approximately 3.9 to 1.3 feet per second (47 to 15.3 inches per second).

*The name vinyl is a general name covering unfilled vinyl co-polymer resins, which may vary somewhat in their physical characteristics.

DIMENSIONS OF RECORDS AND GROOVES (78 r.p.m.).

	U.S.A. (in inches)	English*	
		Present range	Recommended
Outer diameter : 12 in.	$11\frac{7}{8} \pm 1/32$†	11-15/16 – 11-27/32	$11\frac{7}{8}$ – 11-27/32
10 in.	$9\frac{7}{8} \pm 1/32$†	9-15/16 – 9-27/32	$9\frac{7}{8}$ – 9-27/32
Thickness : 12 in.	0.090 ± 0.010†	0.092 – .082	0.090 – .080
10 in.	0.080 ± 0.010†	0.080 – .070	0.080 – .070
Centre hole diameter	0.286 + 0.001† – 0.002	0.292 – 0.284	0.2845 – .2835
Centre pin diameter	.02835 ± .0005	0.282 – 0.280	0.2825 – .2820
Outermost groove diameter : 12 in.	$11\frac{1}{2} \pm 0.02$†	11.500 – 11.395	11.500 ± 0.015
10 in.	$9\frac{1}{2} \pm 0.02$†	9.515 – 9.485	9.500 ± 0.015
Innermost groove diameter	not less than $3\frac{3}{4}$†	3.875 – 3.750	3.875
Grooves per inch	88, 96, 104, 112, 120‡	103 – 72	104 – 72
		(84 to 96 usual on classical recordings)	
Width of groove at top	6.5 – 8 mils‡	6.5 – 8 mils	6.5 – 6.7 mils
Depth of groove	not standardized	—	2.9 mils
Radius at bottom of groove	2.2 max. mils‡	0.8 – 2.5 mils	1.5 – 1.8 mils
Angle of groove	87° – 97°‡	82° – 98°	85° – 90°

N.B. 1 mil = 0.001 inch.

*Based on Ref. 235 for most dimensions ; Refs. 131, 174 for recommended groove cross-sectional dimensions.
†R.M.A. REC-103 (Ref. 260). ‡R.C.A. Victor practice

Additional data (REC-103)

Eccentric stopping groove diameter $3\frac{3}{8}$ in. ; run-out relative centre hole 0.250 ± 0.015 in. ; groove minimum depth 0.003 in.
Lead-in spiral : at least 1 complete turn between outer edge of record and recording pitch.
Lead-out spiral : Nominal pitch $\frac{1}{8}$ in. minimum.

The wavelength for 78 r.p.m. is given by

$$\lambda = (1.3\pi d)/f \qquad (5)$$

where λ = wavelength in inches for 78 r.p.m.
d = groove diameter in inches
and f = frequency in c/s.

Equation (5) gives the following values—

Frequency	50	250	500	10 000 c/s
Wavelength—outermost groove	0.94	0.19	0.094	0.0047 in.
Wavelength—innermost groove	0.31	0.061	0.031	0.0015 in.

The effective width of the stylus with dimensions as in Fig. 17.5B is about 4 mils, giving a radius of curvature of 2 mils. Using eqn. (3) of Sect. 1,

$$A_{crit} = 0.025\ \lambda^2/0.002$$

and for 10 000 c/s the critical amplitude is—

$$A_{crit} = 0.000\,28 \text{ in. for outermost groove}$$
$$A_{crit} = 0.000\,028 \text{ in. for innermost groove.}$$

The critical velocity is given by eqn. (4) of Sect. 1,

Critical velocity r.m.s. = 31.6 cm/sec at outermost groove
= 3.16 cm/sec at innermost groove.

The critical velocity at the outermost groove is more than sufficient for the highest level of recording, but as the groove diameter decreases a point will be reached where the peak recorded velocity is greater than the critical velocity—thus leading to distortion and loss of high frequency response.

A slightly higher critical velocity could be obtained by the use of a somewhat smaller stylus radius, since the two values are inversely proportional.

The maximum instantaneous peak recorded velocity is about 15 cm/sec (American practice) so that there is every likelihood that the critical velocity will sometimes be exceeded on the smaller diameter grooves. The saving feature in practice is that maximum amplitude does not normally occur at 10 000 c/s with either speech or music, except when cymbals are recorded at maximum amplitude.

(B) 45 r.p.m.*

The R.C.A. Victor 45 r.p.m. fine groove records are only made with a nominal diameter of 7 inches, and are primarily intended for ready use in record changers. The inner portion of the record forms a collar which is thicker than the playing area, thus preventing the playing surfaces from touching. The groove dimensions are

Width across shoulders 3.0 mils + 0 − 0.5
Angle 92° ± 3°
Radius at bottom of groove not greater than 0.25 mil.

The recommended vertical stylus force is 5 ± 1 grams.

The grooves per inch vary from 178 to 274. The maximum instantaneous programme peak recording velocity is 14 cm/second (about 4 db below 78 r.p.m. records).

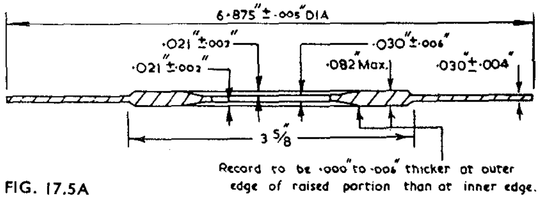


FIG. 17.5A

Fig. 17.5A. *Cross-sectional view of R.C.A. 7 inch* 45 *r.p.m. record* (*Ref.* 254).

The cross-sectional view of a record is shown in Fig. 17.5A. The outermost music groove is 6⅝ inch diameter, while the innermost music groove is 4.875 inches minimum diameter—the latter gives 10% intermodulation distortion and a groove velocity of 11.5 inches per second.

The maximum playing time is 5¼ minutes. A lead-in groove extends from the edge of the record and makes from 1 to 1¼ turns before entering the first music pitch. There are from 1 to 1¼ turns of unmodulated music pitch before the start of music. There is from 0 to ½ turn of unmodulated music pitch at the end of music. The

*For R.C.A. 45 r.p.m. Extended Play records see Supplement.

lead-out groove makes from ¾ to 1¼ turns from the music pitch to 1-15/16 inch radius, beyond which it makes from 1 to 2 turns to the concentric circle (3-13/16 inch diameter).

The central hole is 1.504 ± 0.002 inches in diameter.

References 254, 263, 264, 265.

(C) 33-1/3 r.p.m. (LP)

The long-playing microgroove records revolve at 33-1/3 r.p.m. and are made with outside diameters of 12, 10 and 7* inches.

The R.C.A. Victor records are identical to the 45 r.p.m. records with respect to groove shape, recording pitch, recorded level and recommended playback stylus.

Dimension	Columbia	R.C.A. Victor
Groove angle	87° ± 3°	92° ± 3°
Radius at bottom of groove less than	0.2 mil	0.25 mil
Width across shoulders of groove	—	0.0025 in.
Maximum amplitude	0.9 mil	—
Max. instantaneous programme peak velocity	—	14 cm/sec
Lead-in groove pitch	—	35 to 40 lines/in.
Blank grooves (normal pitch)	—	1 to 2
Grooves per inch (normal pitch)	200 to 300	178 to 274
Grooves per inch (usual values)	224, 260	—
Lead-out groove	—	4 grooves/in.
Thickness	—	0.070 to 0.085 in.
Thickness depressed label area	—	0.060 in. min.
Maximum diameter (12 in.)	—	11-7/8 ± 1/32 in.
(10 in.)	—	9-7/8 ± 1/32 in.
Outer music groove dia. (12 in.)	—	11-15/32 $^{+0}_{-3/64}$ in.
(10 in.)	—	9-15/32 $^{+0}_{-3/64}$ in.
Inner music groove dia.	4-3/4	4-3/4 in.
Nomin. dia. of eccentric groove	—	4-7/16 in.
Eccentric groove off-centre	—	0.125 ± 0.008 in.
Centre hole	—	0.286 in.
Label diameter	—	4-1/16 in.
Outer edge, included angle	—	80°
edge radius	—	1/64 in.
Maximum playing time 12 in.	22-1/2	— mins.
10 in.	15	— mins.
7 in.	5-1/2	— mins.
Optimum stylus force	6 0.21	5 ± 1 grams. 0.18 ounce

References to L-P microgroove: 159, 166, 178, 179, 232, 236, 255, 262.

(iii) Styli

***(A)* Styli used with shellac pressings** *are in five principal groups:*

(1) **Ordinary steel needles** which are ground to shape by the abrasive in the record. The exact shape of the needle point when new is not so important as with permanent or semi-permanent styli. For examples of record wear see Ref. 10 Part 4.

(2) **Semi-permanent needles** such as chromium plated steel. The needle shape is important and "shadow-graph" needles are recommended. For the best results these should not be used for more than one playing of a 12 inch shellac record (for photograph of wear see Ref. 274). Alloys such as osmium are also used.

*Columbia only.

(3) "**Permanent**" **styli** employ a jewel such as a diamond, sapphire or ruby, usually in the form of a jewel tip. The tips of permanent needles should be accurately ground to shape, and highly polished. Diamond tipped needles have a life of several thousands of playings of shellac records for good fidelity. Tungsten carbide is also used. For stylus wear see Sect. 2(vi).

(4) **Fibre needles** are used by some enthusiasts in the belief that they reduce scratch and record wear. While it is true that they reduce scratch they do so by attenuating all the higher frequencies, and they do this no more efficiently than an electrical attenuator. The attenuation of a fibre needle at 4000 c/s is 19 db down as compared with a loud tone steel needle in a typical pickup (Ref. 7). After the first few grooves they wear sufficiently to occupy the whole of the groove and thereby spread the weight of a heavy, stiff pickup of old design. If such pickups are used, contrary to all good advice, then fibre needles are possibly the best compromise because a soft needle damps down the pronounced high-frequency resonance of the pickup. There is evidence to indicate that abrasive particles from the record become embedded in the fibre and thereby cause wear, even though the fibre itself is softer than the record. With modern pickups having light weight and high lateral and vertical compliance the wear from a well polished sapphire point is undoubtedly less than that from a fibre needle.

For photographs of new and worn fibre needles see Ref. 274.

(5) **Thorn needles** are very much harder than fibre, but the amount of needle wear is very much dependent upon the pickup compliance and stylus force. With suitable lightweight pickups, the needle wear is reasonable up to 6 playings (Ref. 309), but some loss of high frequency response is inevitable. If sharpened with the use of very fine glasspaper, there is risk of glass dust becoming embedded in the needle— this danger may be avoided by the use of a very fine rotary cutting wheel (Ref. 309, April 1951).

Since thorn needles are normally in contact with the whole of the bottom of the groove, they will tend to remove all dust from the groove. It therefore seems probable that the noise from a record which has been played exclusively with thorn needles will be no greater at the bottom of the groove than on the sides.

Fine point thorn needles have also been used with fine groove (LP) records (Ref. 309).

The shape of the stylus tip to give optimum results with most English and American recordings may be taken as (RTMA Standard REC-126-A, Ref. 260):

	Radius of tip	Angle
Metal point	2.7 (+ 0.2 - 0.3) mils	40° to 50°
Sapphire	3.0 (+ 0.2 - 0.3) mils	40° to 50°

A cross-sectional view of a correct size of sapphire stylus point in a typical groove is given in Fig. 17.5B. It will be seen that the stylus does not reach to the bottom of the groove; this is very important because the abrasive dust collects at the bottom of the groove. In addition, there should be some allowance for the stylus to wear on the sides without the bottom of the stylus coming too close to the bottom of the groove.

FIG. 17.5B

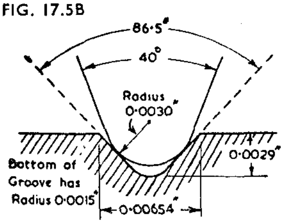


Fig. 17.5B. Cross-sectional view of typical record groove and needle tip.

In some modern records, as well as in transcription discs, a tip radius of 2 mils may be used, but in other (and particularly older) recordings it is likely to scrape the groove bottom and suffer from "groove skating" and single point contact.

One interesting suggestion is to combine a 2 mil radius with a "flattened" extremity (actually a 3.5 mil radius). Although more expensive to produce it seems to have distinct advantages (Ref. 244).

Oval sapphire styli are available with a minor axis of 1.5 to 2.0 mils and a major axis of 2.5 to 3.5 mils. These should be used with the major axis at right angles to the centre-line of the groove, and will permit better response to high-amplitude high-frequency recordings.

The N.A.B. " secondary standard " stylus (permanent point) has an angle of 40° to 55° and a bottom radius of 2.5 ± 0.1 mils. It provides a compromise suitable for the reproduction of both transcriptions and shellac discs.

The use of larger styli (radius 4 mils) is advocated by some engineers (Refs. 223, 225) but it does not appear to be the best all-round compromise.

Needles are made in various sizes. The ordinary steel needles used in mechanical reproducers are used in the stiff heavy weight pickups whose frequency response does not exceed about 6000 c/s ; they are also used in some " needle armature " pickups. For the best high frequency response the " loud tone " or " full tone " needles should be used, because of their smaller size and weight. " Soft tone " and " trailing " needles (as used with acetate discs) cause severe treble attenuation when used with typical pickups. Most light weight pickups with a frequency response extending to 10 000 c/s or over use miniature needles to enable the armature resonance to be at a high frequency. A typical example is the H.M.V. Silent Stylus or Columbia 99 (chromium-plated long-playing). Thorn needles are also made of similar size.

Efforts have been made to develop a stylus tip suitable for both 78 r.p.m and fine groove (see Refs. 279, 281) but a considerable degree of compromise is necessary and the best results are not obtainable from either type of recording.

(B) Styli for fine groove records

With a few exceptions, all styli for fine groove records are permanent types—usually jewels. Diamond tips are the only really satisfactory ones for long life, although expensive to purchase in the first case. Sapphire tips are very common, but wear rather rapidly—see Sect. 2(vi) for stylus wear. Other materials used are tungsten carbide, osmium and other metal alloys.

Dimensions of styli for fine groove records

(RTMA Standard REC-126-A, Ref. 260, for home phonographs)

Radius of tip	0.001 + 0.0001 − 0.0002 inch
Included angle of tip	40° to 50°.

Note : With a 90° groove angle, a tip with a radius of 0.001 inch has an effective radius of 0.0007 at the point of contact.

(C) Colour codes for styli

1. RTMA REC-126-A for home phonographs (Ref. 260). Needles with a 0.001 inch radius shall be colour coded red.

2. English Gramophone Equipment Panel of the Radio and Electronic Component Manufacturers' Federation (Jan. 1951). Red—0.0010 in. ; lemon—0.0020 in. ; green—0.0025 in. ; french blue—0.0030 in. ; orange—0.0035 in. ; violet—universal ; sky blue—oval tip. Material (marked by band on shaft) black—hard metal ; white—diamond ; no colour—sapphire.

(iv) Pinch effect

Owing to the fact that the cutting is done by a stylus having an effectively flat cutting face, the width of the groove measured at right angles to the groove is narrower at two places in each cycle (see Sect. 6). As a result of this effect, the stylus tip should rise and fall twice in each cycle—only a limited number of pickups, however, make adequate provision for this movement.

The flexibility of the stylus, if mounted at an acute angle to the record, together with that of the record itself, tends to prevent the needle from riding merely the peaks of the vertical undulations. The pinch effect undoubtedly increases needle wear and possibly also record wear (Ref. 212).

Various forms of " bent shank " needles have been developed to provide some vertical compliance. All " bent shank " needles tend to give a drooping high-frequency response the amount of which varies considerably from one make to another ; it may, of course, be compensated if desired.

(v) Radius compensation

Radius compensation does not appear to be used with shellac discs, although it is used with LP discs (R.C.A. Victor) and in transcription discs.

(vi) Record and stylus wear

Record wear is a complicated effect depending upon many conditions of operation including :

1. Vertical stylus force.
2. Lateral mechanical compliance at stylus tip.
3. Vertical mechanical compliance at stylus tip.
4. Lateral and vertical pivot friction in pickup arm, or lateral spring tension.
5. Mechanical resonances of pickup and arm.
6. Tracking error.
7. Shape, material and polish of stylus tip.
8. Maximum transverse velocity of record grooves.
9. Record material.
10. Dust.

It is understood that the turntable is free from vibration and wobble and that the record is neither eccentric nor warped ; if not, these are additional causes of record and stylus wear.

The **vertical stylus force** for use on shellac records should preferably not exceed about 1 ounce weight (28.35 grams) and it should be as light as possible to reduce record and stylus wear to the minimum. However care should be taken to provide sufficient force to ensure satisfactory tracking, otherwise the wear will increase. Increased force, say up to 2 ounces (about 60 grams), causes very little additional record wear provided that a well-polished jewel point is used and the pickup has high lateral compliance.

The stylus force with fine groove records is quite critical, but is a function of the pickup. Forces approximating 6 grams weight are common, but it is safer to err slightly on the high side than on the low side. Some manufacturers give a " minimum tracking weight " and a " normal " value—the latter is the correct one to use.

If the required vertical pressure is not known, it may be determined by using an intermodulation test record, decreasing the pressure until the distortion commences to rise—and then increasing by a margin of, say, 50%.

High lateral compliance at the stylus tip is one of the most important requirements for low record and stylus wear. In general, high lateral compliance and light weight go together.

Vertical compliance at the stylus tip permits the tip to maintain contact with the groove in spite of the " pinch effect." Bent shank styli reduce record wear in cases where the pickup has insufficient vertical compliance.

Mechanical resonances of the pickup are serious causes of record and stylus wear. Both the " arm resonance " (if it comes within the recorded frequency range) and the " armature resonance " affect the record and stylus wear, even if electrically equalized.

Tracking error is discussed in Sect. 4 ; if reduced to the usual low values, record and stylus wear from this cause are very slight.

The **shape and polish** of a jewel stylus tip are of the utmost importance in regard to record wear.

Wear of shellac records

One example is a record which had been played 1000 times with a 1.35 ounce (38 grams) pickup and a sapphire stylus and was then demonstrated as giving fidelity virtually unaffected (Refs. 128, 131). It may be stated as a rough guide that the limit of life of an average shellac record is about 4000 playings under good conditions.

Unmodulated grooves on shellac records will wear indefinitely with a jewel stylus on which the vertical force does not exceed 1 ounce (30 grams). By far the most significant cause of wear is the dynamic action of the stylus in the grooves. If the dynamic force at any moment exceeds the elastic limit of the record material, the shellac crumbles. This permits the stylus to drop down a little deeper in the groove, eventually increasing the bearing area of the needle by contact with the bottom of the groove. At this point with a pickup having low stylus force, the wear apparently stops. This wear does not produce any apparent change in quality of the reproduced sound, although it can be seen as a light streak on the surface of the record. Both lateral and vertical forces must be considered in producing the wear (Ref. 155). Wherever there is excessive stylus wear, it is always accompanied by excessive record wear.

It is important to distinguish between visible wear and audible wear. Visible wear does not necessarily cause any audible defect. It is possible that visible wear may occur earlier with a diamond tip, but audible wear, which is caused by actual widening of the groove at corners, will occur far more rapidly with a worn sapphire or metal tip. The flats on the sides act as scrapers in attempting to negotiate sharp bends in the record groove. A well polished spherical diamond or sapphire tip is believed to cause less record wear than a metal alloy tip.

Wear of vinyl records

Wear of vinyl fine groove records is very slight, provided that the stylus force does not exceed about 7 grams, that a pickup of ample lateral and vertical compliance is used, that the jewel tip is well polished, that there are no marked mechanical resonances, and that dust is excluded. **Dust** is the most important cause of record and stylus wear with vinyl records in the home, and care should be taken to reduce it to a minimum—see Sect. 2(i). Wear in vinyl records shows itself principally in widening of the groove thus leading eventually to distortion and rattles (Ref. 155).

Wear of sapphire styli

The wear of sapphire styli is a function of the material of which the pressings are made, the lateral and vertical compliance of the pickup at the stylus tip, the dynamic mass of the pickup at the stylus tip, the characteristics of the armature (high frequency) resonance and the pickup arm (low frequency) resonance, and the stylus force. Additional wear may be caused by " skating " (due to the use of a tip radius which is too small for the groove), by insufficient vertical force to maintain the stylus always in contact with the groove, and by warped or eccentric records or turntables. When using a pickup with high lateral and vertical compliance and low dynamic mass at the stylus tip, an increase of stylus force has only a minor effect in increasing the wear on the stylus tip. It has been shown (Ref. 282) that with such a pickup (GP20) on a heavily modulated **shellac record,** an increase from 7.5 to 14.5 grams in stylus force causes increased flats on the stylus tip resulting in a drop of only 3 db at 10 000 c/s on a test record. Such a stylus and pickup may be used for 800 playings of a 12 inch shellac record with reasonably good fidelity, or 2000 playings with fair fidelity (− 5 db at 10 000 c/s on a test record).

On the other hand a typical light-weight pickup with a stylus force of 1 ounce (28 grams) has been shown to produce wear on sapphire styli on shellac records as follows (Ref. 59).

Wear just noticeable after 50 playings of 12 inch disc.

1 mil flats after 200 playings 2 mil flats after 750 playings 2.5 mil flats after 1500 playings	The effect of flats on distortion is covered in Sect. 6(iv).

It is obvious that this pickup produces much greater wear than the one with high lateral and vertical compliance (GP20) described earlier. It is probable that the greater wear is due principally to the lower lateral and vertical compliance, although the increased stylus force would also be a contributing factor.

Some excellent photographs of stylus wear are given in Refs. 274 and 290.

The use of a test record at, say, 10 000 c/s to indicate wear of the stylus tip requires careful interpretation of the results. The level of recording of the test record is lower than that which may be reached with music, while the effect of wear of the stylus tip is shown less prominently towards the outer diameter of the record than it would be with a smaller groove diameter.

It is wise to avoid using sapphire or other permanent stylus tips on records which have been played previously with steel needles. For a photograph of wear after 20 playings under such conditions see Ref. 274.

Stylus wear with fine groove records

Apparently stylus wear is far more rapid on microgroove than on standard groove vinyl records ; a rough estimate is about three times faster (Ref. 290). For this reason, diamond styli are much to be preferred to sapphire or osmium, even for home use, where high fidelity is required.

In one case, when tested on 12 inch long playing records, with a GE RPX-041 pickup having 8 grams pressure, a diamond stylus showed a slight flat after 37 hours playing time, whereas a sapphire under similar conditions was badly worn after 5¾ hours (15 playings)—see photographs Ref. 290.

There appear to be considerable variations on the hardness of the sapphires, which are practically all made of synthetic sapphire (Ref. 302), so that it is impossible to quote any figures of stylus wear which can be regarded as typical. In all cases the stylus life is very much affected by the pickup.

Osmium tipped styli have a life only two fifths (Ref. 290) or one sixth (Shure) that of sapphire. This makes the effective life with an osmium tipped stylus, for high fidelity, extremely short.

Method for giving positive indication of stylus condition

Obtain a lacquer disc with unmodulated grooves cut on both sides of it—one side for a 3 mil stylus and the other for a 1 mil stylus. Both types of grooves may be on the one side of the disc. Whenever in doubt, play two or three grooves on this disc If the stylus leaves the grooves unchanged in lustre and smoothness, it is in good condition. If, however, the groove walls show score marks or any other difference when compared with the unplayed grooves, the stylus needs replacement. An ordinary magnifying glass will be of assistance (Ref. 298).

SECTION 3 : PICKUPS

(i) General survey (ii) Electro-magnetic (moving iron) pickups (iii) Dynamic (moving coil) pickups (iv) Piezo-electric (crystal) pickups (v) Magnetostriction pickups (vi) Strain-sensitive pickups (vii) Ribbon pickups (viii) Capacitance pickups (ix) Eddy-current pickups.

(i) General survey

The performance expected from good quality pickups includes—

1. Wide frequency response with the minimum of equalizing. No sharp peaks over + 2 db. For most applications a slight droop in the high frequency response is not undesirable as it may be used to compensate for the pre-emphasis in most recordings.
2. Low stylus pressure.
3. High lateral compliance.
4. High vertical compliance at stylus tip.
5. Low effective vibrating mass of armature at high frequencies.
6. Fairly high output level.
7. Low distortion.
8. Freedom from major resonances over the useful frequency range (see below). The low frequency (arm) resonance should be below 30 c/s so that it will have a negligible effect on record wear. The high frequency (armature) resonance should be as high as possible—certainly over 8000 c/s—and preferably above the useful frequency range. Even so, the resonance should be effectively damped.
9. Minimum " needle talk " (direct acoustical radiation).
10. High signal to hum ratio.
11. Negligibly small voltage generation from vertical movement of the stylus tip.
12. General ruggedness.
13. Freedom from the effects of excessive humidity. Pickups having a restricted frequency range (say from 70 to 6000 c/s) should meet the same requirements as good quality pickups, apart from frequency.

Pickups which have sufficient vertical compliance are sometimes fitted with needle guards to reduce or prevent damage to the pickup from accidentally dropping it.

Pickup manufacturers sometimes quote the minimum vertical stylus force to provide perfect tracking. It is generally regarding as sound practice to adopt a stylus force at least 1.5 times this minimum value, thus making some provision for warped and eccentric records.

For styli, see Sect. 2(iii).

Single purpose pickups for home use often incorporate a fixed spring counterbalance. Dual purpose pickups usually apply a higher stylus pressure for 78 r.p.m. than for fine groove records. In some cases the pickup head (or cartridge) includes the additional weight for 78 r.p.m., in other cases this is provided by an adjustment of spring tension or by a counterbalancing weight.

It is desirable in all cases to keep the moment of inertia about both vertical and horizontal pivots to a minimum.

Where a spring counterbalance is used, it should be checked periodically for pressure; during weighing, the height of the stylus from the baseboard must be exactly the same as the top of the record.

Up and down movements of the stylus tip, due to the pinch effect and small record surface irregularities should be absorbed by the vertical compliance of the stylus, without generating any output noise.

Pickups for 78 r.p.m.

A stylus force not more than 1 ounce (say 30 grams) is desirable, with 2 ounces as the upper limit.

One of the difficult problems with permanent tipped styli is provision for changing needles without adding seriously to the armature mass. Certain pickups are designed for use with miniature needles pushed into place and gripped by a wedge against which they are held by the pressure from the record. There are two troubles which may occur. The first is that the needle may rotate about its axis, thus placing its "flats" at some unknown angle to the groove—such a case is known to the author. This may be eliminated by tightening the clutch or by using a little cement. The second trouble is "buzz," which is more serious because there appears to be no cure; however it only seems to occur on deeply modulated recordings of complex waveform, and is only apparent when the frequency range is extended.

Nearly all high fidelity pickups have the stylus permanently fixed to the armature—this appears to be essential for the high frequency resonance to occur above 10 000 c/s.

Pickups for fine groove records

The maximum desirable needle pressure is 6 grams (0.21 ounce) and high lateral compliance is essential. Pickups have been produced by many manufacturers, mainly using diamond, sapphire or osmium tips.

Careful pickup arm design, specifically for fine groove recording, is of paramount importance. It is inadvisable to use a fine groove pickup head or cartridge on an arm other than that designed for it.

A very simple and effective test for the tracking efficiency of a pickup and arm for fine groove records is known as the **McProud Test** (Ref. 314). A 45 r.p.m. record is placed on a standard turntable running at 45 r.p.m. with the maximum possible eccentricity (1¼ inches swing), and the pickup is required to track the record satisfactorily.

Dual purpose pickups have been designed which have two opposed needles 180° apart, suitable for playing either standard 78 r.p.m. or fine groove records.

Pickups employ many principles of operation, but most types are basically either constant velocity or constant amplitude. For example both electro-magnetic (moving iron) and dynamic (moving coil) pickups are basically constant velocity, while piezo-electric (crystal) types are basically constant amplitude. Since the recording characteristic includes both constant velocity and constant amplitude sections, either group is satisfactory although requiring different equalization.

Resonances in pickups

Most pickups have two major resonances. The **arm resonance** occurs at some frequency below 100 c/s, while the armature resonance occurs at some frequency about 3000 c/s. Both resonances have deleterious effects in increasing record wear. The arm resonance tends to cause the pickup to jump out of the groove when a high amplitude is recorded at the frequency of resonance—the frequency of resonance (if undamped) should be well below the lowest frequency for which acceptable tracking is required ; say from 15 to 25 c/s.

A recent development is the use of pickup arms with high viscosity oil or other viscous fluid to damp arm resonance. The damping may be applied as a viscous film in a ball and socket (hemispherical) joint between the pickup arm and the mounting socket, and gives damping in both horizontal and vertical directions. The arm is pivoted at a point which is the centre of both ball and socket, and above the centre of gravity of the arm. The clearance between the two surfaces is about 0.006 inch. By this means the resonant force is greatly reduced, improved resistance to external shock is obtained and protection against damage from accidental dropping of the pickup head is achieved. The amount of mechanical resistance is not a critical value—the upper limit is reached when it interferes with the tracking of records having reasonably small values of eccentricity or warpage. With the usual values of suspension compliance and mass, this would occur at several times the amount of resistance necessary to give critical damping of the arm resonance. Even if the damping is considerably below critical, it still has quite a beneficial effect. The viscosity of the fluid is a function of temperature, but the variation does not seriously affect the performance over a reasonable temperature range. Ref. 311.

The **armature resonance** has a serious effect on needle scratch (see Sect. 1). " During operation the needle is subjected to a continuous shower of blows, and although highly damped by rubber buffers, it is in a state of perpetual oscillation at its own resonance frequency " (Ref. 229). In any quality pickup, the armature resonance with the recommended needle should be over 8000 c/s ; many light-weight pickups have the resonance at a frequency over 12 000 c/s—in some cases over 18 000 c/s.

Pickups tend to be rich in harmonics at frequencies in the region of half the armature resonance frequency. In all cases the armature resonance should be effectively damped. Damping material used to obtain smooth response characteristics may adversely affect the tracking capabilities of the pickup, and therefore should be investigated carefully and used judiciously (Ref. 285).

The frequency of the armature resonance is affected by the record material—for example, a change from a lacquer disc to a shellac pressing causes in one case an increase in the resonant frequency in the ratio 1: 2 approximately (Ref. 276). A pickup with an armature resonance well outside the a-f range on shellac discs, shows a much lower resonance frequency on vinyl—usually inside the a-f range. This is an unfortunate characteristic of vinyl. The only pickups known to the author with armature resonances above 15 000 c/s on vinyl fine groove recordings are of the ribbon armature type.

There is a third resonance caused by the pickup head and arm rotating about the arm. With heavy pickups this resonance occurs at frequencies between 100 and 400 c/s, but with light-weight pickups the frequency would be higher. This resonance does not have any effect on the general tonal balance, and in any case should be very slight with good mechanical design.

Crystal pickups have a fourth resonance which occurs at a high frequency—the resonance of the crystal itself.

References to resonances in pickups : 10 (Part 2), 17 (second letter), 276, 283, 285, 311, 331.

The testing of pickups

The testing of pickups for frequency response characteristics is covered by R.M.A. REC-125-A which states that the test record shall be R.M.A. Frequency Test Record

No. 1 when available. This is recorded on side A at a r.m.s. velocity of 3.16 cm/sec (+ 10 db). Crystal pickups are terminated by a load resistance of 1 megohm (or 5 megohms for ammonium phosphate crystals) shunted by a capacitance of 100 $\mu\mu$F. Other types of pickups should be terminated as required. The response should be stated in decibels (0 db = 1 volt).

Pickups should be tested under the same conditions with which they will operate in normal service. Pickups intended to be used on shellac records should be tested on shellac discs ; pickups intended for use on vinyl records should be tested on vinyl discs, while those intended for use on either type of disc should be tested separately on each. Pickups which are satisfactory on vinyl discs give, in some cases, quite poor results on shellac discs owing to the increased stiffness of the material and the reduction in damping by the record. This also applies to pickups with very limited vertical compliance—while passable on vinyl, they are poor on shellac.

The variable speed turntable is sometimes used as an alternative to the standard frequency records for the calibration of pickups—see Refs. 273, 295.

In the design and production of pickups it is usual to supply some form of electro-mechanical calibrator such as in Ref. 284.

For distortion in pickups and the procedure for determining the " tracking " capabilities of a pickup see Sect. 6(vi).

(ii) Electro-magnetic (moving iron) pickups

All " moving iron " pickups have a steady field supplied by a permanent magnet, a coil wound over the magnetic circuit, and an iron armature in the magnet gap. The old type of heavy pickup of this type used with shellac records weighed about 3½ ounces (say 100 grams) and had low lateral compliance. It will not be further described.

The more recent light-weight models are capable of good fidelity, and some models are among the best pickups available. The increased fidelity and higher compliance are obtained at the cost of lower output level—very much lower in some cases.

Electro-magnetic pickups may arbitrarily be divided into three groups, based on the output voltage developed across the pickup with recorded velocity 3.16 cm/sec (+ 10 db).

(a) High level—output voltage above 100 millivolts.

(b) Medium level—output voltage from 20 to 100 millivolts.

(c) Low level—output voltage below 20 millivolts.

Some typical representatives in each group are described below. In most cases the descriptions are based on published information supplied by the manufacturer. The inclusion of certain models should not be taken as indicating their superiority over types not included.

(a) High level pickups

Decca ffrr pickup type D (English) — standard groove

This pickup is of the needle armature type, having a hollow armature fitted with a sapphire, tungsten carbide or diamond stylus. The armature suspension and damping are of rubber ; the stylus, armature and rubber suspension are replaceable as one unit. The low frequency resonance is 25 c/s, while the armature resonance is about 17 000 c/s. The impedance of the pickup is 4200 ohms at 1000 c/s and the output 0.2 volt at the same frequency ; lower impedances are also available. The frequency response corresponds to the velocity characteristic of the ffrr record within ± 1 db. The whole armature including stylus and damping blocks is replaceable by the user. The stylus tip is available in both round and oval shapes.

Lateral compliance 1.1×10^{-6} cm/dyne

Impedance at arm resonance frequency (approx.)	17 000 dynes/sec./cm.
Distortion in pickup	less than 2%
Stylus force	22 to 24 grams (0.78 to 0.85 ounce).
Load resistance	100 000 ohms

(b) Medium and low level pickups

Connoisseur Super Lightweight pickup (English)—standard and microgroove

This is a high-fidelity pickup with interchangeable heads. Heads are available with 1 mil, 2.5 mil and 3 mil radii sapphire tips. The frequency response is level ± 2 db from 25 to 15 000 c/s. The 25 ohm model gives 10 millivolts output, or 300 millivolts from a 1 : 50 transformer. The 400 ohm model gives 40 millivolts, or 200 millivolts from a 1 : 6 transformer. The armature mass is 20 milligrams, and the dynamic mass* is 0.8 milligram. The stylus force is 8-10 grams (standard) or 4-6 grams (microgroove). The pressure is automatically corrected by weights in the plug-in head.

Goldring Headmaster (English)—standard and microgroove

This is a high-fidelity pickup with interchangeable heads. Heads are available with 1 mil, 2 mil, 2.5 mil and 3.5 mil radii sapphire tips. The frequency response with 2.5 mil needle is level to 7000 c/s, − 1 db at 10 000 c/s, + 1 db at 16 000 c/s, 0 db at 17 000 c/s and − 5 db at 20 000 c/s ; at the other end it rises smoothly from 100 to 30 c/s where it is + 3 db. The output is 40 millivolts (from the pickup itself) and stylus force 20 grams (0.7 ounce). It has high lateral stylus compliance, low inertia, and high vertical compliance. This is a good-all-round pickup for home gramophones.

Pickering cartridges (American) standard and microgroove

Model S-120M (sapphire stylus), or D-120M (diamond), is for standard recordings, and has a 2.7 mil radius tip. A stylus force of 15 grams is sufficient for tracking.

Model S-140S (sapphire), or D-140S (diamond), is for microgroove recordings, and has a 1.0 mil radius tip. A stylus force of 6 grams is recommended.

Both models give an output of 70 millivolts with a recorded velocity of 10 cm/sec. The frequency response with a load resistance of 27 000 ohms is level from 30 to 9000 c/s, + 2 db at 20 c/s, + 2.5 db at 12 000 c/s and falling above that frequency. A lower load resistance attenuates the higher frequencies, while a higher load resistance reduces the damping on the pickup, decreases the signal-to-noise ratio, and is generally undesirable.

Constants of moving system

Lateral moment of inertia	11 mg cm^2
Lateral compliance of stylus	1.0×10^{-6} cm/dyne
Vertical compliance of stylus	0.2×10^{-6} cm/dyne

Pickering Turn-over pickup (American)—all records

This model 260 pickup may be turned over for either 78 r.p.m. or microgroove operation. It has an output of 30 millivolts at a recorded velocity of 10 cm/sec. It is available with diamond stylus only.

* Dynamic mass (also known as equivalent mass or effective mass) is that mass which, if concentrated at the stylus point, would possess the same inertance as that of the moving system.
See also Refs. 248, 283.

G.E. variable reluctance pickup (American)—standard and fine groove

This is a magnetic pickup having almost ideal characteristics except that the output voltage is low (10 millivolts at 4.8 cm/sec.). It has no " needle talk " and has considerable resistance to shock. It has a large degree of vertical compliance, while vertical movement does not cause any electrical output. The suspension is free from any deleterious effects such as standing waves or cross-modulation, and the construction is designed to reduce hum pickup. The frequency response is from 30 to 15,000 c/s. ± 2 db. The inductance is 520 mH for the home type, and 250 mH for the broadcast types (RPX-046 and RPX-047) which also have a lower output (8 mV). The normal stylus force is from $\frac{3}{4}$ to $1\frac{1}{4}$ oz. (1 oz. on home type) with 78 r.p.m., or 6-8 grams on microgroove.

Dynamic mass of stylus	8 milligrams
Suspension compliance (lateral)	0.87×10^{-6} cm/dyne
Load impedance, normal	6800 ohms.

The cartridge is fitted with interchangeable styli, including 1 mil, both diamond and sapphire. For a suitable pre-amplifier see Fig. 17.26.

References 93, 106, 187, 234, Catalogues.

R.C.A. Light weight pickup—transcription and fine groove

Model MI-11874 pickup, MI-11875 arm. See Refs. 296, 313 and R.C.A. catalogues.

A plug-in pickup head is used, permitting immediate change from 1.0 to 2.5 mils without necessitating any adjustment of arm balance. Stylus force is 8 grams for 1.0 mil and 12 grams for 2.5 mil. Diamond styli are used. Tone arm resonances are outside of the operating frequency range The vertical and horizontal pivots have very low friction. Frequency response (1.0 mil) at output from filter 50 to 12 000 c/s ± 1 db, 40 c/s at − 4 db. Voltage output at 1000 c/s on open circuit = 11 mV with 6.1 cm/sec. test record. Output from filter − 64 dbm. Test record 460625-6. Hum level − 139 dbm with magnetic flux density 1 milligauss. Output pickup impedance 135 ohms at 1000 c/s. Filter output should be connected to unloaded input transformer of amplifier designed to operate from 250 ohm source. Intermodulation distortion is low to the point where it is not possible to determine accurately whether the distortion is in the record or the pickup.

E.M.I. Unipivot transcription pickup (English)—standard and microgroove

This Model 17 pickup has interchangeable styli for standard and microgroove, and the arm has an oil damping system. Its impedance is 1 ohm at 1000 c/s, and the output at the secondary of the transformer is 30 millivolts (high ratio), or 4 millivolts (600 ohms), or 2.25 millivolts (200 ohms). The frequency response is sensibly level from 30 to 12 000 c/s with standard stylus (armature resonance above 15 000 c/s). Total harmonic distortion at 400 c/s is less than 5% for a recorded level of + 20 db (0 db = 1 cm/sec). The stylus force is 6 grams.

Audak Polyphase (American)—two styli

This has two separate styli, each with its own vibrating armature. One stylus force (6-8 grams) is used for all records. Either sapphire or diamond styli may be used, and may readily be replaced. Output is about 20 millivolts, and frequency response 30 to 10 000 c/s, level ± 1 db from 80 c/s upwards, with gradual rise to + 2 db at 30 c/s. Armature resonance is at 9000 c/s.

(iii) Dynamic (moving-coil) pickups

A dynamic pickup has a coil, with a stylus attached to cause movement of the coil, mounted in a magnetic field and operating as a generator.

With good design this construction is virtually distortionless at low frequencies, but the output voltage is very low and a high-ratio transformer is always used in conjunction with it. One possible difficulty is hum which may arise either through induction from the turntable motor to the moving coil, or through hum picked up by the transformer ; special mu-metal shielded transformers may be necessary to obviate the latter trouble.

Fairchild dynamic pickup (American)—transcription

The low frequency resonance is at 18 c/s and the armature resonance is over 12 000 c/s with only 2 db rise at the latter frequency. Tracking may be obtained on a flat and true record with a needle pressure of only 5 grams (say 0.2 ounce) but the normal needle pressure has been increased to 25 grams (say 0.9 ounce) for best performance under all conditions. The moving coil is supported by two plastic vanes, and a diamond point is used. Ref. 57.

Leak dynamic pickup (English)—home type

A diamond stylus is standard in the latest moving coil pickup developed by H. J. Leak. The height of the pickup is adjustable. The turntable should be non-magnetic. Spring loading is used without any counterweight. Gimbal mounting is used, with hardened steel pivots. This pickup cannot be used with automatic record changers. The frequency response is level $\pm$ 1 db 40-20,000 c/s, the high frequency resonance being above 27,000 c/s (21,000 $\pm$ 2000 for LP). The low frequency resonance is 20 $\pm$ 5 c/s. The output is 11 mV per cm/sec. recorded r.m.s. velocity. The playing weights are 5-6 gm. on 78 r.p.m. and 2-3 gm. on long-playing records.

(iv) Piezo-electric (crystal) pickups

A piezo-electric crystal is one which, when strained, produces electric charges on certain of its faces, the magnitude of these charges being directly proportional to the strain. In practice, two slabs of a suitable piezo-electric material are usually cemented together with one electrode between the slabs and another in contact with both outer faces. The slabs are cut in such a manner that a torque (in the case of a " twister " crystal) or a flexure (in the case of a " bender " crystal) will produce a potential difference across the electrodes. This assembly is known as a " bimorph," the torsional variety being used in most crystal pickups. The output from a crystal pickup is directly proportional to the amplitude of the stylus displacement.

The most commonly used crystal is sodium potassium tartrate (Rochelle salt). This is seriously affected by both high temperatures (over 125°F) and high humidity ; some units are protected from humidity by a water-tight casing.

Other materials include ammonium dihydrogen phosphate (Ref. 158) which is not affected by high temperature or humidity, and ceramic piezo materials (barium titanate etc.). The latter is described on page 721.

The equivalent circuit of a crystal pickup is a capacitance in series with a generator of zero impedance. At 1000 c/s the impedance of many typical pickups is about 0.5 megohm, indicating a capacitance of about 0.0003 μF. One manufacturer (W.E.) produces pickups with impedances from 0.08 to 0.2 megohm, indicating capacitances from 0.002 to 0.0007 μF respectively.

Some crystal pickups are fitted with bent styli to provide vertical compliance for the " pinch effect " and to reduce " needle talk," while others make provision for vertical compliance inside the pickup.

Crystal pickups may be divided into general-purpose types and light-weight high-fidelity types, although there are some with intermediate characteristics. General-purpose crystal pickups have fairly high output, about 1 volt at 1000 c/s, with both arm and armature resonances within the working frequency range. A simple equalizer circuit is Fig. 17.29, although these pickups are frequently used without any equalizer. The stylus force of modern types is usually less than 2.5 ounces (70 grams). Some crystal pickups are available—both standard and fine groove—with a highly compliant drive and capable of tracking with a stylus force of about 8 grams (e.g. Shure " vertical drive ").

The output from a crystal pickup, which may be 1 volt at 1000 c/s, may rise to more than 3 volts r.m.s. at frequencies around 100 to 250 c/s—if no equalizing is used, there is danger of overloading the first valve in the amplifier. A resistance attenuator may be used to reduce the voltage to any desired value.

One manufacturer (Electro-Voice) produces a torque-drive pickup in which vertical movement of the needle produces no output voltage, thereby reducing noise and rumble (Refs. 142, 158).

High fidelity crystal pickups have outputs between 0.5 and 1 volt at 1000 c/s and stylus forces between 0.5 and 1.5 ounces (14-42 grams). The frequency response, when equalized, is approximately flat from a low limit of 25, 30, 40 or 50 c/s to a top limit of 8000, 10 000 or 12 000 c/s Suitable equalizer circuits are given in Figs. 17.31, 17.32, 17.33. The lateral needle tip impedance of a typical model (Acos GP12) is 1300 grams per centimetre (compliance = 0.8×10^{-6} cm. per dyne).

References to crystal pickups : 81, 106, 120, 142, 158, 301.

The ceramic pickup described in Ref. 178 uses barium titanate in the form of a ceramic. It is free from any appreciable effects from temperature from − 70° to + 70°C, and is also independent of humidity effects. The output obtained from the pickup is 0.75 volt at 1000 c/s and the stylus force is 22 grams (0.8 ounce). The dynamic mass at the stylus point is 4 milligrams at 10 000 c/s. The lateral compliance at the stylus point is 0.5×10^{-6} cm. per dyne or better. The equivalent capacitance of the pickup is about 900 $\mu\mu$F and the optimum load impedance is one megohm. The unequalized output voltage curve is free from sharp peaks and extends from 50 to 10 000 c/s, maximum output occurring at 200 to 400 c/s and falling by 6 db at 50 c/s and 15 db at 10 000 c/s.

A ceramic pickup has been developed for fine groove reproduction with a needle pressure of 6 grams, an output voltage of 0.25 volt at 1000 c/s on a standard test record, and a lateral compliance of 0.75×10^{-6} cm/dyne (Ref. 178).

(v) Magnetostriction pickups

Magnetostriction is that property of certain ferro-magnetic metals, such as nickel, iron, cobalt and manganese alloys which causes them to shrink or expand when placed in a magnetic field. Conversely, if subjected to compression or tension, the magnetic reluctance changes, thus making it possible for a magnetostrictive wire or rod to vary a magnetic field in which it may be placed. This is true for lateral as well as for longitudinal strains, and on this principle the magnetostriction pickup works.

In the pickup a permanent stylus is fastened at right angles to the centre of a piece of nickel wire. Two pickup coils are placed over the magnetostriction wire on each side of the stylus, and the wire is given a slight twist and placed between the poles of a permanent magnet. This effectively gives a push-pull output.

The TM pickup described (Ref. 82) has an output of 0.086 volt from the secondary of the step-up transformer loaded by 0.1 megohm. The stylus force is 0.7 ounce (20 grams). The frequency response (Ref. 76) is level within ± 2 db from 200 to 8000 c/s and − 8 db at 15 000 c/s ; it rises to + 5 db at 100 c/s and + 6 db at 50 c/s. The design is such that magnetic fields cause very little hum pickup.

References 76, 82.

(vi) Strain-sensitive pickups

This pickup is based on the principle that the resistance of a conductor changes when the conductor is strained. Direct current is passed through the conductor while in operation. Some low impedance designs are described in Ref. 234 ; these all require a step-up transformer.

A recent high-impedance commercial type is the Pfanstiehl which has a resistance of about 250 000 ohms, giving an output of about 10 to 15 millivolts and a noise level of about 5 micro-

FIG. 17.6

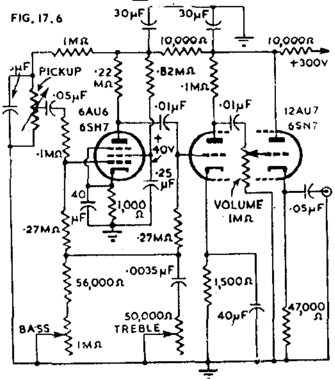


Fig. 17.6. Pre-amplifier for use with strain-sensitive pickup (Ref. 336)

volts. Since the pickup is a constant-amplitude device, special methods are required for frequency compensation. The pre-amplifier of Fig. 17.6 gives the required frequency compensation with continuously-variable controls (see Ref. 336 for settings for some American records) and an output of about 2 volts with types 6AU6 and 12AU7. The final stage is a cathode follower. Refs. 96, 303, 336.

A later model of the pickup has a resistance of 125,000 ohms, an output of 5 to 10 millivolts, and a compliance of 1.2×10^{-6} cm/dyne.

(vii) Ribbon pickups

Ribbon pickups operate on the same general principle as the ribbon microphone, and the output is necessarily very low. For this reason a high ratio step-up transformer, magnetically shielded, and a high gain pre-amplifier are required. One design is described below.

Brierley ribbon pickup (English)—home type (Type 4)

This pickup has two gold ribbons backed by a material selected for its self-damping properties. There is, in consequence, no measurable high frequency resonance and this is largely responsible for an extremely low level of buzz. For vibrations in the direction of the groove the damping is independently controlled and very high, but for lateral movements the restoring force is extremely low—lower than that of any other pickup known to the author. The vertical compliance is high, although only half that of the Pickering transcription pickup. The pickup is supplied with a transformer in a mu-metal case, the secondary being loaded by a 0.1 or 0.25 megohm resistance. This pickup may be used on any type of record, including microgroove, without changing tracking force. However the force on microgroove can be halved.

Normal tracking pressure	1/8 ounce (3.5 grams)
Lateral compliance	13×10^{-6} cm/dyne
Vertical compliance	0.09×10^{-6} cm/dyne
Arm resonance	5 c/s

Armature resonance not less than 32 000 c/s.
Frequency response flat from 30 to 20 000 c/s, rising to + 2 db at 20 c/s.

Voltage output (across secondary)	10 millivolts
Dynamic mass	about 2 milligrams.

Stylus tips are either diamond or tungsten carbide, the life of the latter being claimed to be much longer than that of sapphire under similar conditions (Refs. 157, 277). Stylus tip radii are 1 mil and 2.5 mils.

It seems likely that the **signal to hum ratio** of the pickup itself is approximately the same as that of a multi-turn moving coil pickup—however see Ref. 312. The hum introduced in the pickup leads and the hum introduced by the transformer are more significant with the ribbon pickup, but may be reduced to very low values by good design.

(viii) Capacitance pickups

A capacitance pickup, in which the movement of the stylus causes a change of capacitance, provides such a small output voltage that it normally requires a very high gain pre-amplifier. However, when it is used to change the frequency of an oscillator, and the output from the oscillator is applied to some form of F-M detector, the output voltage is ample to operate the usual 2-stage amplifier in a radio receiver. In the case of a F-M receiver, the output from the oscillator may be coupled directly to the aerial terminal or to some convenient point in the circuit. Care must be taken to avoid radiation on any band used for radio communication.

A simplified arrangement is shown in Fig. 17.7 in which V_1 is used as an oscillator tuned to resonance by L_1C_1. The inductor L_2 in the grid circuit is made self-resonant at a frequency near that of the plate circuit. Conventional grid-resistor biasing is

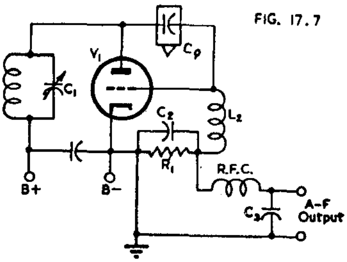


Fig. 17.7. Using a capacitance pickup to provide audio frequency output from an oscillator (Ref. 119).

provided by R_1C_2. The capacitance pickup is connected between grid and plate, and any variation in capacitance will affect the amount of feedback and therefore also the amplitude of oscillation and the voltage drop across R_1. The latter, filtered by RFC and C_3, provides the a-f output which is of the order of 1 volt (Ref. 119).

References to capacitance pickups: 14, 45, 50, 119.

(ix) Eddy-current pickups

In this type of pickup the stylus moves a high-resistance vane in proximity to the inductor of a resonant circuit in an oscillator. The motion of the vane changes the resistance reflected into the tuned circuit and thereby produces amplitude modulation of the oscillator by varying the losses. The amplitude modulation is detected to provide the a-f output voltage. In the Zenith " Cobra " the total harmonic distortion does not exceed 2% and the frequency range extends from 50 to nearly 4000 c/s, with a sharp cut-off at 4000. The level from 1500 to 3500 c/s is 8 db below that at 500 c/s (Ref. 65).

SECTION 4 : TRACKING

(i) General survey of the problem (ii) How to design for minimum distortion (iii) The influence of stylus friction.

(i) General survey of the problem

With any pivoted pickup arm it is obvious that the angle between the axis of the pickup and the tangent to the unmodulated groove must change as the pickup moves across the record. This results in (1) harmonic and inharmonic spurious frequencies caused by frequency modulation ; (2) side thrust on the record grooves ; (3) increased record wear (in extreme cases only).

It is therefore advisable to take steps to reduce these effects to satisfactorily small values. The condition for minimum angular tracking error does not provide minimum distortion, because the tracking angle is most critical at the innermost groove. As a matter of interest, it is possible to design a pickup with an angular tracking error not exceeding 2½° with a length of about 7½ inches, but this is not the optimum design.

References to methods for minimizing angular tracking error: 54 (correction in Ref. 55), 56, 85.

The following summary is based on the detailed analysis by Baerwald (Ref. 228). The subject has also been dealt with in more popular form by Bauer (Ref. 52). The frequency modulation effect is a frequency modulation of the signal by itself, which produces " side band " frequencies. When the signal is a pure sine-wave of frequency f, the dominant " side band " frequency is $2f$, which is the same as the second harmonic. The distortion may therefore be treated as second harmonic distortion, the value being given by:

$$\text{Percentage 2nd harmonic} = (\omega A\alpha/V) \times 100 \quad (1)$$

$$= (v_0\alpha/V) \times 100 \quad (2)$$

where $\omega = 2\pi f$
A = maximum groove amplitude in inches
α = tracking error expressed in radians (= angle in degrees divided by 57.3)
V = longitudinal groove velocity in inches per second.
and v_o = maximum transverse velocity in inches per second = ωA.

Equations (1) and (2) indicate that

(1) Distortion is directly proportional to the maximum transverse velocity.

(2) Distortion is directly proportional to the maximum groove amplitude at any one frequency.

(3) Distortion is directly proportional to the tracking angle.

(4) Distortion is inversely proportional to the revolutions per minute. For equal distortion, more careful tracking angle correction is required with 33-1/3 r.p.m. than with 78 r.p.m., other conditions being the same

(5) Distortion is constant over the " constant velocity " portion of a recording characteristic, other conditions being unaltered

(6) The angular tracking error may be increased in the same proportion that the radius is increased, for the same distortion (roughly 3 : 1 ratio over a 12 inch record).

Example of distortion

Consider the distortion with a 12 inch 78 r.p.m. record having 2° angular tracking at the innermost groove, recorded with a sine wave having a peak amplitude of 0.002 inch at a frequency of 250 c/s (this being the cross-over frequency), the r.m.s. velocity being 6.31 cm/sec.

Here $\alpha = 2/57.3$ radians ; $A = 0.002$; $\omega = 2\pi \times 250$; $r = 1.875$ inches ; $V = 2\pi r(78/60) = 15.3$ inches/second.

From equation (1)

$$\text{Percentage 2nd harmonic} = \frac{2\pi \times 250 \times 0.002 \times 2 \times 100}{57.3 \times 15.3} = 0.72\%.$$

If the cross-over frequency had been 500 c/s, with the same recorded velocity (i.e. half the amplitude), the distortion would have been the same. Some frequency test records are recorded with a velocity less than 6.31 cm/sec, so that the distortion due to tracking error would be less than the value stated above. The harmonic distortion as determined for sinusoidal signals gives a fair estimate of the relative **tracking distortion produced by complex signals** over the " constant velocity " portion of the characteristic.

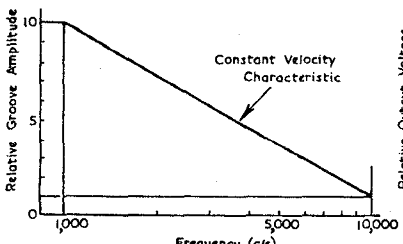


FIG. 17.9

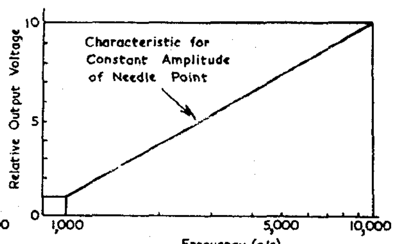


FIG. 17.10

Fig. 17.9. *Constant velocity recording characteristics showing relative variation of groove amplitude with frequency.*

Fig. 17.10. *Frequency characteristic of ideal constant velocity pickup, for constant amplitude of needle point.*

The constant velocity recording characteristic provides a groove amplitude which is inversely proportional to frequency (Fig. 17.9). The ideal constant velocity pickup (a high-fidelity electro-magnetic type is a close approximation) provides an output voltage which is proportional to the frequency, for constant amplitude at the stylus point. It follows that with tracking distortion (or any other form of distortion caused by the groove, needle, or pickup) the harmonics are accentuated in proportion to their frequencies. This effect has been taken into account in the derivation of equations (1) and (2).

It has been proposed (Ref. 228) that a suitable upper limit for tracking distortion is 2% with 0.001 inch peak amplitude as for transcriptions or 4% with 0.002 inch peak amplitude as for shellac discs ; it seems that 1% is a preferable limiting value for good fidelity. On this latter basis the maximum tracking error for 12 inch discs will be 2.8° for 250 c/s cross-over frequency, or 1.4° for 500 c/s crossover frequency, both measured at the innermost groove, or three times these values at the outermost groove.

No additional record wear occurs due to tracking error with permanent needles having spherical tips. Additional record wear may occur with steel needles or with worn sapphire tips if the tracking error is serious.

(ii) How to design for minimum distortion

A straight-arm pickup (not offset) is shown in Fig. 17.11 where D represents the distance from the centre of the record to the pivot of the pickup arm, L represents the length of the arm measured from the pivot to the needle point while r_1 and r_2 represent the radii of the outermost and innermost grooves. In this example the pickup is mounted so that the needle point will pass over the centre of the record, but this is not the position giving the best results. It is obvious that the axis of the pickup is not a tangent to the groove.

Minimum distortion is always obtained from a straight-arm pickup when it is "underhung," that is when the needle point comes short of the centre of the record by a small distance d, the optimum value of which is given below.

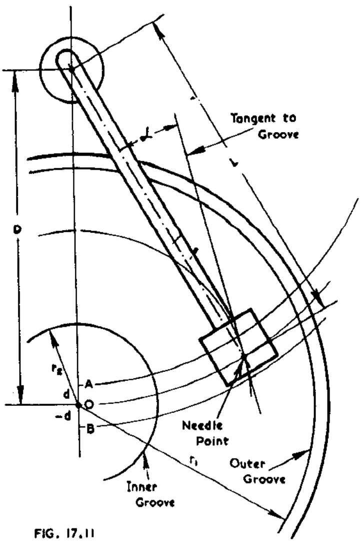


Fig. 17.11. *Straight-arm pickup on record.*

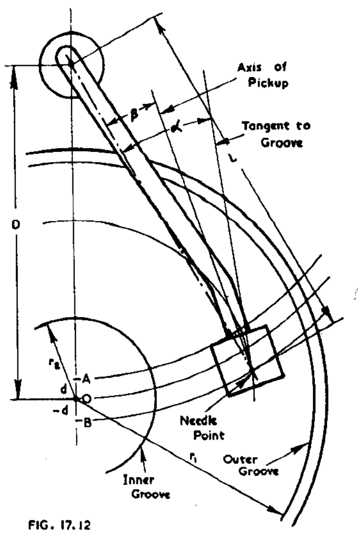


Fig. 17.12. *Offset-arm pickup on record.*

Straight-arm—not offset (Fig 17.11)

$$\text{Optimum underhang} = d_{opt} = \frac{r_1^2 r_2^2}{L(r_1^2 + r_2^2)} \qquad (3)$$

For 10 inch discs $d_{opt} = 3.04/L$.

For 12 inch discs $d_{opt} = 3.18/L$.

These are based on the values :

For 10 inch discs $r_1 = 4.75$ $r_2 = 1.875$ inches.

For 12 inch discs $r_1 = 5.75$ $r_2 = 1.875$ inches.

With $L = 8$ inches, $d_{opt} = 0.380$ inch for 10 inch discs

$= 0.397$ inch for 12 inch discs.

These values for d_{opt} are critical, and should be measured accurately. It is safer to keep below than to go above the optimum overhang.

The angular tracking error α at any position on the record is the angle between the axis of the pickup and the tangent to the groove at the needle point. (Figs. 17.11 and 17.12).

With a straight arm, using any value of underhang (Fig. 17.11),

$$\alpha \approx 57.3\left(\frac{r}{2L} + \frac{d}{r}\right) \tag{4}$$

with an error less than 1°.

The optimum value of underhang is given by eqn. (3) ; using this value and also the values of r_1 and r_2 as for 12 inch discs, with $r = r_2$ (innermost groove) and $L = 8$ inches, the corresponding value of tracking error is approximately 18.6°. The distortion is therefore approximately 6.7% at this point, on the constant velocity characteristic.

Fig. 17.12 shows a pickup with an **offset arm** for the purpose of reducing distortion due to tracking error. This differs from the straight arm in that there is an offset angle β between the axis of the pickup and the straight line joining the pivot to the needle point. Note that this angle β is not equal to the angle of the bend in the arm. In this case minimum distortion is always obtained when the pickup is "overhung," that is when the needle point passes beyond the centre of the record by a distance $-d$, the optimum value of which is given below, on the assumption that the optimum value of offset angle is used.

When a pickup is mounted to provide minimum tracking distortion when used with ordinary needles, the use of bent-shank or trailing type needles will seriously affect the tracking distortion. In cases where either type of needle may be used, a compromise may be necessary. When bent-shank needles only will be used, the increased length of arm should be allowed for.

Offset arm (optimum offset angle) (Fig. 17.12)

$$\text{Optimum overhang} = -d_{opt} = \frac{r_1^2 r_2^2}{L[\frac{1}{4}(r_1 + r_2)^2 + r_1 r_2]} \tag{5}$$

For 10 inch discs $-d_{opt} = 3.99/L$.
For 12 inch discs $-d_{opt} = 4.60/L$.
When $L = 8$ inches :
For 10 inch discs $-d_{opt} = 0.499$ inch.
For 12 inch discs $-d_{opt} = 0.575$ inch.

The optimum offset angle (β in Fig. 17.12) is given by

$$\sin \beta_{opt} = \frac{r_1 r_2 (r_1 + r_2)}{L[\frac{1}{4}(r_1 + r_2)^2 + r_1 r_2]} \tag{6}$$

For 10 inch discs $\sin \beta_{opt} = 2.96/L$.
For 12 inch discs $\sin \beta_{opt} = 3.26/L$.
When $L = 8$ inches :
For 10 inch discs $\beta_{opt} = 21°41'$.
For 12 inch discs $\beta_{opt} = 24°3'$.

The harmonic distortion with optimum overhang and offset angle is given for 12 inch discs approximately by

$$\text{Percentage 2nd harmonic distortion} \approx \frac{5.5}{\sqrt{L^2 - 11.6}}$$

If $L = 8$ inches, 2nd harmonic distortion $\approx 0.76\%$.

(iii) The influence of stylus friction

The stylus friction gives rise to an undesirable excess pressure on the inner groove wall when the optimum offset angle is used. A moderate amount of side-thrust is not detrimental, because it helps to overcome pivot bearing friction, but unduly large values of side-thrust tend to pull the pickup and needle out of the groove towards the centre of the record ; this effect is most pronounced towards the inner groove of the record. In automatic record changers it is sometimes necessary to use an offset angle smaller than the optimum value, accompanied by a reduction in " overhang," and to put up with the increased distortion. With light-weight pickups, manually operated, the side-thrust is harmless when the design is based on minimum distortion.

References to tracking : 52, 53, 54, 55, 56, 85, 228, 249.

SECTION 5 : RECORDING CHARACTERISTICS, EQUALIZERS AND AMPLIFIERS

(i) Recording characteristics (ii) Pre-amplifiers for use with pickups (iii) Introduction to equalizers (iv) High-frequency attenuation (scratch filter) (v) Equalizers for electro-magnetic pickups (vi) Equalizers for crystal pickups (vii) Equalizers applying negative feedback to the pickup (viii) Miscellaneous details regarding equalizing amplifiers (ix) Complete amplifiers (x) Pickups for connection to radio receivers (xi) Frequency test records.

(i) Recording characteristics

If a constant input voltage is applied to a recording amplifier, the curve relating frequency and the r.m.s. velocities recorded is known as the recording characteristic Some ideal theoretical recording characteristics are shown in Fig. 17.13.

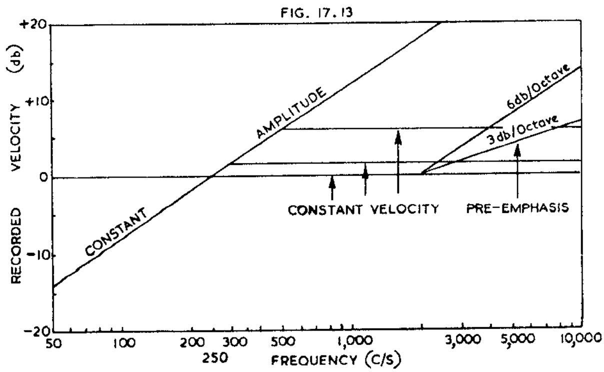


Fig. 17.13. *Ideal recording characteristics.*

The recording characteristic is usually regarded as having three sections—

1. A constant amplitude characteristic from the lowest recorded frequencies to the cross-over frequency. This has a slope of 6 db per octave.

2. A flat characteristic (constant velocity) from the cross-over frequency to the frequency at which high-frequency pre-emphasis commences.

3. A high-frequency pre-emphasis section.

When examining recording characteristics it is helpful to be able to convert readily from db per octave to db for a frequency ratio of 10* :

6 db/octave = 20 db/10 times frequency ratio.

3 db/octave = 10 db/10 times frequency ratio.

The recorded velocity is proportional to the output voltage from an " ideal " electro-magnetic pickup. When using such a pickup it is necessary to boost the output voltage at frequencies below the cross-over frequency, and to attenuate at frequencies covered by the pre-emphasis. This frequency selective amplification is called **equalizing.**

*A table of frequency ratios, octaves and decades is given in Chapter 7 Sect. 3(v), page 368.

Cross-over frequency

The most popular cross-over frequencies are 250, 300, 350 and 500 c/s, and these are compared in Fig. 17.13 on the basis of equal peak amplitude in the constant amplitude sections. For convenience the 250 c/s cross-over point has been taken as 0 db The constant velocity section of the characteristic with 300 c/s cross-over frequency is at a level of + 1.5 db, while that of the characteristic with 500 c/s cross-over frequency is at a level of + 6 db relative to the characteristic with a 250 c/s cross-over frequency.

Thus it is possible to increase the level of recording of the constant velocity section of the characteristic without increasing the maximum amplitude, provided that the cross-over frequency is increased. This appears very attractive at first sight since it increases the signal-to-noise ratio, but for an increase of 6 db above the cross-over frequency it involves

(a) Twice the recorded velocity,
(b) Twice the tracking distortion,
(c) At least twice the harmonic distortion from a given pickup,
(d) An additional 6 db of " equalizing " amplification of low frequencies, tending to cause trouble with hum and rumble.

There is no " optimum " cross-over frequency because the choice is necessarily a compromise. Where distortion is the principal criterion, a low cross-over frequency from 250 to 350 c/s will be adopted for standard groove 78 r.p.m. Where needle scratch is troublesome with 78 r.p.m. a high cross-over frequency of say 500 c/s may be adopted. With fine groove recordings a cross-over frequency of 400 or 500 c/s is about the optimum choice.

In practice the sharp knee between sections 1 and 2 is rounded off ; the cross-over frequency is then defined as the frequency of intersection of the two asymptotes, provided that the recording characteristic at this frequency is not more than 3 db below the point of intersection of the asymptotes.

If the recording characteristic includes high-frequency pre-emphasis, it is necessary to re-draw the curve for the condition without high-frequency pre-emphasis before determining the cross-over frequency as described above.

High-frequency pre-emphasis

The third section of the recording characteristic is the high-frequency pre-emphasis curve. This may, in the ideal case, be taken as a straight line with a slope of, say, 3 or 6 db/octave as in Fig. 17.13. Of course in practice the sharp junction is rounded off and the recording characteristic gradually approaches the " ideal " straight line. Alternatively the pre-emphasis may be specified in the form of a time constant such as, say, 100 microsecond pre-emphasis. The latter method is covered in Chapter 15 Sect. 1(vi); it is restricted to an asymptotic slope of 6 db/octave, but the time constant determines the frequency at which it becomes effective as tabulated below :

Time constant	40	50	75	100	150 μsecs.
Rise of 3 db at	4000	3220	2150	1610	1075 c/s.

All modern American and some English records use some degree of high-frequency pre-emphasis*, although they differ in degree. Assuming that in each case the amplifier is equalized* to provide a level-play-back characteristic, the greater the pre-emphasis the greater the possible dynamic range and the lower the scratch level.

However there are two factors which place a limit on the amount of pre-emphasis which may be used. The first of these factors is the radius of curvature of the groove which at high frequencies and high amplitudes, especially towards the inner portion of the record, cannot be tracked accurately. The radius of curvature is inversely proportional to the maximum amplitude of recording. If the maximum amplitude is reduced, the high frequency pre-emphasis may be increased and in the extreme case constant amplitude recording may be used throughout (Ref. 240).

*Any equalizing which is necessary to correct deficiencies of any of the components of the recording system is corrective equalization, not pre-equalization. The distortion of the frequency characteristic from flat (from air to record track) to some other characteristic is pre-equalization or pre-emphasis (Ref. 247).

There is reason to believe that some record manufacturers who nominally adopt 16 db pre-emphasis at 10 000 c/s use part of this for corrective equalization for deficiencies of their equipment at high frequencies, and only the balance for true pre-emphasis (Refs. 247, 256 ; 193 discussion by E. W. Kellogg).

The second factor is the peak frequency spectrum characteristic of the music being recorded. The effect of the decreased amplitudes at high frequencies in speech and music has been investigated (notably Ref. 42) but there is insufficient information available concerning the instantaneous distribution of energy within the recorded spectrum. Curves based on the work of Sivian, Dunn and White indicate that " no large increase in distortion occurs in reproducing the 16 db pre-emphasized continuous spectrum . . . yet the addition of a few prominent tones to this spectrum in the region above 2000 cycles will result in intolerable distortion " (Ref. 42).

Pre-emphasis on shellac discs

If the tracking* difficulty could be overcome, it is possible that the N.A.B. pre-emphasis characteristic would not be excessive (Ref. 193) but unfortunately it is the tracking* problem which is the stumbling block. In one test, three records were cut simultaneously with different values of pre-emphasis and played back on a system with the maximum de-emphasis. The record with the 6 db pre-emphasis " reproduced more highs and cleaner highs than the one with the 15, indicating that the overload on the latter was so bad that it was not being tracked* " (Ref. 193, discussion by J. P. Maxfield).

The use of the full N.A.B. pre-emphasis (16 db at 10 000 c/s) on standard shellac discs has come in for much criticism. It is claimed that the cymbals and certain brass instruments will overload the system at high frequencies, although this could be taken care of by the use of a limiting amplifier which reduces the gain for the short period required (Ref. 197). Another writer states that trouble had been experienced through overmodulation by second and third harmonics of the soprano voice when a rising characteristic between 1000 and 5000 c/s had been introduced (Ref. 174). Another writer refers to the " muddiness " and " smearing " in the high level, full-orchestra passages of many records (Ref. 117). Still another writer states that the present N.A.B. pre-emphasis curve effectively guarantees excessive distortion and he refers to the insufficient attention which is paid to the difference between transient response tests and the steady state (Ref. 257). Another refers to the fact that the N.A.B. characteristic unduly weights the importance of the signal to noise ratio and produces the undesirable condition of signals having high velocity with high amplitude (Ref. 189). Another again states " since the pickup stylus can track* the recorded high frequencies more clearly without excessive pre-emphasis, the high frequency reproduction from such records is notable for its clarity " (Ref. 241). Other criticisms have also been published (Refs. 155, 174).

It is interesting to note that one leading American manufacturer, R. C. A. Victor, limits the high-frequency pre-emphasis on home records to a maximum value of 12.5 db at 10 000 c/s in place of 16 db as with the N.A.B. characteristic, while the AES Standard Playback Curve provides for 12 db pre-emphasis at 10 000 c/s.

Pre-emphasis with fine groove recordings

Owing to the lower recording level, smaller radius stylus tip and more elastic material with fine groove records, a higher value of high frequency pre-emphasis may be used than with 78 r.p.m. shellac discs, for the same distortion in both cases.

Measurement of recorded velocities

The recorded velocities may be measured either by the light-pattern method (see (v) below) or by the use of a special high-fidelity pickup. These two methods do not give the same result, owing partly to the mechanical characteristics of the record material and partly to the finite needle size which causes tracing distortion (see Sect. 6). It is current practice to use the special pickup at low frequencies and the light-pattern method at high frequencies ; the latter may be checked by the pickup after allowing for the loss caused by tracing distortion. It has been stated that the mechanical impedance limits at the reproducing point should be included in any standardization of frequency characteristic (Ref. 131).

*It is unfortunate that the word " tracking " should be used both here (meaning that the stylus tip is capable of following the modulations in the groove) and also in " tracking distortion " which is due to the angle between the axis of the pickup and the tangent to the unmodulated groove (see Sect. 4). No alternative nomenclature seems to be in current use.

Practical recording characteristics

There does not appear to be any generally accepted definition of published recording characteristics. In most cases, however, it is fairly safe to assume that the user is expected to provide an equalizer amplifier characteristic which is the inverse of the recording characteristic. Of course, some discretion is required in using full equalization for extreme high and low frequencies—this may be provided in the form of tone controls.

The recording characteristics used by English, Australian and the majority of European manufacturers are shown in Fig. 17.14. Curve 1 is that used by the E.M.I. group of companies for all normal 78 r.p.m. recordings. Curve 2 is that used by the Special Recordings Department of E.M.I. Studios Ltd. and is notable in that it extends to 20 000 c/s. Curve 3 is that used by Decca ffrr (1949). Curve 4 that used by the B.B.C. for transcriptions (Ref. 294).

The Decca (London) LP characteristic is not shown on the curves, but is − 17.5 db at 30 c/s, − 14 db at 50 c/s, − 9 db at 100 c/s, − 3 db at 300 c/s, 0 at 1000 c/s, + 14 db at 10 000 c/s and + 16 db at 15 000 c/s (Jan. 1951).

The recording characteristics used by most American record manufacturers are shown in Fig. 17.15. Curve 1 is that used in the Columbia long playing micro-groove

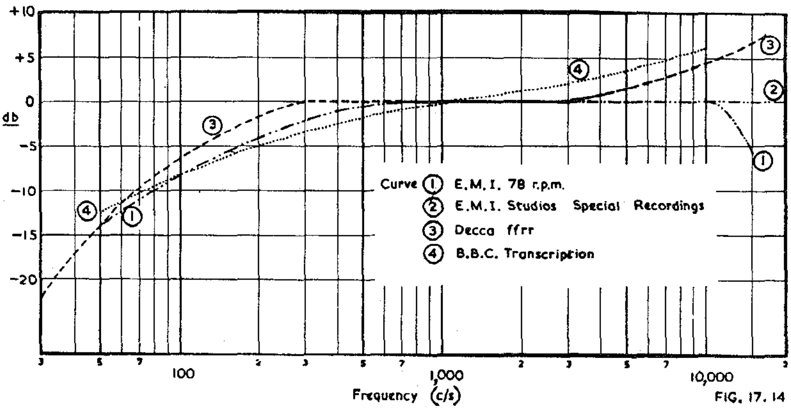


Fig. 17.14. Recording characteristics used by all English, Australian and the majority of European record manufacturers for 78 r.p.m., together with B.B.C. transcriptions.

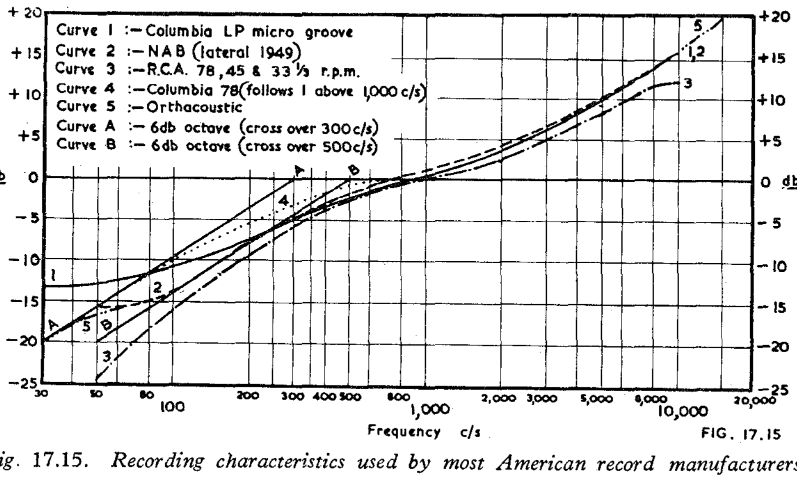


Fig. 17.15. Recording characteristics used by most American record manufacturers.

records. Curve 2 is the N.A.B. (lateral 1949) standard for transcriptions. Curve 3 is that used by R.C.A. Victor for 78 r.p.m. shellac discs, 45 r.p.m. and 33-1/3 r.p.m. fine groove. Curve 4 is that used by Columbia for 78 r.p.m. shellac discs—the cross-over frequency is 300 c/s. Curve 5 is that used for Orthacoustic transcription recording—it follows very closely the N.A.B. curve from 60 to 10 000 c/s but is extended down to 30 c/s (− 20 db) and up to 15 000 c/s.

Standard Playback Curve

For many reasons it has been impossible to achieve a standard recording characteristic, even in a single country and for a specified cross-over frequency. An entirely different approach has been made by the Audio Engineering Society of U.S.A. which has put forward a Standard Playback Curve with the idea of getting this adopted by all designers of equipment for reproduction from records (Ref. 307). The onus would then be on the record manufacturers to produce records which sound well when played with such equipment. The curve (Fig. 17.15A) is based on the frequency of 1000 c/s as a reference point, and the de-emphasis at 10 000 c/s is 12 db, being less than the N.A.B. de-emphasis at this frequency. However the AES playback curve is extended to 15 000 c/s with a de-emphasis of 15.5 db. Both the straight portions of the curve have slopes of 6 db/octave, and the intersections of the extensions of these straight portions with the reference axis occur at 400 c/s (the cross-over frequency) and 2500 c/s.

This playback curve may be duplicated on a flat amplifier with two sections of RC equalization, as shown in Fig. 17.15B, which is one possible arrangement. Alternatively the network of Fig. 17.15C may be used.

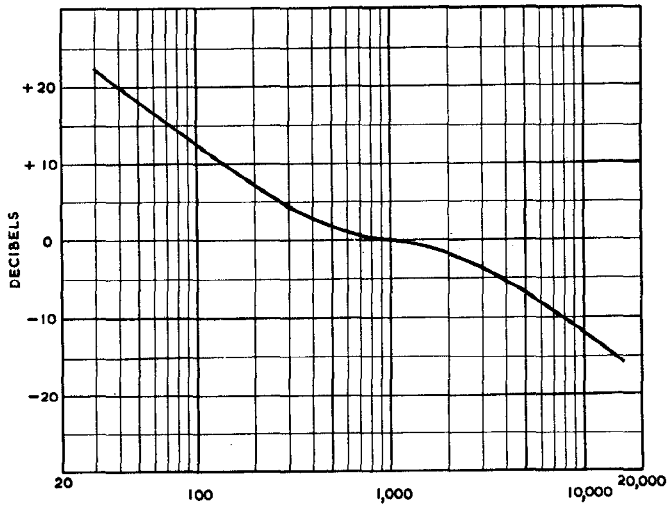


Fig. 17.15A. *AES Standard Playback Curve* (*Ref.* 307).
See Supplement for new Standard Playback Curve.

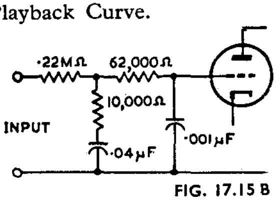
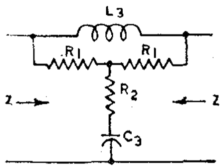


Fig. 17.15B. *High impedance network to provide standard playback curve in grid circuit of amplifier stage* (*Ref.* 307).

It seems that this Standard Playback Curve is what is really needed by the designers of equipment for reproduction from records. Even if record manufacturers do not accept it, the error for any cross-over frequency from 325 to 500 c/s is not more than 2 db, and no problems will be encountered in the reproduction of NAB recording, all fine groove records and most 78 r.p.m. discs except those with a cross-over frequency of 250 c/s and without any high frequency pre-emphasis. The latter may be covered by a separate network.

The C.C.I.R. (Geneva, June 1951) proposed a compromise characteristic with a 450 μsec. curve below 1000 c/s and a 50 μsec. curve above 1000 c/s, giving turnover frequencies of 360 and 2800 c/s, for radio programmes for international exchange.



Z (Ohms)	L3 (H)	C3 (μF)	R1 (Ohms)	R2 (Ohms)
150	0·545	24·08	123*	30
250	0·910	14·44	204	50
500	1·81	7·22	408	101
600	2·18	6·02	491	121

FIG. 17.15C

Fig. 17.15C. *Low impedance network to provide close approximation to standard playback curve, with total insertion loss* 20 *db at* 1000 *c/s* (*Ref.* 307).

General comments

It has been shown that the choice of recording characteristic is necessarily a compromise between many factors.

By careful attention to all aspects of record manufacture, particularly the material used for the pressings, it is possible to produce records having extremely fine performance.

The best of the fine groove records have demonstrated by results that the performance obtainable is equal to that from the best shellac discs, and superior as regards noise. The fact that there are many mediocre recordings of all kinds proves nothing from the technical angle.

Reference to recording characteristics : 62, 63, 88, 131, 155, 156, 174, 197, 214, 240, 247, 307.

(ii) Pre-amplifiers for use with pickups

Pickups may be divided into three groups, those of the high impedance type (e.g. crystal) normally always used with direct connection to a grid circuit, those of the low impedance type normally always used with a step-up transformer, and those which may be either used with or without a transformer.

In all cases, pickups should be loaded by a substantially resistive load of the value specified by the manufacturer, or determined experimentally—see also Sect. 3. A change in load resistance usually results in a change of frequency characteristic.

The equalizer may be incorporated into the first stage of the pre-amplifier—see Sect. 5 : 2(iii), (v), (vi) and (vii)—or it may follow a normal pre-amplifier stage. In the latter case its design is quite straight forward and follows the general principles of r.c.c. amplifiers—see Chapter 12 Sect. 2 for triodes and Sect. 3 for pentodes ; also Chapter 18 Sect. 2 for microphone pre-amplifiers.

Pre-amplifiers for pickups with high output level (e.g. crystal) may usually be designed without special regard to hum or noise. In other cases the pre-amplifier should be designed as for a microphone pre-amplifier—see Chapter 18 Sect. 2.

A modified cathode follower for use as a low-noise input stage for a crystal microphone or pickup is described in Chapter 18 Sect. 2(vi)D and Fig. 18.6B.

(iii) Introduction to equalizers

(A) Low-frequency equalizers

The amount of bass boosting required by various " ideal " recording characteristics is given below. It is assumed that a constant amplitude characteristic is maintained below the cross-over frequency.

Cross-over frequency	250	300	350	400	500	800 c/s
Bass boost at 70 c/s	11.0	12.6	13.8	15.1	17.1	21.1 db
Bass boost at 50 c/s	14.0	15.6	16.8	18.0	20.0	24.0 db
Bass boost at 30 c/s	18.4	20.0	21.2	22.5	24.5	28.5 db

Cheap pickups usually have a peak in the bass region which reduces the amount of bass boosting required, and in some cases no bass boosting whatever is provided by the amplifier.

Some practical recording characteristics have an approach towards a constant velocity characteristic below some low frequency (e.g. Fig. 17.15 Curves 1, 2 and 5). The equalizing circuit should be designed to suit the individual recording characteristic. The following treatment, however, is based on the 6 db/octave constant amplitude characteristic as approached by Fig. 17.14 Curve 1 and Fig. 17.15 Curves 3 and 4.

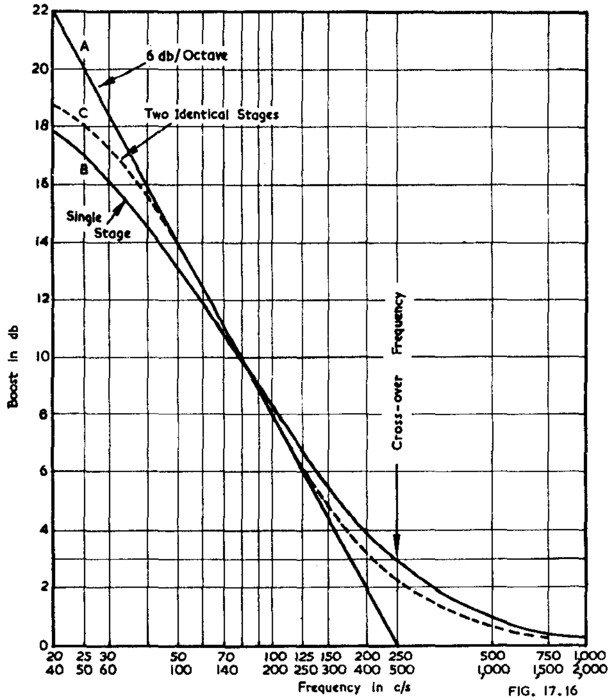


Fig. 17.16. *Bass equalizer characteristics (A) " ideal " characteristic with slope of* 6 *db/octave (B) characteristic with single stage r-c equalizer having total boost of* 20 *db and max. slope* 4.9 *db/octave (C) characteristic with two r.c. stages in cascade, each having total boost* 10 *db and max. slope* 3 *db/octave (circuit as Fig.* 17.17).

Conventional resistance-capacitance equalizing circuits

The form of bass boosting which is normally used results in a " saturation " shape of curve as in Fig. 15.4. Maximum slope is obtained at the point of half total boost, the value being a function of the total boost (Chapter 15 Sect. 2) :

Total boost	20	15	10	6	3 db
Slope at half-boost point	4.9	4.1	3.0	2.0	1.0 db/octave

The desired slope is 6 db/octave, so that there is an appreciable error even with a total boost of 20 db or more. This is plotted in Fig. 17.16 for a total boost of 20 db with alternative frequency scales for 250 and 500 c/s cross-over frequencies. With a cross-over frequency of 250 c/s the error is about − 1 db at 50 c/s and − 2.5 db at 30 c/s, which is generally acceptable, even though there is inevitably some additional loss in the extreme bass, due to coupling condensers. In the case of a cross-over frequency of 500 c/s, however, the error is − 3 db at 50 c/s and − 4 db at 40 c/s, here again increased by the effect of coupling condensers. Some designers adopt a total boost of as much as 40 db to provide a satisfactory characteristic for use with high cross-over frequencies such as 800 c/s. In either case, it is good practice for the amplifier to include a bass tone control which will permit an adjustment to suit the circumstances. If no tone control is fitted, it is usually desirable to attenuate the extremely low frequencies ; a value of coupling capacitance may be chosen to give, for example, an additional 3 db attenuation at 70 c/s and 5 db at 50 c/s.

In the circuit of Fig. 15.3 suitable values of components would be :

V_1 = 6J5 (half 6SN7-GT) ; R_L = 50 000 ohms ; R_1 = 20 000 ohms ; R_2 = 1 megohm ; R_4 = 2800 ohms ; C = 0.25 μF for very good bass response or 0.05 μF for bass attenuation. Voltage gain at 1000 c/s = 1.5 times = + 3.5 db. Total boost = 20 db. C_2 = 0.2 μF for cross-over 250 c/s or 0.1 μF for 500 c/s.

Alternatively the total boost of 20 db could be obtained in **two separate stages** each having a total boost of 1.1 db at the cross-over frequency. By this means a maximum slope of 6 db is obtained at a frequency of 100 or 200 c/s with a cross-over frequency of 250 or 500 c/s and more accurate equalizing is possible. The frequency characteristic obtained is shown with a broken line (C) in Fig. 17.16, and the circuit diagram is given in Fig. 17.17.

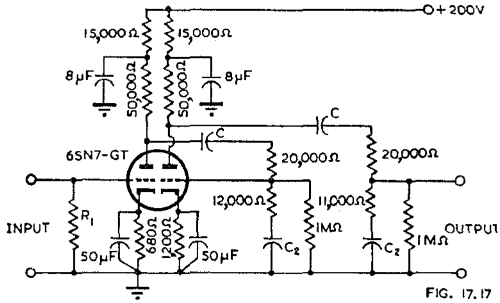


FIG. 17.17

Fig. 17.17. *Circuit diagram of two stage bass equalizing amplifier with bass boosting in each stage. Pin 4 of the 6SN7-GT should be used for the input circuit. Total boost is 20 db and max. slope 6 db/octave. C = 0.25 μF for good bass response or 0.1 μF for some bass attenuation ; C_2 = 0.1 μF for cross-over 250 c/s or 0.05 μF for 500 c/s. Voltage gain at 1000 c/s = 22 times = 26.8 dbvg.*

Instead of having two networks separated by a valve, the complete two-section equalizer may be incorporated into a single network as in Fig. 17.18. The maximum slope is 7 db/octave which is adjustable down to 3 db/octave by means of control R_7, which should be tapered ; maximum slope is obtained with maximum value of R_7. The plate load resistors may be increased if it is desired to increase the gain. This circuit provides 25 db bass boosting with a very close approach to the true 6 db octave slope (when R_7 is correctly adjusted) and has the additional merit of incorporating a tone control providing a total control of 13 db in the region 20 to 50 c/s depending on the cross-over frequency. With an input voltage of about 50 millivolts, the output will be about 1 volt.

Frequency-selective feedback to provide equalizing

A resistance-capacitance network may be used in the feedback loop of an amplifier to provide bass boosting which gives a close approximation to the correct degree of

Fig. 17.18. *Two section equalizer to provide for 3 values of cross-over frequency and adjustable slope of characteristic (Ref.* 127). *V_1 + V_2 = 6SL7 or 6SC7 or 7F7 or any high-mu triodes.*

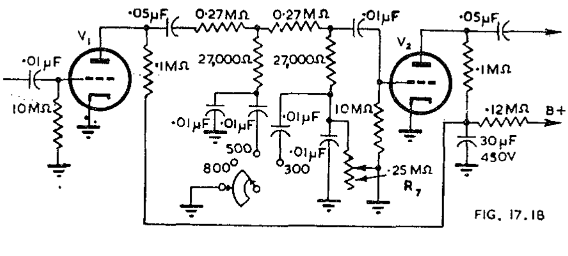


FIG. 17.18

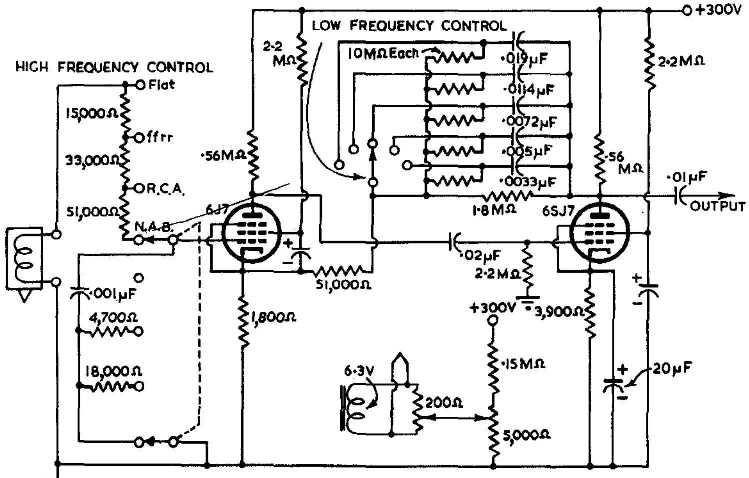


FIG. 17.19A

Fig. 17.19A. *Circuit diagram of equalizing amplifier using negative feedback to provide bass equalizing* (1) 250 *c/s* (2) 300 *c/s* (3) 500 *c/s* (4) 750 *c/s* (5) 1200 *c/s cross-over frequency. A choice of four high-frequency de-emphasis circuits is provided* (1) *flat* (2) *ffrr* (3) *R.C.A.* (4) *N.A.B.* (*Ref.* 239).

FIG. 17.19 B

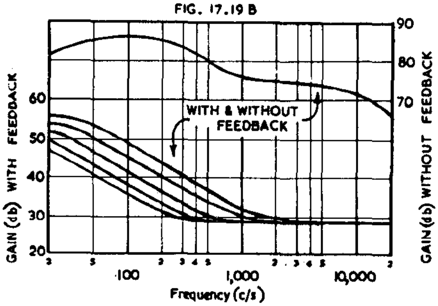


Fig. 17.19B. *Frequency characteristics of circuit of Fig.* 17.19A *with high frequency control in "flat" position* (*Ref.* 239).

FIG. 17.19C

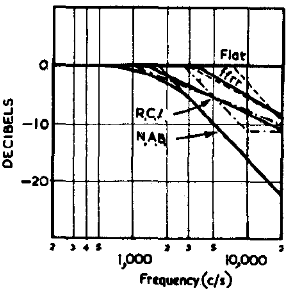


Fig. 17.19C. *High frequency de-emphasis characteristics of the circuit of Fig.* 17.19A (*Ref.* 239).

equalizing. The principle is demonstrated in the circuit of Fig. 15.11 and the frequency characteristics of Fig. 14.12, which are limited to a maximum boost of 12 db. Increased bass boosting could, of course, be obtained by increasing the feedback. With the value of capacitance used in Fig. 15.11 (0.005 μF) a satisfactory compromise is obtained for a cross-over frequency of 250 c/s ; half this capacitance would be suitable for 500 c/s.

This same principle is used in the circuit of Fig. 17.19A to produce the low frequency characteristics of Fig. 17.19B (Ref. 239). The low-frequency control is a shorting type, while the 10 megohm resistors are click suppressors. This circuit also provides four values of high frequency de-emphasis (curves Fig. 17.19C).

Another variation of the same general principle is incorporated in Fig. 17.20 (Ref. 144). It is suitable for use with the GE variable reluctance pickup, or any other low level electro-magnetic pickup which has been equalized to give a constant-velocity characteristic. The values of components are designed for a cross-over frequency of 500 c/s and a high-frequency hinge frequency of 2000 c/s with a slope of 6 db/octave.

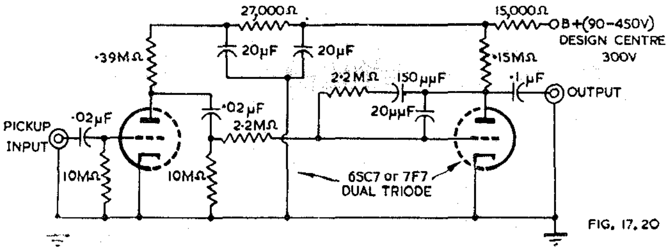
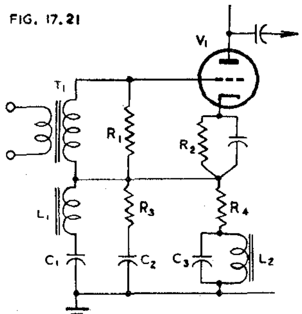


Fig. 17.20. *Circuit diagram of equalizing amplifier for low-level electromagnetic pickup using negative feedback over the second stage to accomplish equalization (Ref.* 144).

A different form of frequency-selective feedback is used in Fig. 17.21 which provides correct equalizing for English (H.M.V.) records from 25 to 8500 c/s within 2.5 db. V_1 is the first pre-amplifier valve having a series tuned circuit L_1C_1 (with a minimum impedance below 25 c/s) in its cathode circuit so that at higher frequencies an increasing proportion of the input signal is fed back. The condenser C_2 in series with R_3 serves to flatten the response above 1000 c/s ; no provision is made for de-emphasis. The level between 250 and 1000 c/s is flattened by the network $L_2C_3R_4$ in which L_2 and C_3 are tuned to 250 c/s. R_4 and L_2 carry the plate current of the valve, and the value of R_1 primarily determines the degree of feedback at 1000 c/s.



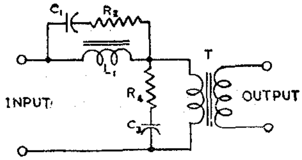


FIG. 17.22

Fig. 17.21. *Frequency selective negative feedback used to provide equalizing for English records.* (*Ref.* 199). V_1 = *MH4* (μ = 40, r_p = 11 000 *ohms*), *load resistance* = 50 000 *ohms.*

Fig. 17.22. *Bass equalizer incorporating L, C and R* (*Ref.* 188).

Bass equalizers incorporating *L*, *C* and *R*

A network incorporating L, C and R may be used to provide a very close approach to the 6 db/octave ideal characteristic, or even higher values if desired. The simplified circuit is shown in Fig. 17.22 in which L_1 is tuned by C_1 to the cross-over frequency, R_2 controls the shape of the band and R_4 controls the slope of the characteristic.

Suggested values for a cross-over frequency of 400 c/s are—L_1 = 2.9 henrys ; C_1 = 0.07 μF ; C_3 = 1.0 μF ; R_2 = 6800 ohms ; R_4 = 2200 ohms.

For a slight change in cross-over frequency only C_1 and R_2 need be altered (Ref. 188).

References to equalizers (general) : 15, 54, 106, 108, 109, 113, 117, 120, 126, 127, 133, 144, 187, 188, 197, 198, 199, 209, 220, 226, 239, 240.

(B) High-frequency equalizers (de-emphasis)

A shunt capacitance provides for attenuation at the nominal rate of 6 db/octave (see Chapter 15 Sect. 6). The attenuation is 3 db when the reactance of the shunt condenser is equal to the resistance of the circuit across which it is connected, that is when

$$C = 1/(2\pi f_0 R) \qquad (1)$$

or capacitance in microfarads $= 157\,000/(f_0R)$ (2)
where C = shunt capacitance in farads
f_0 = frequency at which the attenuation is 3 db (it is also the " hinge point " of the ideal 6 db/octave line)
and R = resistance of circuit across which C is connected, in ohms.

If it is desired to limit the attenuation to a specified value, while approaching the nominal slope of 6 db/octave, the circuit of Fig. 17.23A may be used. Here R_1 represents the resistance of the input circuit ; R_3 should be as high as is practicable—it is assumed to be very much greater than R_2. The maximum attenuation in decibels will be given by

max. attenuation (x db) $= 20 \log_{10}[R_2/(R_1 + R_2)]$ (3)

Eqns. (1) and (2) may be used with reasonable accuracy for maximum attenuations not less than 10 db—at lower values the attenuation at the " hinge point " frequency f_0 will be less than 3 db (the actual values are 2.4 db for 10 db total boost, 2 db for 6 db total boost, 1.2 db for 3 db total boost). The frequency characteristic is indicated in Fig. 17.23B.

FIG. 17.23

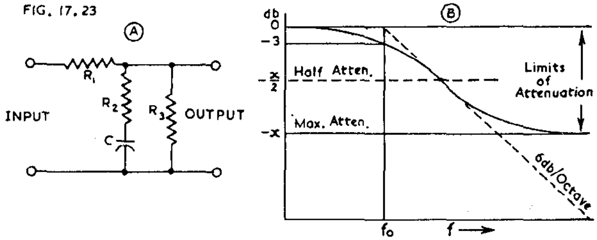


Fig. 17.23. (A) *Circuit providing high-frequency attenuation with a specified limit to the attenuation* (B) *Frequency characteristics.*

If the maximum attenuation is 10 db, the maximum slope (which occurs at half maximum attenuation) is 3 db/octave. This may therefore be used to provide a 3 db/octave de-emphasis characteristic within the limitations of its range.

High frequency equalizers are incorporated in the circuits of Figs. 17.19, 17.20, 17.27.

For general treatment of equalizers see Ref. 258.

(iv) High-frequency attenuation (scratch filter)

In addition to the normal manual tone control it is advisable in good amplifiers to incorporate a filter which provides very rapid attenuation above a certain frequency, say 7000 c/s, so that the upper scratch frequencies on old or noisy records may be rendered inaudible. This is provided by the circuit of Fig. 17.24A (Ref. 15) which has negligible attenuation at 7000 c/s, — 60 db at 8700 c/s and over 36 db attenuation at all frequencies above 8000 c/s. The filter is designed for an impedance of 24 000

FIG. 17.24A

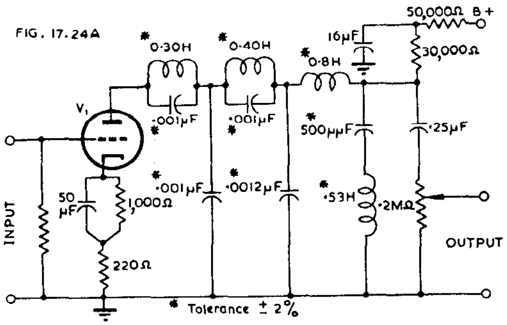


Fig. 17.24A. *Amplifier stage incorporating filter with* 7000 *c/s pass-band and very rapid attenuation at higher frequencies* (*Ref.* 15). V_1 = *MH4*, μ = 40, r_p = 15 000 *ohms.*

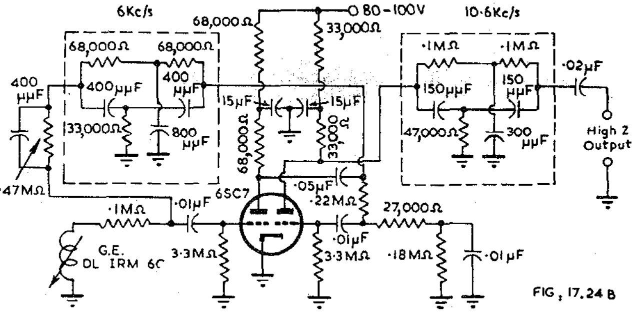


Fig. 17.24B. *Circuit of pre-amplifier and filter circuit with high attenuation at* 10 000 *c/s* (*Ref.* 113).

ohms ; the plate resistance of V_1 is increased to this value by means of a partially unbypassed cathode resistor, while the output end is loaded directly. See reference for coil winding and other details.

An alternative method is used in the pre-amplifier circuit of Fig. 17.24B to produce the response characteristic of Fig. 17.24C. This is suitable for use with low level electro-magnetic pickups. The 10.6 Kc/s parallel-T network provides a maximum attenuation of 34 db, while the 6 Kc/s parallel-T network in the feedback loop removes the attenuation which would otherwise occur at this frequency and thus give a sharper knee (Ref. 113).

There appears to be substantial evidence that too sharp a knee on the attenuation characteristic gives an unpleasant effect to the listener. If the knee is initially too sharp, it may be slightly rounded by the addition of a "roll-off" characteristic at some suitable point—e.g. in the preceding stage.

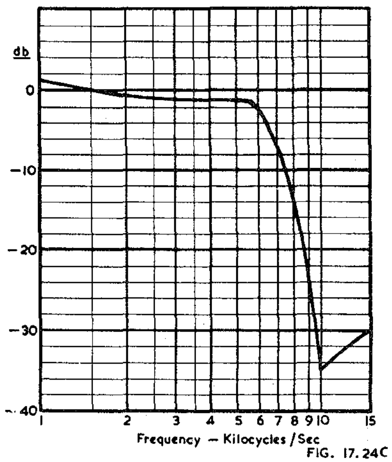


Fig. 17.24C. *Response curve of amplifier and filter shown in Fig.* 17.24B (*Ref.* 113).

(v) Equalizers for electro-magnetic pickups

The general principles of equalizing have been covered in the earlier portion of this section, and may be applied directly to electro-magnetic pickups (Figs. 17.17, 17.18, 17.19, 17.21, 17.22, together with high-frequency de-emphasis). Fig. 17.24B is directly applicable.

With any form of electro-magnetic or dynamic pickup the pickup itself has an impedance which, above about 1000 c/s, is almost entirely inductive reactance. If a capacitance is connected in shunt with the pick-up, or across the secondary of the transformer, this capacitive reactance will resonate with the inductive reactance of the pickup at some frequency determined by *L* and *C*. As a result, the output voltage is boosted at the frequency of resonance and falls rapidly at higher frequencies. If, now, a variable resistance is also connected in shunt with the pickup or across the secondary of the transformer, there will be found a value at which the resonance peak just disappears—this value of shunt resistance is the maximum which can be used to permit the condenser to act purely as an attenuator. For an analysis of this effect on the E.M.I. No 12 pickup see Ref. 109 and for that on the Pickering and G.E. variable reluctance pickups see Ref. 117. The inductance of the E.M.I. No. 12 pickup is of the order of 1 mH. The inductance of the Pickering pickup is approximately 100 mH and that of the G.E. pickup* 120 mH. The correct value of shunt-resistance is given by

R (ohms) $= 1.2\ f_c$ for the Pickering pickup

and R (ohms) $= 0.9\ f_c$ for the G.E. pickup

where f_c is the frequency at which the attenuation is 3 db. Beyond this frequency the rate of attenuation is approximately 15 db/octave.

The shunt capacitance required for various values of the cut-off frequency is :

Frequency		4000	5000	6000	7000 c/s
Capacitance	Pickering	0.02	.013	.009	.0065 μF
	G.E.	0.03	.019	.013	.0095 μF

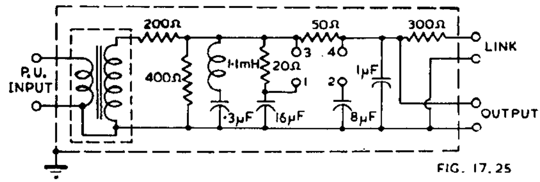


Fig. 17.25. Equalizer for use with E.M.I. and Marconiphone Model 12A pickup. Output as shown is 200 ohms; with link closed, output is 600 ohms. For English E.M.I. records join terminals 1 and 2, also 3 and 4; for N.A.B. and American records leave unjoined. (E.M.I. Australia).

Pre-amplifier for E.M.I. and Marconiphone Model 12A

A suitable equalizer is shown in Fig. 17.25 which gives the following output levels at 1000 c/s with Decca Z718 frequency record.

Termination	Equalizer English	Equalizer N.A.B
200 ohms	− 49 dbm	− 50 dbm
600 ohms	− 54 dbm	− 55 dbm

Pre-amplifier for use with G.E. variable reluctance pickup

The circuit of Fig. 17.26 is suitable for use with the G.E. variable reluctance pickup. This pickup gives an output of about 10 mV (with recorded velocity of 4.8 cm/sec.), the amplifier has a voltage gain of 35 db at 1000 c/s, so that the output voltage is about 0.6 volt. The input shunt resistor of 6800 ohms (which is suitable for the N.A.B. characteristic) may be varied to control the frequency response, a higher value increasing the high frequency response. A low plate voltage is desirable. A slight improvement in response may be effected by shunting the 0.01 μF condenser by a resistance of 180 000 ohms (Ref. 187). See also Fig. 17.34 for input transformer arrangement and Fig. 17.24B as an alternative pre-amplifier.

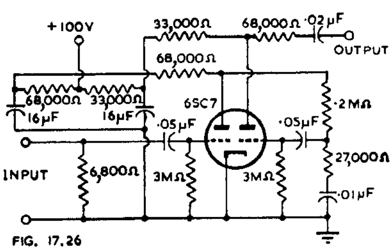


Fig. 17.26. Pre-amplifier and equalizer for use with the G.E. pickup (Ref. 187).

Continuously-variable equalizing pre-amplifier

If a sufficiently flexible equalizer is used, it does not require any additional tone control. Such a circuit is shown in Fig. 17.27A in which the additive method of equalization is employed. This has three transmission channels, one channel having a characteristic which is essentially flat below 1000 c/s, falling off at the rate of 12 db/octave at higher frequencies ; a second channel having 40 db more gain than the basic channel at very low frequencies but with its gain falling off at the rate of 12 db/octave above about 50 c/s ; and a third channel whose gain rises at the rate of 12 db/octave up to 15 000 c/s, above which frequency its gain is 40 db more than the basic

*Later models of G.E. pickups have inductances of 250 mH (Broadcast type RPX-046) and 520 mH (Home type).

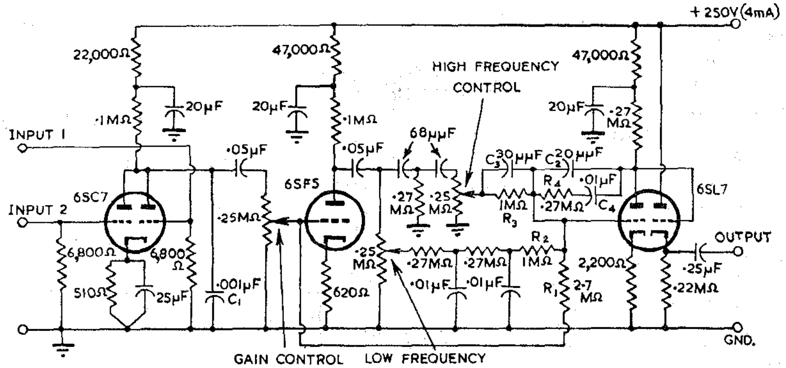


FIG. 17.27A

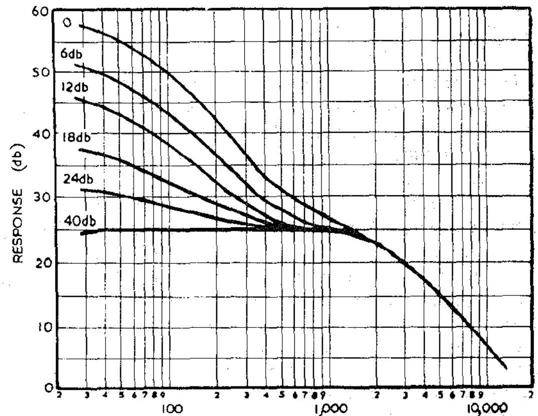


FIG. 17.27B

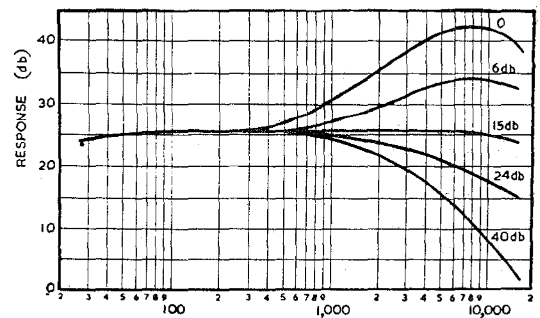


FIG. 17.27C

Fig. 17.27. (A) *Circuit of continuously variable equalizing pre-amplifier* (B) *Variation in attenuation in low frequency control* (C) *Variation in attenuation in high frequency control* (*Ref.* 246).

channel. Outputs from the three channels are added in a single valve feedback summing amplifier ; potentiometers which add flat loss in the auxiliary channels permit control of the resultant transmission characteristic. The input allows for the connection of two G.E. variable reluctance pick-ups simultaneously. The maximum output is of the order of 1 volt, and the pre-amplifier may be used at a moderately remote location, owing to the cathode follower output.

The frequency characteristics are given in Figs. 17.27B and C (Ref. 246).

Equalizers applying feedback to the first pre-amplifier stage

It has been demonstrated by Ellis (Ref. 209) that the feedback circuit may be made frequency-selective to give a close approach to the required equalizing characteristic for an electro-magnetic pickup, as in Fig. 17.28. This circuit does not apply any appreciable feedback to the pickup itself, owing to the isolating resistor R_1. The cross-over frequency may be adjusted by changing either C or R_2, but changing R_2 without making a similar change in R_1 affects the gain. This arrangement is said to be " the quietest and most stable " (Ref. 287), and a very low hum level is possible if the cathode is well by-passed. The input impedance of the stage is low, owing to the feedback circuit. The resistor R_1 should be at least 10 times the nominal impedance of the pickup. The normal gain, above the cross-over frequency, is approximately (R_2/R_1), so that unity gain is obtained when $R_2 = R_1$. By making $R_2 > R_1$ this circuit can provide gain as well as bass boosting, but this reduces the available increase for low frequencies, since the upper limit of gain is the normal gain of the valve without feedback.

FIG. 17.28

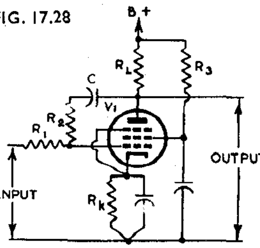


Fig. 17.28. *Equalizer which applies negative feedback to an electro-magnetic pickup (Ref.* 209). *Original values were V_1 = EF36, $R_1 = R_2 = 1\ M\Omega$, $R_L = 0.22\ M\Omega$, $R_3 = 2.2\ M\Omega$, $C = 600\ \mu\mu F$, $E_{bb} = 250$ volts, unity gain.*
Suggested adaptation for 19 *db gain and bass boost of* 26 *db is* : *V_1 = 6J7 or 1620, $R_1 = 0.1\ M\Omega$, $R_2 = 1\ M\Omega$, $R_L = 0.47\ M\Omega$, $R_3 = 3.0\ M\Omega$, $C = 330\ \mu\mu F$ for 500 c/s, or 510 $\mu\mu F$ for 300 c/s, or 620 $\mu\mu F$ for 250 c/s. V_1 may also be replaced by a high-mu triode (6AT6) where $R_1 = 0.1\ M\Omega$, $R_2 = 0.33\ M\Omega$, $R_L = 0.22\ M\Omega$, R_3 omitted, $C = 1200\ \mu\mu F$ for 500 c/s, 2000 $\mu\mu F$ for 300 c/s or 2400 $\mu\mu F$ for 250 c/s, giving gain of 8 db and bass boost of 26 db (see Ref.* 287).

A modification of the circuit of Fig. 17.28 is described in Ref. 280 which gives both bass boosting (with a " very low frequency roll-off ") and high frequency de-emphasis. Values of components are : R_1 = 0.33 megohm, R_2 = 1.0 megohm, R_L = 0.22 megohm, C = 600 $\mu\mu$F approx. (adjustable), C_2 = 25 $\mu\mu$F approx. (adjustable) shunted across R_2, and V_1 = EF37.

A different modification of this circuit is given in Fig. 15.13 ; see Chapter 15 Sect. 2(iv)C This modified circuit enables adjustment to be made for any cross-over frequency by means of a continuously variable potentiometer ; unfortunately no measured frequency characteristics have been published but this circuit seems to be close to the ideal for simplicity and to provide a response characteristic as good as that of any other RC feedback amplifier.

(vi) Equalizers for crystal pickups

A crystal pickup, when working into a high load resistance of the order of 2 to 5 megohms gives a practically level response characteristic over the constant amplitude section of a gliding-tone frequency test record (A in Fig. 17.30). If the load resistance is decreased to 0.5 megohm (Curve B) the output at 50 c/s may fall in a typical case by 6 db, the attenuation ratio at other frequencies being inversely proportional to the frequency.

High temperatures cause a reduction in bass response ; an increase from 68°F to 104°F causing a decrease of about 5 db at 50 c/s in a typical case (Curve B).

The output from a crystal pickup is so high that, if it is not attenuated between the pickup and the first amplifier stage, it may overload the valve. Unless the equalizer provides heavy attenuation, it is advisable to place the volume control between the pickup and the first grid.

Above the cross-over frequency the output voltage from an unequalized high-fidelity crystal pickup tends to fall at the rate of 6 db/octave. In popular types there is usually a resonance peak which gives some additional lift to the top end of the characteristic, thus decreasing the amount of equalization required.

A simple equalizer for use with crystal pickups is shown in Fig. 17.29. If R_2 = 0.5 megohm, R_1 may be taken as $10R_2$ or 5 megohms. This gives an attenuation at very low frequencies of 20.8 db. The effect of variation of C_1 is shown in curve C Fig. 17.30 ; these response curves are only satisfactory when considerable high-frequency de-emphasis is required.

FIG. 17.29

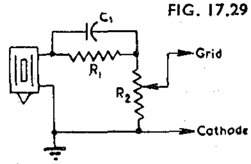


Fig. 17.29. *Simple equalizer circuit for a crystal pickup.*

Better equalization is obtained when $R_1 = 40R_2$, thus giving a maximum attenuation of 32 db. Suitable values are : R_1 = 5 megohms, R_2 = 0.125 megohm, $C_1 = 100\ \mu\mu F$. The resultant response curve is shown in curve D.

A more flexible equalizer suitable for use with a high-fidelity crystal pickup is shown in Fig. 17.31 (Ref. 127). This gives a choice of three load resistors, thus giving some control of the bass, and three values of capacitance suitable for three cross-over frequencies.

An improved equalizing circuit suitable for use with the Acos GP12 high-fidelity pickup is shown in Fig. 17.32 (Ref. 120). This gives correct equalization for H.M.V. records within + 2.5 db, − 3.5 db from 30 to 8000 c/s.

An equalizer suitable for use with the Brush high-fidelity pickup is shown in Fig. 17.33 (Ref. 106). Position (1) is for quiet shellac records with a 500 c/s cross-over

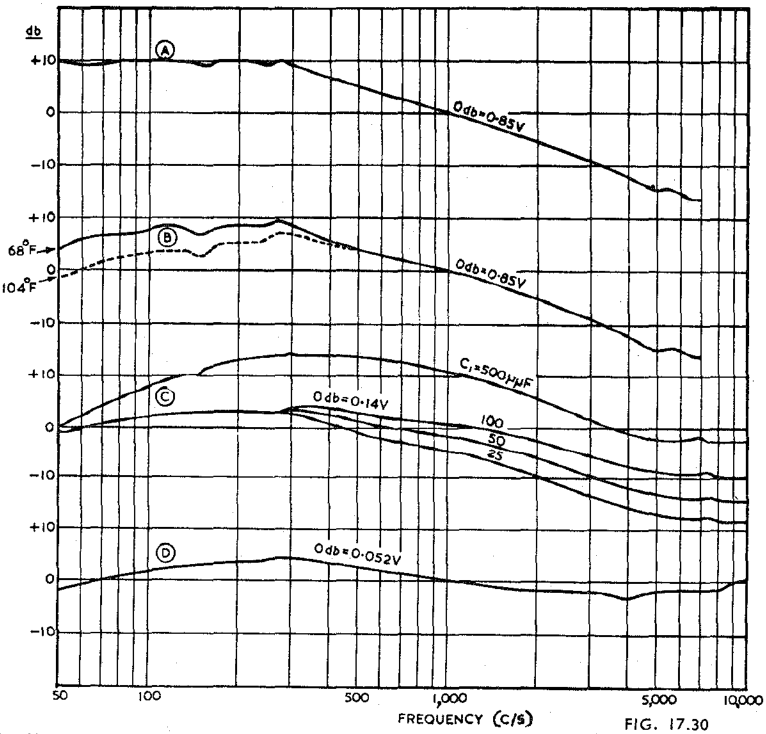
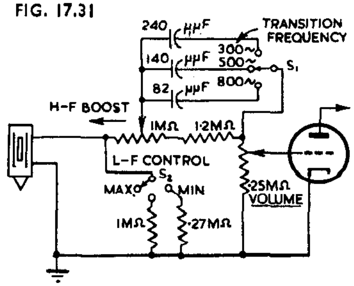


FIG. 17.30

Fig. 17.30. *Response curves of typical crystal pickup.* (*A*) *load resistance 2 megohms, temperature 68° F* ; (*B*) *load resistance 0.5 megohm, temperature 68° and 104°F* ; (*C*) *with simple equalizer circuit as Fig. 17.29 having R_2 = 0.5 megohm, R_1 = 5 megohms* ; (*D*) *with R_2 = 0.125 megohm, R_1 = 5 megohms, C_1 = 100 μμF. Test record Audiotone for* (*A*), (*B*) *and* (*C*) ; *Columbia M-10 003 for* (*D*). *Curves based on data for Astatic FP-18.*

FIG. 17.31



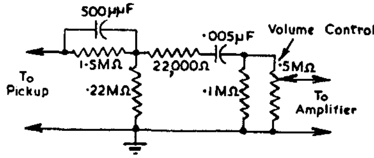


FIG. 17.32

Fig. 17.31. *Flexible equalizer for high-fidelity crystal pickups (Ref.* 127).
Fig. 17.32. *Equalizer for Acos GP12 high fidelity crystal pickup, for* 250 *c/s cross-over frequency (Ref.* 120).

frequency ; (2) for scratchy and noisy shellac records ; (3) good Orthacoustic transcriptions and (4) noisy transcriptions. The low frequency filter reduces rumble and hum.

See also Sect. 5(x).

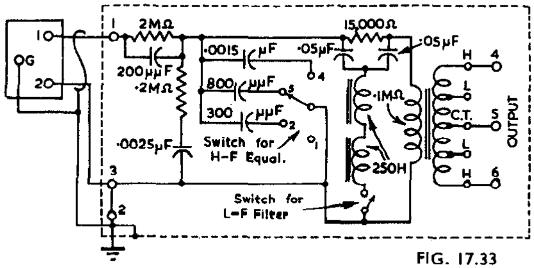


FIG. 17.33

Fig. 17.33. *Equalizer for use with Brush high-fidelity crystal pickup (Ref.* 106).

(vii) Equalizers applying negative feedback to the pickup

It is advantageous in all cases to apply negative feedback to the pickup, whether electro-magnetic or crystal. This may be accomplished in any conventional manner and the feedback reduces non-linear distortion and the effects of mechanical resonances.

Various possible combinations of *CR* and *LCR* in the feedback network of both crystal and electro-magnetic pickups are described in Ref. 220. Most of these apply a very limited amount of feedback, but the same principle could be applied to a high-gain pre-amplifier stage with increased feedback. It is evident that any type of pickup may be equalized by this method, with the additional advantages of increased damping on the pickup. It seems that more detailed investigation of the subject is well merited.

(viii) Miscellaneous details regarding equalizing amplifiers

Position of equalizer

In general it is preferable to place the equalizer following the first stage of the pre-amplifier in the case of low level pickups. With high level pickups it may be possible to incorporate the equalizer in the main amplifier.

Input transformers

Although input transformers are not necessary with electro-magnetic pickups, they have some distinct advantages. The step-up ratio provides useful gain, while they permit the use of a balanced-to-earth input line which gives improved signal-

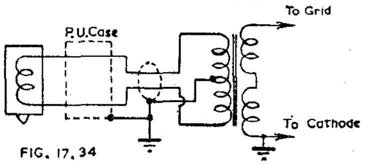


FIG. 17.34

Fig. 17.34. *Low impedance pickup with balanced-to-earth input to step-up transformer.*

to-noise ratio (Fig. 17.34). With low level pickups the transformer improves the signal-to-hum and signal-to-noise ratios.

Rumble

Rumble may be reduced, if necessary, by a filter which cuts off sharply below, say, 50 c/s. The cut-off frequency and attenuation necessary are dependent upon the motor, turntable and amount of bass boosting in the equalizer and tone control. One example is incorporated in Fig. 17.35B.

(ix) Complete amplifiers

Complete amplifiers for the reproduction of sound from records may include—

1. A suitable pickup.

2. An equalizer to provide constant velocity output (only required for electro-magnetic pickups, and even then only when not provided as part of the main equalizer).

3. A first stage pre-amplifier (only required in the case of a low level pickup).

4. A main equalizer, preferably provided with adjustable cross-over frequencies and variable high-frequency de-emphasis.

5. A tone control, preferably comprising separate bass and treble controls. If the main equalizer has flexible adjustments of its characteristics, it may be used in place of a separate tone control.

6. A rumble filter, preferably with switch to cut in or out (may be omitted if response is attenuated below 70 c/s).

(Continued on page 748)

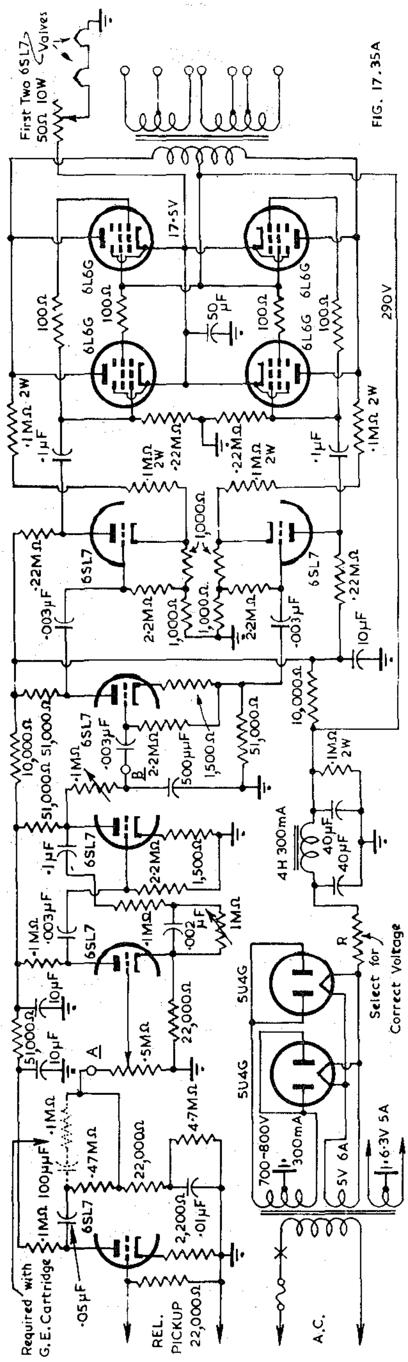


Fig. 17.35A. *Circuit of* 25 *watt amplifier using G.E. variable reluctance or Pickering* 120*M pickup* (*Ref.* 240).

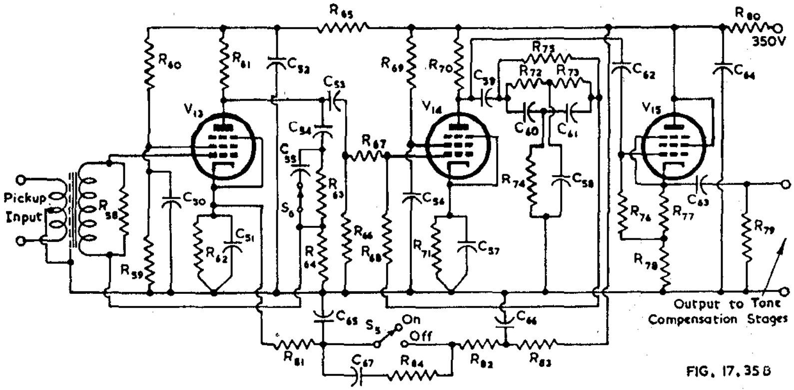


Fig. 17.35B. *Williamson pre-amplifier including equalizer and high-pass filter (rumble attenuator). Ref.* 270. *In the original amplifier* $V_{13} = V_{14} = V_{15} =$ *type EF37.* V_{13} *and* V_{14} *may be replaced by type* 6J7 *or* 1620 *if* $R_{71} = 1600\ \Omega$.

		Type	*Rating*	*Tolerance*
R_{58}	*Value to suit transformer*	*High-stability carbon*		
R_{59}	0.1 $M\Omega$	*High-stability carbon*	½*W*	20%
R_{60}	0.68 $M\Omega$	*High-stability carbon*	½*W*	20%
R_{61}	0.22 $M\Omega$	*High-stability carbon*	½*W*	20%
R_{62}	4700 Ω	*High-stability carbon*		20%
R_{63}	0.22 $M\Omega$	*Composition*		10%
R_{64}	20 000 Ω	*Composition*		
R_{65}	22 000 Ω	*High-stability carbon*	½*W*	20%
R_{66}	0.22 $M\Omega$	*Composition*		10%
R_{67}	0.20 $M\Omega$*	*Composition*		
R_{68}	4.7 $M\Omega$	*Composition*		5%
R_{69}	1.0 $M\Omega$	*Composition*	½*W*	20%
R_{70}	0.22 $M\Omega$	*Composition*	½*W*	20%
R_{71}	2200 Ω	*Composition*		20%
R_{72}	2.0 $M\Omega$	*Composition*		1% or *matched*
R_{73}	2.0 $M\Omega$	*Composition*		1% *or matched*
R_{74}	1.0 $M\Omega$	*Composition*		1% *or matched*
R_{75}	10 $M\Omega$	*Composition*		5%
R_{76}	47 000 Ω	*Composition*		10%
R_{77}	1000 Ω	*Composition*		20%
R_{78}	47 000 Ω	*Composition*	1 *W*	20%
R_{79}	0.22 $M\Omega$	*Composition*		20%
R_{80}	10 000 Ω	*Composition*	1 *W*	20%
R_{81}	0.22 $M\Omega$		½*W*	
R_{82}	0.22 $M\Omega$		½*W*	
R_{83}	47 000 Ω			
R_{84}	100 Ω			

All resistors may be ¼*W rating, tolerance* 20% *unless otherwise specified.*
*May require adjustment.

			(V d.c. working)	
C_{50}	0.5 μF	*Paper*	250	20%
C_{51}	50 μF	*Electrolytic*	12	

C_{52}	16 μF	*Electrolytic*	450	
C_{53}	0.02 μF	*Paper*	350	10%
C_{54}	4000 $\mu\mu F$	*Silvered mica*	350	10%
C_{55}	100 $\mu\mu F$	*Silvered mica*	350	10%
C_{56}	50 μF	*Electrolytic*	12	
C_{57}	50 μF	*Electrolytic*	12	
C_{58}	0.01 μF	*Silvered mica*	350	1% *or matched*
C_{59}	0.25 μF	*Paper*	500	20%
C_{60}	5000 $\mu\mu F$	*Silvered mica*	350	1% *or matched*
C_{61}	5000 $\mu\mu F$	*Silvered mica*	350	1% *or matched*
C_{62}	7000 $\mu\mu F$	*Silvered mica*	350	10%
C_{63}	0.5 μF	*Paper*	500	20%
C_{64}	16 μF	*Electrolytic*	450	
C_{65}	4 μF		250	
C_{66}	2 μF		350	
C_{67}	0.1 μF		350	

S_5 *single pole single throw*
S_6 *single pole single throw*

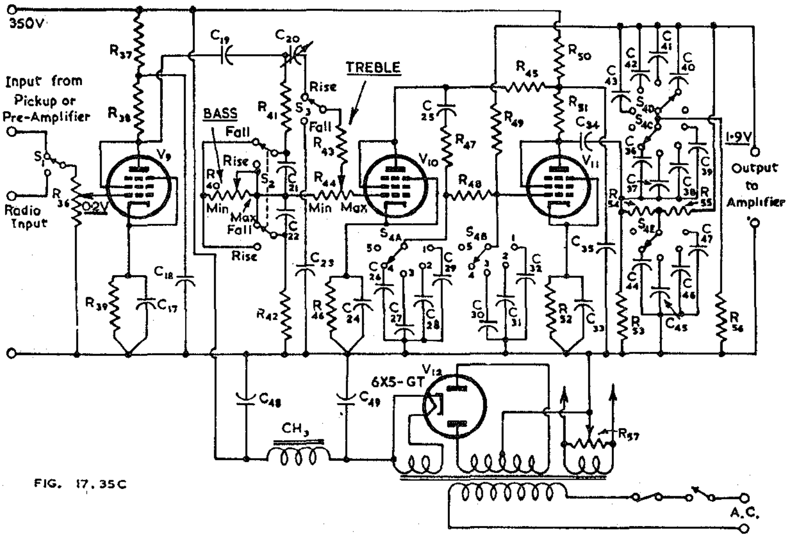


FIG. 17.35C

Fig. 17.35C. *Williamson tone compensation and filter unit* (*Ref.* 270). *In the original amplifier* $V_9 = V_{10} = V_{11}$ = *type* EF37. *All may be replaced by type* 9002, *or by type* 6*AU*6 *with a slight increase in gain, or by type* 6J7 (*or* 6J5 *triode*) *with a slight decrease in gain.*

		Rating	*Tolerance*
R_{36}	0.25 $M\Omega$ *log.*		
R_{37}	47 000 Ω	1*W*	
R_{38}	47 000 Ω	1*W*	
R_{39}	3300 Ω		
R_{40}	0.25 $M\Omega$ *log.*		
R_{41}	100 000 Ω		
R_{42}	6800 Ω		
R_{43}	10 000 Ω		
R_{44}	0.1 $M\Omega$ *linear*		

R_{45}	100 000 Ω	1*W*	
R_{46}	2200 Ω		
R_{47}	0.1 *M*Ω		10%
R_{48}	0.47 *M*Ω		10%
R_{49}	0.47 *M*Ω		10%
R_{50}	33 000 Ω	1*W*	
R_{51}	100 000 Ω	1*W*	
R_{52}	3300 Ω		
R_{53}	1 *M*Ω		
R_{54}	0.1 *M*Ω		1% *or matched*
R_{55}	0.1 *M*Ω		1% *or matched*
R_{56}	50 000 Ω		1% *or matched*
R_{57}	100 Ω		

All resistors may be ¼W rating, tolerance 20% unless otherwise specified.

		Type	*Rating (V d.c. working)*	*Tolerance*
C_{17}	50 *μF*	*Electrolytic*	12	
C_{18}	8 *μF*	*Electrolytic*	450	
C_{19}	0.25 *μF*	*Paper*	500	20%
C_{20}	150 *μμF max.*	*Preset*		
C_{21}	0.01 *μF*	*Paper*	250	20%
C_{22}	0.05 *μF*	*Paper*	250	20%
C_{23}	1000 *μμF*	*Silvered mica*		20%
C_{24}	50 *μF*	*Electrolytic*	12	
C_{25}	0.05 *μF*	*Paper*	500	20%
C_{26}	100 *μμF*	*Silvered mica*		5%
C_{27}	200 *μμF*	*Silvered mica*		5%
C_{28}	300 *μμF*	*Silvered mica*		5%
C_{29}	500 *μμF*	*Silvered mica*		5%
C_{30}	50 *μμF*	*Silvered mica*		5%
C_{31}	100 *μμF*	*Silvered mica*		5%
C_{32}	250 *μμF*	*Silvered mica*		5%
C_{33}	50 *μF*	*Electrolytic*	12	20%
C_{34}	0.05 *μF*	*Paper*	500	
C_{35}	8 *μF*	*Electrolytic*	450	
$C_{36, 40}$	75 *μμF*	*Silvered mica*		1% *or matched*
$C_{37, 41}$	100 *μμF*	*Silvered mica*		1% *or matched*
$C_{38, 42}$	150 *μμF*	*Silvered mica*		1% *or matched*
$C_{39, 43}$	200 *μμF*	*Silvered mica*		1% *or matched*
C_{44}	150 *μμF*	*Silvered mica*		1% *or matched*
C_{45}	200 *μμF*	*Silvered mica*		1% *or matched*
C_{46}	300 *μμF*	*Silvered mica*		1% *or matched*
C_{47}	400 *μμF*	*Silvered mica*		
C_{48}	16 *μF*	*Electrolytic*	450	
C_{49}	16 *μF*	*Electrolytic*	500	

Choke : CH_3 50 *H at* 20 *mA*. *Resistance about* 1500 Ω.
Mains Transformer—
Primary : 200-220-240 *V*, 50 *c/s*.
Secondaries : 1. 325-0-325 *V*, 20 *mA d.c.*
2. 6.3 *V*, 0.6*A*.
3. 6.3 *V*, 1.5*A*.

Switches—
S_1 Single pole single throw.
S_2 Double pole single throw.
S_3 Single pole single throw.
S_4 5 bank, 5 position selector switch.

7. A high frequency attenuator or filter for worn or noisy records (may be omitted if a sufficiently flexible tone control is fitted). One very effective form of filter is a capacitance connected across the secondary of the output transformer—see page 214.

An example of a complete amplifier is given in Fig. 17.35A. This is a 25 watt amplifier suitable for operation from a G.E. variable reluctance pickup, or Pickering 120M. The total harmonic distortion is under 1%. The pre-amplifier consists of a triode with proper compensation in the output circuit. Bass boosting is obtained by the use of frequency-selective negative feedback in the second and third stages. Hum from the heater is reduced to the vanishing point by making the heaters of the first two twin triodes part of the cathode resistor of the output stage. The output stage draws approximately 300 mA, which is the correct current for the heaters of the 6SL7 valves, and the additional bias required for the output valves is obtained by a resistor (Ref. 240).

Another example of a complete amplifier is that due to D. T. N. Williamson (Ref. 270) shown in Figs. 17.35 B, C, D, E, F and G. The main amplifier (Fig. 17.35F) is a new version of the earlier Williamson amplifier of which one adaptation is Fig. 7.44. The circuit differs in minor details only from Fig. 7.44 ; the balancing adjustment on V_1 and V_2 has been omitted as unnecessary, provided that $R_5 R_7$ R_{11} and R_{13} have the specified values and tolerances, while a transitional phase-shift network $R_{26} C_{10}$ has been added to increase the margin of stability at high frequencies.

Output transformer specifications (3.6 ohm secondaries)—Williamson Amplifier :

Core : 1¾ in. stack of 28A Super Silcor laminations (M. and E.A.). The winding consists of two identical interleaved coils each 1½ in. wide on paxolin formers 1¼ in. × 1¾ in. inside dimensions. On each former is wound :

5 primary sections, each consisting of 440 turns (5 layers, 88 turns per layer) of 30 S.W.G. enamelled copper wire interleaved with 2 mil. paper,

alternating with

4 secondary sections, each consisting of 84 turns (2 layers, 42 turns per layer) of 22 S.W.G. enamelled copper wire interleaved with 2 mil. paper.

Each section is insulated from its neighbours by 3 layers of 5 mil. Empire tape. All connections are brought out on one side of the winding, but the primary sections may be connected in series when winding, two primary connections only per bobbin being brought out. Windings to be assembled on core with one bobbin reversed, and with insulating cheeks and a centre spacer.

Curves showing the loop gain and phase-shift characteristics of the main amplifier are shown in Fig. 17.35G.

The pre-amplifier Fig. 17.35B has a voltage gain of 250 times from the grid of the first valve to the voltage across the output terminals. The input grid voltage must not be less than 0.8 mV ; this minimum voltage can readily be provided by a suitable transformer from any pickup. Care should be taken to avoid overloading the pre-amplifier by too high an input voltage. The overall frequency response, when tested with an ideal "velocity" pickup on an English Decca disc is level within 1 db from 20 to 14 000 c/s ; below 20 c/s there is attenuation at the rate of 30 db/octave to eliminate rumble. For the English E.M.I. characteristic, switch S_1 should be opened. Other recording characteristics can be handled by the use of the tone compensation unit.

This overall frequency characteristic, which provides bass boosting and high-frequency de-emphasis to suit the recording characteristic, together with a rumble filter, is provided by a careful combination of

(1) bass boosting by V_{13} together with the feedback network C_{54} C_{55} R_{63} R_{64}.

(2) Attenuation produced by the combined inter-valve couplings.

(3) Feedback over V_{14}, through the parallel-T network. This provides a peak at 20 c/s which is used to give a sharp knee to the frequency characteristic instead of the gradual attenuation produced by the inter-valve couplings. (Note that the recording characteristic contributes 6 db/octave to the slope below 20 c/s).

The final stage V_{15} is merely a cathode follower to permit the use of long leads between the pre-amplifier and the tone-compensation unit.

If a high-impedance output is permissible, and an attenuation of 8 db at 10 c/s is sufficient to reduce the rumble, stage V_{13} may be used as a single stage pre-amplifier with a gain of 11 times. Under these circumstances $C_{53} = 0.05\ \mu F$, $C_{54} = 4000\ \mu\mu F$, $R_{64} = 22\,000$ ohms, $R_{66} = 2.2\ M\Omega$, R_{67} is omitted, and the output is taken from the junction of C_{53} and R_{66}.

In the cathode circuit of V_{13}, closing the switch S_5 reduces the gain to zero in about 1 second for use while changing records.

The noise level, with R_{57} adjusted for minimum hum, is about 3 to 5 μV at V_{13} grid, excluding the noise due to the pickup transformer and auxiliaries. The total harmonic distortion of the pre-amplifier and tone compensation units combined, is considerably less than 0.1%.

The tone compensation and filter unit Fig. 17.35C provides—

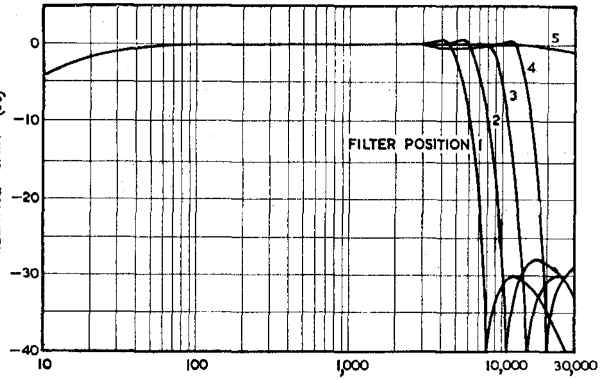


Fig. 17.35D. *Measured overall response of low-pass filter (stage* V_{11} *in Fig.* 17.35C *together with network controlled by switch* S_4*). Ref.* 270.

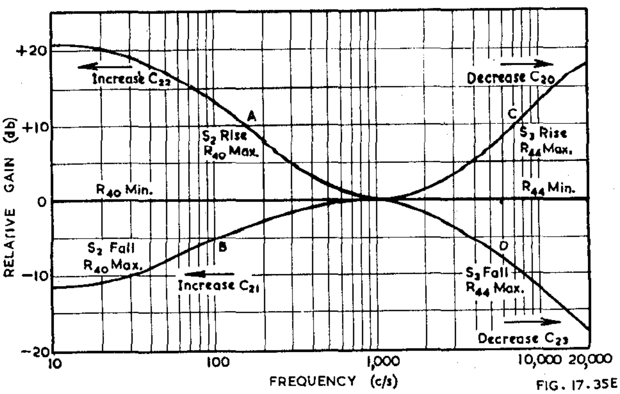


Fig. 17.35E. *Response curves of the tone compensation circuit following* V_9 *in Fig.* 17.35C. *Curves are limiting positions for continuously-variable controls (Ref.* 270).

(1) A universal tone control (switches S_2S_3 and controls $R_{40}R_{44}$) with frequency characteristics as Fig. 17.35E. The curves may be shifted bodily along the horizontal axis by modifying the capacitance values shown by the arrows in Fig. 17.35E.

(2) A low-pass filter with nominal cut-off values of 5000, 7000, 10 000 and 13 000 c/s, together with a flat position (switch S_4) providing response characteristics as Fig. 17.35D. This characteristic is provided by a parallel-T network in the feedback loop of V_{11} which gives a symmetrical valley at the frequency of resonance. A capacitor from the grid of V_{11} to earth introduces a lagging phase shift which gives

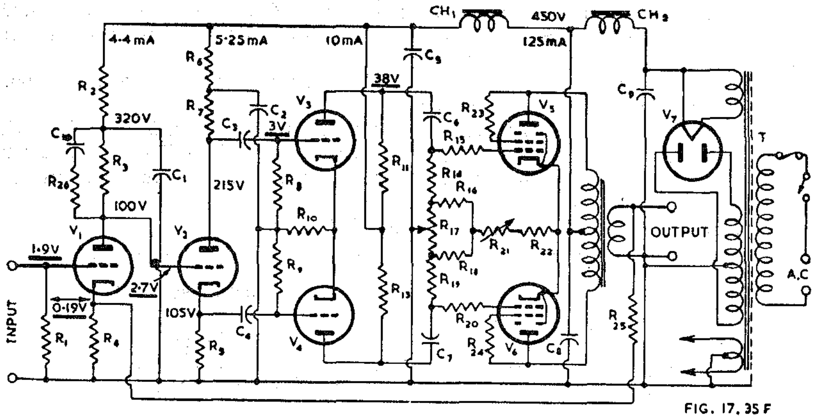


FIG. 17. 35 F

Fig. 17.35F. *Williamson main amplifier—new version (Ref.* 270). *Voltages underlined are peak signal voltages at* 15 *watts output.*

R_1	1 $M\Omega$	¼ *watt* ± 20%
R_2	33 000 Ω	1 *watt* ± 20%
R_3	47 000 Ω	1 *watt* ± 20%
R_4	470 Ω	¼ *watt* ± 10%
R_5, R_7	22 000 Ω	1 *watt* ± 5% (*or matched*)
R_6	22 000 Ω	1 *watt* ± 20%
R_8, R_9	0.47 $M\Omega$	¼ *watt* ± 20%
R_{10}	390 Ω	¼ *watt* ± 10%
R_{11}, R_{13}	47 000 Ω	2 *watt* ± 5% (*or matched*)
R_{14}, R_{19}	0.1 $M\Omega$	¼ *watt* ± 10%
R_{15}, R_{20}	1000 Ω	¼ *watt* ± 20%
R_{16}, R_{18}	100 Ω	1 *watt* ± 20%
R_{17}, R_{21}	100 Ω	2 *watt wirewound variable*
R_{22}	150 Ω	3 *watt* ± 20%
R_{25}	1200 $\Omega \times \sqrt{\text{speech coil impedance}}$	¼ *watt*
R_{26}	4700 Ω	¼ *watt* ± 20%
C_1, C_2, C_5, C_8	8 μF	500V *wkg.*
C_3, C_4	0.05 μF	350V *wkg.*
C_6, C_7	0.25 μF	350V *wkg.*
C_9	8 μF	600V *wkg.*
C_{10}	200 $\mu\mu F$	350V *wkg.*
CH_1	30H *at* 20 mA	
CH_2	10H *at* 150 mA	
T	*Power transformer*	

Secondary 425-0-425V, 150 mA, 5V, 3A, 6.3V, 4A, *centre-tapped*

V_1, V_2 2 × *L*63 *or* 6*J*5, 6*SN*7 *or B*65

V_3, V_4 *do.* *do.*

V_5, V_6, *KT*66, V_7 *Cossor* 53*KU*, 5*V*4.

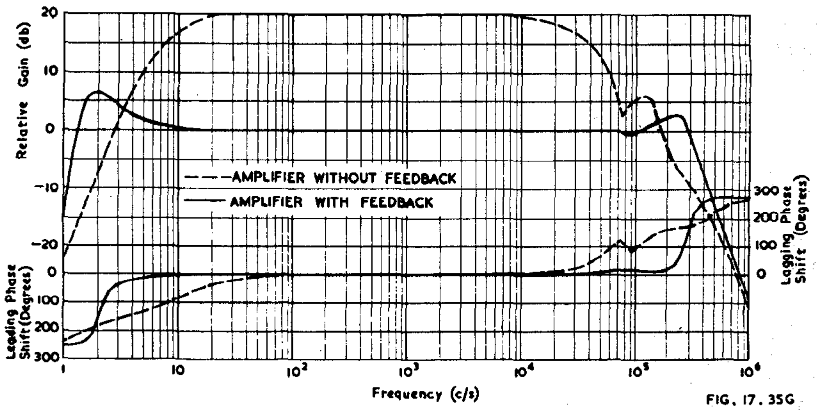


Fig. 17.35G. *Loop gain and phase-shift characteristics of Williamson main amplifier (Ref.* 270):

positive feedback below resonance and negative feedback above resonance, thereby unbalancing the characteristic and giving a sharp knee before the attenuation commences. The addition of an independent *RC* network controlled by S_{4A} gives further treble attenuation and leads to the final result in Fig. 17.35D.

(x) Pickups for connection to radio receivers

When a separate pickup and turntable unit is used in conjunction with a radio receiver, it is often most convenient for the user to operate the device at some distance (say up to 15 feet) from the receiver. The most desirable arrangement is a Record Player in the form of a small cabinet enclosing the motor, turntable, pickup, and (possibly) volume control, pre-amplifier and equalizer, with the top of the cabinet about 20 inches from the floor so as to be accessible from an easy chair.

The design problem hinges on the use or otherwise of a pre-amplifier. **If no pre-amplifier is permissible,** on account of cost or other factors, it is necessary to employ a pickup delivering a high output voltage or whose output voltage is capable of being stepped up by a high ratio transformer.

When pickup terminals are fitted to receivers, they usually provide a resistive load of the order of 0.5 megohm, with some capacitive shunting. The input voltage required to give full power output is usually about 0.25 volt, although some receivers require a higher voltage. If a receiver is being designed specially for good performance with a pickup, full power output should be obtained with an input voltage not exceeding 0.1 volt. This usually demands a pentode first a-f amplifier, especially if negative feedback is used.

If bass equalization of 20 db is required for use with an electro-magnetic pickup, the available voltage must be at least 10 times the input voltage to the amplifier, e.g. 1 volt and 0.1 volt respectively There is a strong temptation to use a popular pickup which provides at least part of the bass boosting by arm resonance, but this is very undesirable on account of record wear, distortion and heavy stylus force required. There are electro-magnetic pickups capable of providing an output of about 1 volt from the secondary of a transformer, which do not employ arm resonance in the vicinity of 100 c/s ; these are much to be preferred to those employing arm resonance. However, the high cost of a good quality transformer, and the hum and poor frequency response with a cheaper transformer, make this a rather unsatisfactory arrangement. The necessary bass boosting may be provided by a resistor and capacitor in series, connected across the secondary of the transformer A choice of cross-over frequency may be provided by a tapping switch and several values of capacitance. High-frequency de-emphasis may be provided by one or more values of shunt capacitance, although there is danger of pickup resonance unless an isolating resistor is used, with consequential loss of gain. Volume control may be provided by a potentiometer having a total resistance preferably not exceeding 50 000 ohms. A screened cable may be used to link the record player to the pickup terminals of the receiver.

If a crystal pickup is used, it is quite satisfactory to incorporate the equalizer and volume control in the Record Player. In this case there is no danger of hum from the pickup or transformer. With a general-purpose crystal pickup the arrangement of Fig. 17.29 may be used in which $R_1 = 2$ megohms, $R_2 = 0.5$ megohm and $C_1 = 0.000\,25\ \mu F$ for a cross-over frequency of 250 c/s or half this value for 500 c/s. Some measure of tone control may be provided by a variable resistance of 1 megohm in series with C_1.

With a high fidelity crystal pickup, the circuit of Fig. 17.31 or any similar equalizer may be used.

In all cases it is advisable for the listener, if possible, to set the volume control on the record player to about half-way, then to adjust the volume control on the receiver for satisfactory operation under normal conditions, and to make all adjustments (during listening) with the control on the record player.

There will be some inevitable loss of the higher frequencies due to the screened cable. This may be kept within reason by arranging that the total effective impedance of the line, under operating conditions, is of the order of 50 000 ohms or less. For example, the equalizer of Fig. 17.32 may be modified by changing the 0.1 megohm fixed resistor into a volume control.

If a pre-amplifier is used, both it and the equalizer will normally be incorporated into the receiver chassis. A volume control may readily be fitted across the pickup, and shunt capacitances may be used in conjunction with a tapping switch for high frequency de-emphasis, with due precautions against resonance. With this arrangement it is difficult to make any adjustment for cross-over frequency in the record player.

Alternatively the pre-amplifier and equalizer may be incorporated into the record player, thus giving the maximum flexibility of control. The final stage in the record player may be either a cathode follower, or a general-purpose triode with a low ratio transformer in its plate circuit. The record player may incorporate a power transformer, rectifier and filter, or it may obtain its plate supply from the receiver. Trouble may be experienced with hum owing to the proximity of the motor, transformer and pre-amplifier, particularly if a low level pickup is used. However, in spite of these design problems, the arrangement is practicable.

(xi) Frequency test records

Frequency test records are of two general types—banded tone and gliding tone. Banded tone records are recorded with a number of constant frequencies which may be played in sequence ; they are generally used when measurements are being made. Gliding tone records are useful when it is desired to check for peaks but may also be used for frequency response measurements by appropriate timing. These normally commence at a high frequency f_1, maintain constant velocity characteristics down to the cross-over frequency f_0, then follow the recording characteristic down to the final frequency f_2 (approximately at the rate of 6 db/octave). In some cases the high-frequency response follows the recording characteristic—details are given in the table. The frequency response may be checked to a fair degree of accuracy by the optical method (see below). Over the " constant velocity " range the width of the light pattern should be constant, while over the " constant amplitude " range the width should taper downwards in proportion to the frequency.

References to frequency test records : Refs. 161, 254, 260 ; record catalogues.

The optical method of testing frequency test records

A frequency test record, either of the stepped-frequency or gliding-tone type, may be checked optically to indicate the amplitude at all parts of the record, with a possible error of about 1 or 2 db. The lamp should have a concentrated filament and clear bulb ; it should be at least 8 feet from the record and only high enough above the plane of the record to give a brilliant pattern. The eye should be directed vertically downwards on to the side of the record nearer to the lamp, and should be as far above the record as possible.

A pair of dividers may be used to measure the width of the reflected light pattern for each frequency; the width of the light pattern is proportional to the voltage output from a perfect constant-velocity pickup. This method becomes increasingly less accurate below the cross-over frequency, although it is very satisfactory at higher frequencies.

The theoretical analysis and calculation of errors is given by Ref. 243.

References 25 (Part 5), 99, 219, 243, 258, 293.

TABLE 1: GLIDING FREQUENCY RECORDS

Record	f_1	f_0 (cross-over)	f_2
English			
Decca ffrr K1802	14 000 c/s		10 c/s
K1803	14 000 c/s	300 c/s	10 c/s
American			
R.C.A. 12 in. (12-5-5)	10 000 c/s	500 c/s (−1.5 db)	30 c/s
London (album LA-32)			
T-4996 12 in. 78 r.p.m.	14 000 c/s (+8 db)	250 c/s (−1 db)	100 c/s (−5 db)
T-4997 12 in. 78 r.p.m.	14 000 c/s (+8 db)	250 c/s (−1 db)	10 c/s (−33 db)
Universal D61B Band 1	10 000 c/s (0 db)	500 c/s (0 db)	
Band 2		500 c/s (−7 db)	200 c/s (−7 db)
Band 3		200 c/s (−14 db)	50 c/s (−14 db)
Columbia XERD281 12 in.	10 000 c/s	500 c/s	50 c/s

TABLE 2: COMBINED GLIDING FREQUENCY AND BANDED FREQUENCY RECORDS

	f_1	f_0 (cross-over)	f_2
R.M.A. Standard REC-128 78 r.p.m.			
No. 1 Side A	10 000 c/s	500 c/s	30 c/s
	Constant frequencies 1000 (+ 10 db), 10 000, 9000, 8000, 7000, 6000, 5000, 4500, 4000, 3500, 3000, 2500, 2000, 1500, 1000, 700, 500, 400, 300, 250, 200, 180, 160, 140, 120, 100, 90, 80, 70, 60, 50, 40, 30.		
No. 1 Side B	Voice announcements. Constant frequency 1000 c/s at levels +10, +12, +14, +16, +18 db. Then alternate gliding and constant frequencies from 3000 to 30 c/s at level +16 to +18 db (1000 c/s).		

TABLE 3 : BANDED FREQUENCY RECORDS

English and Australian (78 r.p.m.)	
E.M.I. Australia (ED1189)	20 000, 18 000, 16 000, 14 000, 12 000, 10 000, 8000, 6000, 4500, 3500, 2000, (arbitrary 0 db) ; 500 (−1), 160 (−5.5), 70 (−12 db). 19 000, 17 000, 15 000, 13 000, 11 000, 9000, 7000, 5000, 4000, 3000, 1000 (arbitrary 0 db) ; 250 (−3), 100 (−8.5), 50 (−14 db).
E.M.I. Australia (ED1190)	13 000 (−1.2 db), 12 000 (−1.3), 11 000 (−0.4), 10 000 (−0.2), 9000 (−0.2), 8000 (−0.2), 7000 (+0.4), 6000 (+0.2), 5000 (+0.2), 4000 (+0.7), 3000 (+1.2), 2000 (+0.6), 1000 (0 db arbitrary level), 500 (+0.2), 250 (−2.9), 140 (−6), 100 (−8.9), 70 (−10.4), 50 (−12.8), 35 c/s (−14 db).
E.M.I. Studios JG449 (1)	20 Kc/s, 18, 16, 14, 12, 10, 8, 6, 4.5, 3.5, 2 Kc/s (0 db) ; 500 c/s (−1), 160 c/s (−5.5), 70 c/s (−12 db).
(2)	19 Kc/s, 17, 15, 13, 11, 9, 7, 5, 4, 3, 1 Kc/s (0 db) ; 250 c/s (−3), 100 c/s (−8.5), 50 c/s (−14 db).
Columbia LOX-650	1000 (0 db), 10 000 (−1), 9000 (−1.6), 8000 (−1.6), 7000 (−1), 6000 (−0.8), 5000 (−0.8), 4000 (−0.8), 3000 (−0.8), 2000 (−0.8), 1500 (−1), 800 (−0.8), 500 (−0.8), 300 (−3.4), 200 (−5.2), 150 (−7.1), 100 (−9.4), 70 (−11.2), 50 (−13.6 db).
Decca Z718	50, 70, 100, 160, 250, 500, 1000, 2000, c/s −14 −11 −8 −4 0 0 0 0 db 3000, 3500, 4000, 4500, 5000, 6000 c/s 0 0 0 0 0 0 db
Decca K1804	14 000 to 400 c/s (constant velocity) 250 to 30 c/s (constant amplitude) ; in steps. Level +10 db at 1000 c/s.
American	
R.M.A. Standard REC-128 78 r.p.m. No. 2(A)	Constant frequency bands at same frequencies as No. 1 Side A without announcements.
No. 2(B)	8000, 6000, 4000, 2000 (+10 db) ; alternate gliding and constant frequencies 3000 to 30 c/s (+16 to 18 db) ; 8000, 6000, 4000, 2000 (+10 db).
R.C.A. (12-5-19) 12 in. 78 r.p.m. Unfilled vinyl, SF	Approx. const. vel. 10 000 ; 9000 ; 8000 ; 7000 ; 6000 ; 5000 ; 4000 ; 3000 ; 2000, 1000 ; (0 db = 8.6 cm/sec. approx.) 800 c/s ; 500 (−1.5 db) ; Const. ampl. 300 ; 200 ; 100 ; 50 ; 1000 (−2 db) ; 10 000.
R.C.A. (12-5-25) (=460625-6) 12 in. 33-1/3 r.p.m. Unfilled vinyl, SF	12 000 (−2.5 db) ; 11 000 (−3) ; 10 000 (−1.5) ; approx. const. vel. down to 700 (−0.5 db) ; 400 (1.2 db below const. ampl.) ; 300 (0.6 db below const. ampl.). Also 400 and 4000 c/s tone for intermodulation testing. Groove has bottom radius less than 0.5 mil. Max. stylus radius 3 mils.
R.C.A. (12-5-31) 7 in. 45 r.p.m. Unfilled vinyl, D.F. (Opposite side of 12-5-29)	Approx. const. vel. 10 000 (−0.5 db) ; 9000 ; 8000 ; 7000 (−1) ; 6000 ; 5000 (−1.3) ; 4000 ; 3000 (−1) ; 2000 ; 1000 (0 db = 5.2 cm/sec.) ; 700 (−0.5) ; 400 (−1.5) ; approx. const. ampl. 400 ; 300 ; 200 ; 100 ; 50 ; 1000. Velocity at 1000 c/s = 5.2 cm/sec.

Columbia	
TL-1 LP microgroove 33-1/3 r.p.m.	10 000 (+12 db) ; 9000 (+12) ; 8000 (+11.5) ; 7000 (+11) ; 6000 (+11) ; 5000 (+10) ; 4000 (+7.5) ; 3000 (+5.5) ; 2000 (+3) ; 1500 (+2) ; 1000 (0 db = 1 cm/sec. r.m.s.) ; 800 (−1) ; 500 (−2.5) ; 400 (−4) ; 300 (−6) ; 200 (−8.5) ; 150 (−10) ; 100 (−11) ; 70 (−12) ; 50 (−13). This record is cut with the microgroove recording characteristic including high-frequency pre-emphasis.
TL-2 LP microgroove 33-1/3 r.p.m.	10 000 (+5.5 db) ; 9000 (+5.5) ; 8000 (+5) ; 7000 (+5.5) ; 6000 (+5) ; 5000 (+7) ; 4000 (+7.5) ; 3000 (+7) ; 2000 (+4.5) ; 1500 (+6.5) ; 1000 (+7.5) ; 800 (+7.5) ; 500 (+7.5) ; 400 (+6) ; 300 (+3.5) ; 200 (−0.5) ; 150 (−3.0) ; 100 (−6) ; 70 (−7.5) ; 50 (−10.5) ; 30 (−12 db). 0 db = 1 cm/sec. r.m.s.
RD-103 LP microgroove 33-1/3 r.p.m. 12 in. Bands	10 000 (+5 db) ; 9000 ; 8000 ; 7000 ; 6000 (+5) ; 5000 ; 4000 (+7) ; 3000 ; 2000 (+5) ; 1500 ; 1000 (+7.5) ; 800 ; 500 (+7.5) ; 400 ; 300 ; 200 (0 db) ; 150 ; 100 (−6) ; 70 ; 50 ; 30 c/s (−12) ; 0 db = 1 cm/sec. Essentially flat over constant-velocity portion, with cross-over 500 c/s.
RD-103A LP microgroove 33-1/3 r.p.m. 12 in. Bands	10 000 (+12 db) ; 9000 ; 8000 ; 7000 ; 6000 (+10 db) ; 5000 ; 4000 ; 3000 (+5) ; 2000 ; 1000 (0 db) ; 800 ; 500 (−2.5) ; 400 ; 300 (−6) ; 200 ; 100 (−11) ; 70 ; 50 c/s (−13 db). 0 db = 1 cm/sec. Levels arranged to reproduce ± 2 db of " flat " on correctly equalized LP reproducing system.
(10003-M) 78 r.p.m. 12 in. shellac	1000 c/s ; 10 000 (−7 db) ; 9000 ; 8000 ; 7000 ; 6000 ; 5000 ; 4000 ; 3000 ; 2000 ; 1500 ; 1000 (−1 db) ; 800 ; 500 ; 300 ; 200 ; 150 ; 100 ; 70 ; 50 (−17 db). Cross-over 300 c/s. Level approx. 4.8 cm/sec. at 1000 c/s.
(10004-M) 78 r.p.m. 12 in. shellac	As (10003-M) but with cross-over frequency 500 c/s.
Audiotone	
78-1 78 r.p.m.	50 to 250 c/s (peak amplitude 0.0017 inch) ; 250 c/s upwards (constant velocity).
London Gramophone	
T4998 12 in. 78 r.p.m.	14 000 c/s (0 db) ; 13 000 ; 12 000 ; 11 000 ; 10 000 ; 9000 ; 8000 ; 7000 ; 6000 ; 5000 ; 4000 ; 3000 ; 2000 ; 1000 ; 400 (0 db) ; 250 (−2) ; 100 (−6) ; 55 ; 30 c/s (−16 db).
Clarkstan	
(2000S) 78 r.p.m.	50 to 500 (constant amplitude) 500 to 10 000 c/s (constant velocity) in 17 steps.
(20002S) LP microgroove	One side recorded flat, other side with NAB curve.
Cook	
Series 10, 10 in. Plastic DF. Side A 78 r.p.m.	Constant velocity (9 cm/sec.) above 500 c/s. with 3 db knee at crossover. Bands 1000 c/s ; 20 000 ; 17 000 ; 15 000 ; 12 000 ; 10 000 ; 9000 ; 8000 ; 7000 ; 6000 ; 5000 ; 4000 ; 3000 ; 2000 ; 1500 ; 1000 ; 700 ; 500 ; 350 ; 250 ; 125 ; 62.5 ; 40 ; 35 ; 1000 c/s. Side B : 33-1/3 r.p.m. ; Band 1-LP spot check for standard LP pre-emphasis—100 ; 1000 ; 3000 ; 6000 ; 10 000 c/s. Band 2—100 and 7000 c/s intermodulation test, with 7000 c/s 12 db lower than 100 c/s, on

	flat basis. No pre-emphasis. Band 3—slow sweep frequencies from 1000 c/s to 35 c/s with 350 c/s crossover. Both sides cut for use with 1 or 3 mil reproducer stylus.

TABLE 4: SPECIAL TEST RECORDS

R.C.A. Victor	
(12-5-1) 10 in. 78 r.p.m. Shellac DF	Unmodulated grooves at normal recording pitch with lead out and eccentric. Same both sides.
(12-5-3) 12 in. 78 r.p.m. Shellac DF	Unmodulated grooves at normal recording pitch with lead out and eccentric. Same both sides.
(12-5-7) 12 in. 78 and 33-1/3 r.p.m. Shellac DF	On 78 r.p.m. bands 2300 ; 1000 c/s. On 33-1/3 r.p.m. 1000 ; 433 c/s. Frequencies constant within 0.2% instantaneous (12-5-5 on opposite side).
(12-5-9) 12 in. 78 r.p.m. Shellac SF	Band 1—silent ; 2—400 c/s at 5.9 cm/sec. ; 3—1000 c/s at 9.6 cm/sec ; 4—silent. Frequencies constant within 0.2% instantaneous.
(12-5-11) 12 in. 78 r.p.m. Shellac DF	Landing area with no lead-in spiral ; at least one unmodulated normal pitch groove ; steep blank spiral ; normal pitch inside groove ; lead out and eccentric Same both sides.
(12-5-13) 10 in. 78 r.p.m Shellac DF	As for (12-5-11). Same both sides.
(12-5-15) 12 in. 78 r.p.m. Unfilled vinyl DF	Warble frequency bands, sweep rate 5.5 c/s. Band (1) 500—2500 c/s ; (2) 750—1250 c/s ; (3) 1250—1750 c/s ; (4) 1800—2600 c/s. Same both sides.
(12-5-17) 10 in. 78 r.p.m. Shellac DF	As (12-5-15). Same both sides.
(12-5-21) 12 in. 78 r.p.m. Unfilled vinyl DF	For checking automatic record changers. Three modulated bands with large eccentric groove. Bands define standard 10 and 12 in. landing areas without lead in grooves. Inner band 936 c/s (1 minute) for checking wow.
(12-5-23) 12 in. 78 r.p.m. Unfilled vinyl DF	Various modulated bands joined by spiral grooves to indicate limits of standard recording dimensions (12-5-21 on other side).
(12-5-29) 7 in. 45 r.p.m. Unfilled vinyl DF	For checking landing and tripping action of changer mechanisms. Bands 1000 ; 400 ; 1000 c/s.
(12-5-35) 7 in. 45 r.p.m. Unfilled vinyl DF	For checking landing and tripping action of changer mechanisms ; for checking pickup sensitivity, turntable flutter and rumble.
(12-5-37) 7 in. 45 r.p.m. Unfilled vinyl DF (RL-419)	Bands of 400 and 4000 c/s signals combined, the 4000 c/s being 12 db below the 400 c/s level. Peak velocities from 3.8 to 18 cm/sec. in approx. 2 db steps. 0 db = 6 cm/sec. Intermodulation distortion in the record is less than 4%. For testing pickup " tracking " at various levels and stylus forces (Ref. 285).
(12-5-39) 12 in. 78 r.p.m. Unfilled vinyl DF (RL-420)	Bands of 400 and 4000 c/s signals combined, the 4000 c/s being 12 db below the 400 c/s level. Peak recorded velocities run from 27 to 4.4 cm/sec. in approx. 2 db steps. 0 db = 9.1 cm/sec. Intermodulation distortion in the record is less than 3%. Groove has small bottom radius suitable for testing with 1.0 or 3 0 mil styli. Same use as 12-5-37.

(12-5-41) 12 in. 33.3 or 78 r.p.m. Unfilled vinyl DF	For routine testing of record changer operation with 1.0 or 3.0 mil styli. Standard R.M.A. landing areas for 10 and 12 inch records are defined by short interrupted tones. Short bands of 400 and 1000 c/s tones are included for routine pickup sensitivity measurements.
Clarkstan	
1000 A 12 in. 78 r.p.m. vinylite SF	Sweep frequency record for oscillographic observation of equipment response. Frequency range 70 to 10 000 c/s, flat within ± 1 db. Sweep frequency rate 20 times/sec. Crossover 500 c/s.
1000 D 12 in .78 r.p.m. vinylite SF.	Sweep frequency record as 1000A but covering range from 5000 to 15 000 c/s.
E.M.I. Studios	
JH138 10 in. 78 r.p.m. for use with 2.5 mil radius stylus.	Side 1 : 400 c/s (+22.5 db) with approx. 4000 c/s (+10.5 db) superimposed additively for I.M. testing of pickups. Peak lateral velocity of combined wave is equal to that of a sine wave at a level +24.5 db. The succeeding 10 bands have levels of both tones reduced 2 db below those of the foregoing band. Side 2 : 60 c/s (+8.6 db) with 2000 c/s (+10.3 db) superimposed additively. When the 2000 c/s is reduced in the pickup bass correction equalizer by the correct amount relative to 60 c/s (i.e. 13.7 db), its effective level will be −3.4 db, i.e. 12 db below the 60 c/s tone. On a velocity basis, the peak lateral velocity of the combined wave is equal to that of a sine wave at a level +15.5 db. The peak combined amplitude is equivalent to that of a 60 c/s sine wave having a level of +10 db. The succeeding 10 bands each have the level of both tones reduced by 2 db below those of the foregoing band. 0 db = 1 cm/sec. r.m.s. (Ref. 310).

See Supplement for additional Frequency Test Records.

SECTION 6 : DISTORTION* AND UNDESIRABLE EFFECTS

(i) Tracing distortion and pinch effect (ii) Playback loss (iii) Wow, and the effects of record warping (iv) Distortion due to stylus wear (v) Noise modulation (vi) Pickup distortion (vii) Acoustical radiation (viii) Distortion in recording.

(i) Tracing distortion and pinch effect

Tracing distortion (also known as playback distortion) is non-linearity introduced in the reproduction of records because of the fact that the curve traced by the centre of the tip of the reproducing stylus is not an exact replica of the modulated groove.

Detailed mathematical analyses of tracing distortion have been made (Refs. 41 and 213, 42, 224, 264) and some popular articles have been written (Refs. 40, 146). The distortion arises from the shape of the cutter, which has a chisel edge, so that a spherical tipped needle follows a different path—in other words it introduces harmonic distortion. Odd harmonics are shown up in the lateral movement of the needle, while even harmonics make their presence felt through vertical movement of the needle—the **"pinch effect."**

* See also Chapter 37 Sect. 1 (vi) N for I.R.E. tests on phonograph combinations.

Harmonic tracing distortion

It had earlier been believed (Ref. 42) that the dominant harmonic was the third, but a more recent analysis (Ref. 264) has proved that the higher harmonics also should be considered. The values of the fundamental and harmonics up to the seventh may be calculated from the equations below. The harmonic distortion, when reproducing with a constant velocity pickup, is given by the ratio of the harmonic to the fundamental, multiplied by the harmonic number (e.g. 3 for third harmonic).

$$\text{Fundamental amplitude} = A - \frac{1}{16}R^2A^3\left\{1 - \tfrac{1}{4}A^2 + \frac{5}{64}A^4 - \ldots\right\} + \frac{1}{768}R^4A^5\left\{1 - \tfrac{5}{8}A^2 + \ldots\right\} - \frac{1}{73\,728}R^6A^7\left\{1 - \ldots\right\} + \ldots \quad (1)$$

$$\text{Third harmonic amplitude} = -\frac{1}{16}R^2A^3\left\{1 - \tfrac{3}{8}A^2 + \frac{9}{64}A^4 - \ldots\right\} + \frac{9}{512}R^4A^5\left\{1 - \tfrac{3}{4}A^2 + \ldots\right\} - \frac{81}{40\,960}R^6A^7\left\{1 - \ldots\right\} + \ldots \quad (2)$$

$$\text{Fifth harmonic amplitude} = \frac{1}{128}R^2A^5\left\{1 - \tfrac{5}{8}A^2 + \ldots\right\} + \frac{25}{1536}R^4A^5\left\{1 - \frac{5}{4}A^2 + \ldots\right\} - \frac{625}{73\,728}R^6A^7\left\{1 - \ldots\right\} - \ldots \quad (3)$$

$$\text{Seventh harmonic amplitude} = -\frac{1}{1024}R^2A^7\left\{1 - \ldots\right\} - \frac{49}{6144}R^4A^7\left\{1 - \ldots\right\} - \frac{2401}{368\,640}R^6A^7\left\{1 - \ldots\right\} - \ldots \quad (4)$$

where $A = 2\pi a/\lambda$
$R = 2\pi r/\lambda$
a = amplitude of lateral modulation of groove, measured in the plane of the record
r = stylus radius
and λ = wavelength of sinusoidal modulation measured in the direction of an unmodulated groove.

These formulae only hold when RA does not exceed $\sqrt{2}$.

Example: Groove velocity 10 inches/sec., lateral groove velocity 2 inches/sec for f = 4000 c/s,
r = 2.3 mils.
Wavelength = λ = 10/4000 = 0.0025 inch.
Amplitude = a = $2/2\pi(4000)$ = $1/4000\pi$ inch.
$A = 2\pi\, a/\lambda = 0.2.$
$R = 2\pi(0.0023)(400) = 1.84\pi.$
From (1): Fundamental amplitude = 0.1839 (this is 91.9% of the groove amplitude).
From (2): Third harmonic amplitude = − 0.0113.
Percentage third harmonic with constant velocity pickup =
3 × 0.0113 × 100/0.1839 = 18.4%.
From (3): Fifth harmonic amplitude = + 0.0035.
Percentage fifth harmonic with constant velocity pickup =
5 × 0.0035 × 100/0.1839 = 9%.
Total r.m.s. distortion = 20%.

Intermodulation tracing distortion

The harmonic distortion so far discussed implies the existence of intermodulation distortion which causes the most distressing effects on the listener and is still audible when the offending harmonics are inaudible. The ratio of intermodulation distortion to total harmonic distortion may be as high as 10 times (Ref. 110). Intermodulation distortion may, in severe cases, be audible as a buzz.

Since the higher order harmonics are substantial, the most convenient method of comparison for different conditions is given by intermodulation distortion (Ref. 264) and four curves for selected operating conditions are given in Fig. 17.37A. Under these operating conditions the upper limit for good reproduction is 10% intermodulation—this does not hold for other conditions.

The minimum groove diameters for reasonable fidelity (less than 10% calculated intermodulation distortion as given by Fig. 7.37A) are :

R.P.M.	Stylus radius	Min. groove diameter
78	3.0 mils	6.1 inches
45	1.0	4.9
33-1/3	1.0	6.5
33-1/3	2.3	10.1

Fortunately, owing to the smaller amplitudes which usually occur in both speech and music at the higher frequencies, the actual distortion under the prevalent listening conditions is usually less than the values given above. In addition, the yield of the record material reduces the distortion (Ref. 265); this is appreciable with vinyl, but negligible on shellac records. A further effect is the translation loss which may be about 6 to 8 db at 10 000 c/s at the inner radius with 78 r.p.m. standard groove, whereby both fundamental and harmonics are reduced. All these subsidiary effects tend to decrease the actual tracing distortion.

However, the deterioration in both frequency response and fidelity is plainly audible to a critical listener as the groove radius decreases towards the end of a record; this applies to 78 r.p.m., transcriptions and all types of fine groove recording.

The effect of recording characteristics on tracing distortion

Over the range of constant velocity recording, the tracing distortion is proportional to the square of the frequency

With high-frequency pre-emphasis followed by the correct amount of de-emphasis, at the rate of 6 db/octave above a "hinge frequency" f_1 (P in Fig 17.37B) the third harmonic tracing distortion at a recorded frequency f_1 will be one third of the value calculated by the procedure outlined above provided the constants are the same in both cases. This relationship will, however, not hold at any other point. For example, at frequency f_2 where $f_2 = 2f_1$, the amplitude at Q' will be twice that at Q and the

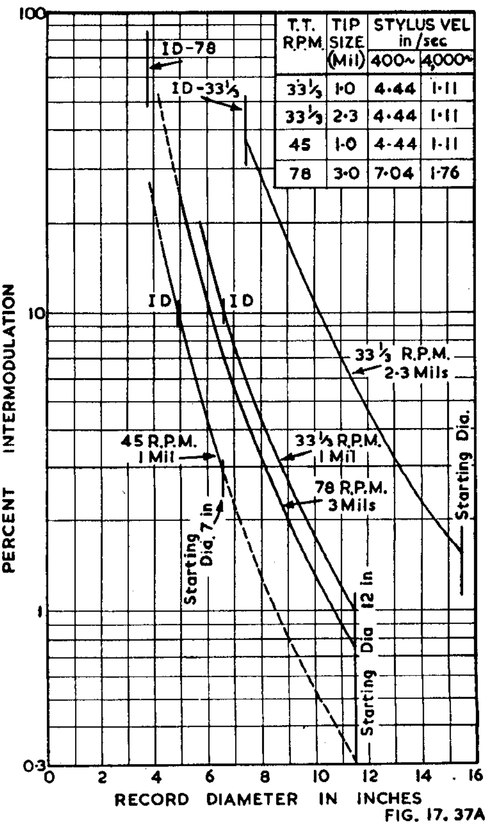
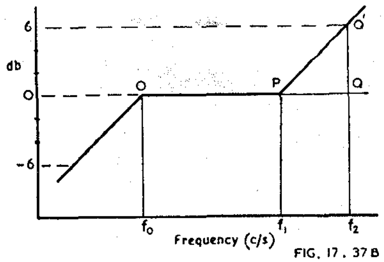


Fig. 17.37A. Variation of calculated intermodulation tracing distortion with record diameter (based on Ref. 292).

Fig. 17.37B. *Ideal recording characteristic for calculating tracing distortion.*



distortion will therefore be four times as great with pre-emphasis : de-emphasis as at point P. This may be expressed in the general form

$$\frac{H_3\% \text{ (constant amplitude)}}{H_3\% \text{ (constant velocity)}} = \frac{m^2}{3} \quad (5)$$

where $m = f_2/f_1$

f_2 = recorded frequency

f_1 = hinge frequency of pre-emphasis

and the pre-emphasis and de-emphasis are both at the rate of 6 db/octave above f_1

If $f_2 = f_1$ $m = 1$ Ratio of $H_3\% = 1/3$

$f_2 = 2f_1$ $m = 2$ Ratio of $H_3\% = 4/3$

$f_2 = 4f_1$ $m = 4$ Ratio of $H_3\% = 16/3$

Other distortion effects

In the foregoing treatment it is assumed that the pickup stylus and armature are able to follow ideally all the sharp and sudden changes in the modulation of the groove which occur with complex sounds. In many cases this is obviously not the case, so that additional causes of spurious intermodulation products (mainly inharmonic) arise. These are reduced by the use of a really good pickup but in most cases it is probably true that the best available pickup will introduce distortion additional to the theoretical tracing distortion.

The distortion arising from overmodulation at high frequencies due to a high value of pre-emphasis has already been covered in Sect. 5(i). Similar effects may occur at low frequencies with organ music, but may be avoided by the use of a low frequency limiter in the recording amplifier.

The effect of finite size of needle tip on the reproduction of the fundamental recorded frequency is covered in Sect. 2(i), also translation loss.

The **pinch effect** has already been mentioned. It causes increased combination products, forced vibration of the armature at its high resonant frequency, increased noise in the output voltage and needle talk. Fortunately these bad effects may be considerably reduced by the introduction of vertical compliance either in the needle (bent shank or trailer type) or in the pickup itself.

References to tracing distortion, intermodulation distortion and pinch effect: 11, 40, 41, 42, 47, 110, 146, 193, 212, 213, 223, 224, 225, 248, 264, 265, 285.

(ii) Playback loss

Playback loss has been defined as the difference between the recorded and the reproduced level at the very same point of a record. It is due to the physical properties of the record material, being evident as a loss of the higher frequencies. A comparatively stiff and hard material such as is used with shellac pressings has very little playback loss ; vinyl and lacquer are very much more flexible and exhibit appreciable playback loss. It is also a function of the pickup used. Reference 227.

(iii) Wow and the effects of record warping

Wow is a low-frequency modulation effect caused by spurious variations in groove velocity, either in recording or in reproduction. In recording, the American N.A.B. recommends that the maximum instantaneous deviation from the mean speed of the recording turntable shall not exceed ± 0.1% of the mean speed. The B.B.C. " D channel" limit is ± 0.05% (Ref. 297). In reproduction, most turntables used in combination sets suffer from an appreciable slowing down on heavily recorded passages. This effect is reduced by the use of a light-weight pickup with high lateral compliance. The effect may be noticed, in severe cases, by a movement in the pattern produced on a stroboscopic disc at the commencement and end of a heavily recorded passage.

A warped disc or wobbling turntable will produce greater wear and eventually greater scratch level on the high portions of the record. This is much less with well-designed light-weight pickups than with older models. However, it is important that the stylus force should be considerably more than the minimum for correct tracking on a perfectly flat record. A record with warp in excess of 1/16 inch is likely to cause trouble.

An eccentric disc or turntable will tend to cause wow ; a very small amount of eccentricity is sufficient to be noticeable in recording (max. ± 0.002 inch N.A.B. ; also English—Ref. 235). This will produce a tonal pitch variation of 0.1% on reproduction (10 or 12 inch records).

Flutter is similar to wow but at a high frequency ; the ear is very sensitive to this form of distortion. This also may occur both in recording and in reproduction.

References to wow etc. in recording : 84, 90, 193, 231.

Reference to tests on wow in phonograph combinations : 267.

See also Chapter 37 Sect. 1 (vi) N for I.R.E. tests on phonograph combinations.

(iv) Distortion due to stylus wear

All theoretical work on disc reproduction assumes that the needle point is perfectly spherical. A jewel or other form of permanent tip suffers wear on two opposite faces. The wear is usually measured in terms of the width of the nearly flat portion. The distortion arising from the worn stylus is independent of amplitude, and consists principally of odd harmonics. The distortion is a function of d/l

where d = width of flat on needle

and l = wavelength of recorded tone.

The following table has been calculated from published data (Ref. 59) for standard groove constant velocity recording :

d/l	fundamental	H_3	H_5	at innermost groove	
				f = 1000 c/s	f = 10 000 c/s
0.16	− 1 db	4.8%	6.6%	d = 1.5 mil	d = 0.15 mil
0.22	− 2 db	10%	12%	d = 2.4 mil	d = 0.24 mil
0.275	− 3 db	20%	17%	d = 3.3 mil	d = 0.33 mil
0.36	− 5 db	44%	—	d = 4.1 mil	d = 0.41 mil
0.5	−10 db	—	—	—	—

The distortion becomes very severe before there is any appreciable attenuation of the fundamental caused by the needle wear. Although the harmonics of the higher frequencies may be outside the frequency range of the equipment, the intermodulation products will be apparent.

If the recording characteristic is constant amplitude (6 db/octave high frequency pre-emphasis followed by de-emphasis) the values of distortion in the table should be divided by 3 and 5 for H_3 and H_5 respectively. In this case pre-emphasis : de-emphasis shows to considerable advantage over constant velocity, in that styli last longer before requiring replacement, for the same distortion.

It is obvious that, for high fidelity, no observable stylus flat is permissible. This seriously limits the life of sapphire styli, even when using a good quality pickup with high lateral and vertical compliance—see Sect. 2(vi).

(v) Noise modulation

The noise level is usually measured as the high-frequency noise developed by an unmodulated groove. When a high degree of noise is present and the groove is modulated by a single-frequency signal, it is found that the signal tends to modulate the noise. The noise modulation reaches a maximum twice each cycle, and the peak amplitude may be over ten times the peak amplitude of the measured noise in an unmodulated groove. The use of pre-emphasis : de-emphasis is to reduce the noise itself but to increase noise modulation. This effect is not apparent when the intermodulation is less than 4%.

This effect may be minimized during recording, by special means suggested in the article.

Reference 145. See also Ref. 193 (proposed standards).

(vi) Pickup distortion

Non-linear distortion in a pickup may vary from practically nil in the best high-fidelity types to over 5% total harmonics in some types. The total harmonic distortion with a well designed crystal pickup is well under 2% (Ref. 120).

The usual method **to test harmonic distortion** is to use a suitable frequency test record, check it for distortion with a pickup which is known to have very low distortion, then measure the distortion with a wave analyzer. A simple test is to use a C.R.O., but this is not capable of indicating less than about 2% or 3% total harmonic distortion. The distortion is always a function of frequency, so that it should be checked at all practicable frequencies. " The minimum stylus force for a given pickup to track a given frequency recorded at a given level can be determined . . by the observation of waveform on an oscilloscope. The waveform produced by failure to track has a characteristic ' spiked ' appearance, and a very small trace of this form of distortion is easily detectable "—Ref. 310(b).

Intermodulation distortion is preferable to total harmonic distortion as a general indication of pickup performance. Recommended test frequencies are 400 and 4000 c/s, with the latter 12 db lower than the former. Test records are available with bands recorded at different levels, from below normal level, increasing by 2 db steps to +10 db (e.g. R. C. A. Victor RL-419, RL-420, E.M.I. JH 138).

In most cases the intermodulation distortion of a pickup increases very gradually up to a certain level, and then rises very rapidly as the level is further increased. This " knee " should occur at a level of about +6 db, on record RL-420, that is at about 18.2 cm/sec. A high fidelity pickup, tested on record RL-420 shows about 2.5% intermodulation distortion at a level of +6 db ; most of this distortion is due to the record (Ref. 291). Other modern lightweight pickups give up to 8% intermodulation at 0 db (9.1 cm/sec.).

The " tracking " capability of a pickup may be checked by plotting a curve of intermodulation distortion against recorded level, for selected values of vertical stylus force (for details see Ref. 285).

Intermodulation distortion may be measured either as the r.m.s. sum or as the arithmetical peak sum—see Chapter 14 Sect. 3(ii) and (v). An intermodulation analyser using the peak sum method is described in Ref. 291.

(vii) Acoustical radiation

Acoustical radiation or needle chatter varies considerably among pickups. Some pickups have no audible radiation. In other cases the radiation may be reduced, if desired, by the use of a bent-shank needle or trailer type (Ref. 225).

(viii) Distortion in recording

If the distortion in the cutter head includes, say, 1% third harmonic distortion, this will result in 4% third harmonic distortion if both the fundamental and the harmonic frequencies are recorded and reproduced at constant velocity. On the other hand pre-emphasis followed by de-emphasis will reduce this form of harmonic distortion, although intermodulation products will still be present (Ref. 189).

See also Sect. 9(i) for distortion on original recordings.

Proposed standards for the measurement of distortion in sound recording : Ref. 193.

SECTION 7 : NOISE REDUCTION

(i) Analysis of noise (ii) High-frequency attenuation (iii) High-frequency pre-emphasis and de-emphasis (iv) Volume expansion (v) Olson noise suppressor (vi) Scott dynamic noise suppressor (vii) Price balanced clipper noise suppressor.

(i) Analysis of noise

Noise in the reproduction of sound from records may be divided into two distinct groups, low frequency noise such as hum and rumble, which has already been dealt with, and surface noise (scratch) which is the subject of this section.

Surface noise, when reproduced with a high fidelity pickup, covers the whole audible frequency range and beyond, but is most distressing to the ear at frequencies from about 1500 to 15 000 c/s. The surface noise per 1 c/s increases with increasing frequency.

When a pickup is used which has a pronounced peak in the region of 3000 to 6000 c/s, the noise in the output appears to have a peak at this frequency. This effect is due partly to the increased response of the pickup at the frequency in question (which could be removed by equalization) and partly to shock excitation of the pickup armature. The remedy is to use a better quality pickup.

References 15, 21.

(ii) High-frequency attenuation

The distressing effects of surface noise on the listener may be reduced by any form of high-frequency attenuation. Soft needles, such as fibre, thorn, bent shank or trailer type, introduce attenuation of this kind but it is not controllable and, in the case of fibre and thorn needles, variable.

Electrical attenuation is to be preferred, although it may be combined with the use of, say, a bent shank needle. Best results are obtained with a combination of two attenuation characteristics—

1. A very rapid attenuation above a fixed frequency (say 7000 c/s, or a choice between 4500, 7000 or 10 000 c/s) for use with old or noisy records. A suitable circuit is Fig. 17.24A.

2. A gradual attenuation characteristic with a hinge point at about 1500 c/s with variable rate of attenuation up to at least 6 db/octave, in addition to any de-emphasis as such. Some possible circuits are described in Chapter 15 Sect. 6. See also Figs. 17.19, 17.23 and 17.27. Crystal pickups used without an equalizer give an attenuation approaching 6 db/octave.

If it is not practicable to have two independent attenuation characteristics, a single characteristic may be used provided that it is capable of giving an attenuation of at least 30 db at 7000 c/s, for use with worn records.

(iii) High-frequency pre-emphasis and de-emphasis

This method has already been described, and reduces the noise by approximately half the amount of pre-emphasis at 10 000 c/s (for characteristics which follow the time-constant roll-off).

(iv) Volume expansion

Volume expansion provides an increase in the dynamic range and, effectively, reduces the surface noise level with reference to the maximum power output. Full details are given in Chapter 16. On account of the limitations of available types of volume expanders, a maximum expansion of 8 db is suggested as a satisfactory compromise.

A combined volume expander and scratch suppressor is described in Ref. 211.

(v) Olson noise suppressor

The Olson noise suppressor works on the principle of the threshold effect. If the noise is below a certain low threshold value it is not amplified. The output versus input voltage characteristic is approximately horizontal for an input up to, say, 0.5 volt ; this may be accomplished by means of a network incorporating voltage-delayed diodes (such as 6H6) or germanium crystal diodes. The distortion products (all harmonic and most of the intermodulation) are eliminated by splitting the high frequency part of the amplifier into channels each covering only one octave. Some possible combinations are

1. 0-3000 c/s ; 3000-6000 c/s (2 channels).
2. 0-2000 c/s ; 2000-4000 c/s ; 4000-8000 c/s (3 channels).
3. 0-1500 c/s ; 1500-3000 c/s ; 3000-6000 c/s ; 6000-12 000 c/s (4 channels).

Filters are used which provide attenuation at the rate of approximately 30 db/octave at both ends of each channel, except the low frequency end of the first channel. A filter network for two channels is given in Ref. 115, while one for four channels is given in Ref. 138.

The only known defects are that signals below the threshold value are lost, and that there are some intermodulation products.

(vi) Scott dynamic noise suppressor

The Scott dynamic noise suppressor controls the bandwidth of the amplifier by means of separate high-frequency and low-frequency tone controls which are automatically controlled by the signal. Fig. 17.38 shows one simple application suitable for home use (Ref. 251 based on Ref. 114). V_1 is an amplifying stage which also provides the voltage for application to both high-frequency and low-frequency control circuits which in turn control the grid voltages of V_2 and V_3. The parallel resonance between L_1 and C_1 provides an attenuation at high frequencies and a high attenuation above the normal operating range ; it may also be used as a whistle filter. V_2 is used as a reactance valve providing variable capacitive reactance which, together with C_2 and its companion series condenser, forms a series resonant circuit with L_2. The low-frequency gate including V_3 is quite readily understood. Switch S_1 allows the suppressor to be opened, providing maximum frequency range when no suppression is desired. When S_1 is closed, R_3 controls the amount of suppression. For bad records, switch S_2 allows restriction of the maximum frequency range. Switch S_3 closes the high-frequency gate and leaves the low-frequency gate open.

The frequency characteristics of an experimental model built in our Applications Laboratory is given in Fig. 17.39 (Ref. 251). Scott recommends that C_1 should be

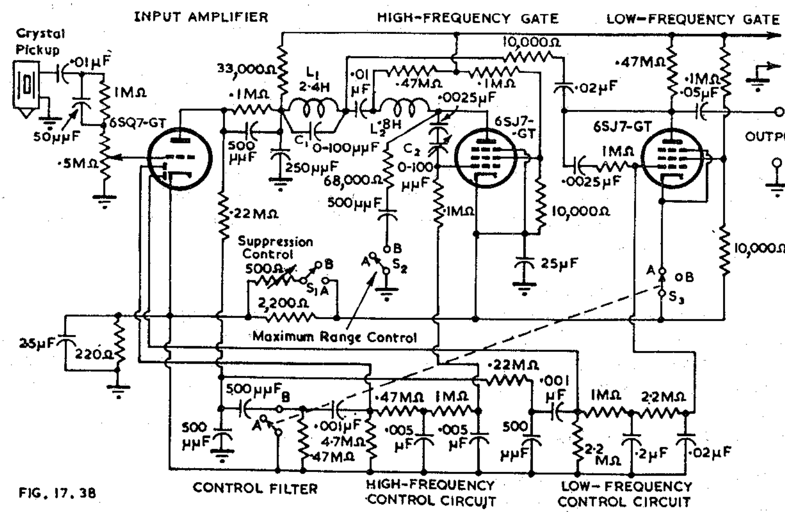


Fig. 17.38. *Simple Scott dynamic noise suppressor* (*Ref.* 251 *based on Ref.* 114).

adjusted for minimum output at 9000 c/s, but it was found preferable to tune C_1 and L_1 for minimum output at 7500 c/s to avoid too great a rise in output between the two frequencies of maximum attenuation. This simple circuit cannot provide a response extending above about 6000 c/s.

A more recent model with minimum output at 10 000 c/s is described in Ref. 184.

Performance data of a more flexible dynamic noise suppressor built into a complete amplifier are given in Ref. 173.

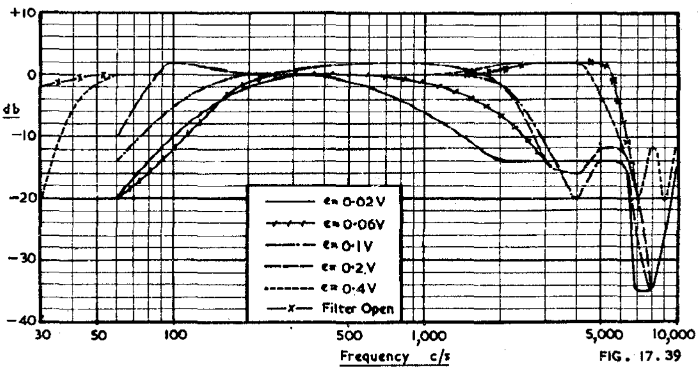


Fig. 17.39. *Frequency characteristics of circuit of Fig.* 17.37 (*Ref.* 251).

A modified circuit for home use is that used in the Goodell radio-phonographs (Ref. 133 Fig. 1). This includes provision for a switch to short-circuit the high-frequency filter (L_1C_1 in Fig. 17.38) ; the sharp cut off is at a frequency from 10 000 to 16 000 c/s. This and the Scott amplifier (Ref. 173), are to be preferred to the earlier circuit of Fig. 17.38.

A more elaborate circuit, which also includes a pre-amplifier suitable for use with a low-level electromagnetic pickup, a 3 stage power amplifier, frequency-compensated volume control and bass and treble tone controls, is described in detail in Ref. 250. See also Ref. 188 for further information.

A simpler modification is described in Ref. 165 in which a combined equalizer suitable only for use with low-level electro-magnetic pickups (such as G.E. or Pickering). This uses one 12SG7 valve and two 12SL7 twin triodes, with d.c. heater supply.

Much more elaborate dynamic noise suppressors for use in broadcast stations are described in Refs. 114, 133, 275.

An analysis of the filter characteristics for the dynamic noise suppressor are given in Ref. 140.

References to Scott dynamic noise suppressor : 83, 114, 133, 165, 173, 184, 188, 250, 275.

To obtain the best results from the dynamic noise suppressor requires intelligent attention from the operator, using the minimum degree of suppression rather than the maximum. The level should be controlled at some point after the suppressor (see comments, Ref. 149).

A comparison between the Scott, Fisher and Goodell versions of the dynamic noise suppressor is given in Ref. 182.

(vii) Price balanced clipper noise suppressor

This is a modification of the Olson noise suppressor described above. It differs from the Olson design in that a push-pull clipper is used in order to eliminate second harmonic distortion and thus permit an increase in the frequency coverage of each high-frequency channel. Possible arrangements are 0-3500 ; 3500-8000 c/s or 0-3000 ; 3000-7000 ; 7000-15 000 c/s (Ref. 150).

The principle of operation is open to the objection that it will respond to certain intermodulation products, more so than the Olson design.

SECTION 8 : LACQUER DISC HOME RECORDING (DIRECT PLAYBACK)

(i) General description (ii) Recording characteristic (iii) Cutting stylus (iv) Cutter head (v) Equalization of cutter (vi) Motor and turntable (vii) Amplifier (viii) Pickups for use on lacquer discs (ix) Recording with embossed groove.

(i) General description

Lacquer discs for home recording usually consist of a thin coating of cellulose nitrate on an aluminium disc, but other coating and disc materials are also used. There are considerable differences in the performance obtained with the best quality discs as compared with others.

The principal defects shown by some lacquer discs are

1. High noise level.
2. Loss of high frequencies on play-back.
3. Distortion, particularly due to drying out after cutting.

Lacquer discs can be used either with a standard stylus or a fine groove stylus. The following details apply to the standard stylus except where otherwise indicated.

With a suitable light-weight pickup, as many as 100 playings are possible. The discs may be processed for making a large number of pressings (for studio use). The signal to noise ratio with the best lacquer discs under the best conditions with a standard stylus may be between 50 and 60 db, the noise level being lowest at the greatest recording diameter and increasing by 2 to 8 db at a recording diameter of 5 inches. With a fine groove stylus the signal-to-noise ratio may be about 58 to 60 db at 10 in. recording diameter, 54 to 58 db at 8 in. and 40 to 50 db at 5 in. diameter. The signal-to-noise ratio may be less than the values quoted above, owing to the use of poor discs and technique ; the difference between a good and a poor disc may exceed 10 db. The overall distortion under the best conditions may be less than 5%.

Discs are available with diameters of 5, 6, 7, 8, 10, 12, 13½ and 16 inches. Discs for home recording are usually limited to 12 inches. If recording is made at 33-1/3 r.p.m. it is wise not to record below a diameter of 8 inches, owing to the loss of high frequencies and increased noise. With 78 r.p.m. it is wise not to record below a diameter of 5 inches, for good fidelity.

The thread (swarf) is highly inflammable, and should be disposed of in water or a closed metal container.

References : 9, 163, 189, 218, 230, 274.

Standards for " Disc Home Recording "
(based on R.M.A. REC-105, Aug. 31, 1947)

Drive pin at radius of 1 in. from centre of turntable.
Drive pin diameter 0.180 to 0.185 in.
Drive pin hole 1/4 inch nominal.
Centre hole of rigid base discs, 0.284 in. min. diameter.

Cutting stylus length	5/8 in.
shank diameter	0.0625 in.
face angle	87°
heel angle	50°
shank flat length	3/8 in.
shank flat depth	0.010 in.
max. tip radius (if any)	0.002 in.

Cutting face to be parallel with stylus axis.

(ii) Recording characteristics

The most generally used cross-over frequency is 500 c/s. It is usual to adopt a close approach to the N.A.B. pre-emphasis characteristic (+16 db at 10 000 c/s) followed by de-emphasis. The soft coating material causes some loss of higher frequencies during playback, so that a smaller amount of de-emphasis is required than would be used with hard discs, such as shellac.

(iii) Cutting stylus

The usual cutting stylus has a tip radius of about 2 mils with an included angle of about 90°. The depth of cut is usually between 1.5 and 2.5 mils. Steel cutting styli are cheap, but give poor performance all round, and only last for about 15 to 30 minutes of recording. Sapphire cutting styli are very much to be preferred ; they may be reground when necessary Some alloys (e.g. stellite) approach the sapphire performance, and are readily re-ground.

The shape of the cutting stylus is vitally important ; it normally has burnishing facets to produce a noise-free polished groove (Refs. 95, 222).

A hot stylus recording technique has been developed to reduce the noise level by 12 to 18 db while retaining good high-frequency response. No burnishing facets are required (Refs. 288, 289, 315).

(iv) Cutter head

The cutter head requires an available electrical driving power of at least 10 watts, with a higher value preferred. Electro-magnetic cutters with good characteristics (Ref. 233) are preferable but expensive. Crystal cutters with reasonably flat characteristics from about 50 to 9000 c/s are cheaper and satisfactory for home use.

The cutter head is mounted on a feed mechanism which usually provides 96, 112 or 120 grooves per inch.

(v) Equalization of cutter

Equalization is required, firstly to correct any shortcomings in the cutter itself, and secondly to provide the desired recording characteristic. In home recorders using electro-magnetic cutters it is usual to omit the first, and to limit the second to high-frequency pre-emphasis. The cross-over frequency is thus fixed by the cutter design.

High-frequency pre-emphasis (treble boosting) may be provided in a conventional manner to give any desired characteristic. Home recorders usually limit the maximum frequency to 8000 c/s or less, with a maximum boost from 10 to 14 db.

If a crystal cutter is directly connected to the secondary of the output transformer, and if the output resistance of the amplifier (reflected on to the secondary) is less than the capacitive reactance of the crystal at the highest frequency, the recording characteristic will be constant amplitude. The Brush RC-20 crystal cutter has a capacitance of 0.007 μF, with a reactance of about 2500 ohms at 9000 c/s. The maximum signal voltage across the cutter (RC-20) should be about 50 volts ; the step-down ratio of the transformer should be calculated to provide this voltage at maximum power output. The English Acos cutting head requires an input of the order of 150 volts for 1 mil amplitude. This method is only satisfactory with triode valves.

If pentode valves are used it is necessary to connect a suitable shunt dummy load to provide correct matching at about 500 c/s.

The conventional constant velocity characteristic above a specified cross-over frequency may be achieved with a crystal cutter by designing so that the impedance of the driving source is equal to the capacitive reactance of the cutter at the cross-over frequency. With a low impedance source it is necessary to use a series loading resistance.

(vi) Motor and turntable

Motors and turntables for recording purposes must be specially designed for the purpose, as higher power, less vibration and more constant speed are required than with play-back alone. Some equipments are designed for 78 r.p.m. alone, while others are designed for either 33-1/3 or 78 r.p.m.

(vii) Amplifier

The amplifier should be capable of an output of at least 10 watts, with low distortion and good frequency response. The noise and hum level should be at least

45 to 50 db below maximum power output (40 db is an extreme limit for poor recordings). The amplifier should preferably have push-pull triodes with negative feedback, although triodes without feedback or beam power valves with feedback may be used.

(viii) Pickups for use on lacquer discs

The pickup must be a light-weight type, preferably well under 1 ounce (28 grams) needle pressure. The play-back needle should be of the permanent type, usually sapphire, with a point radius of about 3 mils. The needle or pickup must have vertical compliance, and a trailer type of needle is frequently used.

Reference 252.

(ix) Recording with embossed groove

An embossed groove in place of a cut groove has, so far at least, had very limited use. One application (Ref. 103) makes use of 33-1/3 r.p.m. discs with 220 grooves per inch which provide 15 minutes playing time on each side of a 7 inch disc. The frequency range is from 150 to 4000 c/s, being suitable for dictation machines. Smaller discs provide 7½ minutes playing time. A special application called for 330 grooves per inch with 30 minutes playing time on each side of a 7 inch disc, working at 22 r.p.m.

See also Refs. 63, 210, 242.

SECTION 9 : REPRODUCTION FROM TRANSCRIPTION DISCS

(i) Introduction (ii) Characteristics of record material, wear and noise (iii) Sound track (iv) Recording characteristics and equalization (v) Translation loss and radius compensation.

(i) Introduction

Reproduction from transcription discs follows the same general principles as other disc reproduction, and will only be dealt with briefly. The special features of transscription disc recording and reproduction have been adequately covered in the literature, to which a number of references have been given.

The principal characteristics of N.A.B. (Ref. 237) and B.B.C. (Ref. 214) 16 inch 33-1/3 r.p.m. transcription discs are given below :

Detail	N.A.B. (1949)	B.B.C.
Outer diameter	15-15/16 ± 3/32	16 ins.
Outermost groove diameter	15-1/2 ± 1/16 (for inside start, 15-9/16 ins max.)	15-1/2 ins.
Innermost groove diameter	7-1/2 ins. min.	
Grooves per inch	96, 104, 120, 128, 136 etc.	120
Width of groove at top	< 4.0 mils	—
Radius at bottom of groove	1.5 mils max.	1.5 mils
Angle of groove	88° ± 5°	90°
Turntable speed	33-1/3 ± 0.3%	33-1/3 r.p.m.
Wow factor	≯ ± 0.1%	—
Reproducing stylus : Angle	40° – 55°	—
Bottom radius (primary standard)	2.0 ± 0.1 mils	2.5 mils
(secondary standard*)	2.5 ± 0.1 mils	—
Recorded level† (1000 c/s)	Peak velocity 7 cm/sec.	—
Direction of recording	either	outside-in

Some 10 inch and 12 inch discs are also used, but these have been covered in Sect. 2.

The pickups to be used with transcription discs should have a stylus force not exceeding 1-1/2 ounces (42 grams). Only permanent points should be used.

The total harmonic distortion on an original recording at 1000 c/s or less, in accordance with good practice, would be less than 2% (Ref. 219).

Intermodulation distortion measured on recordings made by three recording heads, with low frequency peak amplitudes of 2.5 mils and high frequency velocity 12 db lower, were approximately 1.0, 9.2 and 52% (Ref. 269). The first head is one giving exceptionally low distortion, while the second is representative of good practice. The readings were very little affected by the choice of low or high frequency. When the level was reduced 6 db, the I.M. distortion was reduced to 23% with the third recording head (say 6% harmonic distortion).

References to transcription recording (general) : 4, 7, 63, (92, 99, 163), (135, 205, 146), 189, 214, 216, 218, 219, 230, 237.

Standards : Refs. 2, 87, 214, 237 : Specifications : 185 ; Bibliography : 105.

(ii) Characteristics of record material, wear and noise

Most processed transcription disc are made of vinyl. Vinyl records will reproduce up to 1000 playings with a suitable light-weight pickup and permanent tip. For the effects of elastic deformation see Ref. 212

*Compromise for reproduction of both lateral transcriptions and 78 r.p.m. shellac discs.
†This is the deflection of a standard volume indicator. Programme peaks up to 21 cm/sec. would be anticipated.

Wear of stylus tips is covered in Sect. 2(vi).

The N.A.B. (1949) standard for **signal to noise ratio** states that the noise level measured with a standard volume indicator (ASA Standard C.16.5-1942) when reproducing a record on a flat velocity basis over a frequency range between 500 and 10 000 c/s shall be at least 40 db below the level obtained under the same conditions of reproduction using a tone record of 1000 c/s having a peak velocity of 7 cm/sec. Response of the system at 500 c/s shall be 3 db below the response at 1000 c/s, and the response shall fall at the rate of at least 12 db/octave below 500 c/s. Response of the noise measuring system at 10 000 c/s shall be 3 db below the response at 1000 c/s and the response shall fall at the rate of at least 12 db/octave above 10 000 c/s.

The standard N.A.B. pre-emphasis will increase this value by approximately 8 db, resulting in an effective signal to noise ratio (under minimum conditions) of 48 db. The peak signal to noise ratio will be at least 10 db better than this figure, with normal programme material—say 58 db. Lacquer discs (direct recordings) under similar conditions may have peak signal to noise ratios up to 68 db or even higher (Ref. 63).

(iii) Sound track

The ratio of maximum to minimum groove radius (N.A.B.) is 2.07 : 1. The groove speed varies from 27 to 13.1 inches per second. As the groove diameter approaches 7-1/2 inches there is a progressive loss of high frequencies and increase in harmonic distortion during both recording and play-back. For an analysis of the radius of curvature see Ref. 146. For tables giving groove/land ratios see Ref. 205.

(iv) Recording characteristics and equalization

The recording characteristic standardized by N.A.B. (1949) is given in Fig. 17.15 Curve 2, while that used by the B.B.C. is given in Fig. 17.14 Curve 4. The Orthacoustic recording characteristic is given in Fig. 17.15 Curve 5.

Equalization has been covered in Sect. 5. De-emphasis of the high frequencies (N.A.B.) may be accomplished by a capacitor connected across a resistive network. The value of the capacitance is given by

$$C = 100/R \qquad (1)$$

where C = capacitance in microfarads
R = total circuit impedance (supply resistance and load resistance in parallel) across which C is placed
and 100 = time constant in microseconds.

This provides de-emphasis of approximately 16 db at 10 000 c/s.

(v) Translation loss and radius compensation

Translation loss is defined as the loss in the reproduction of a mechanical recording whereby the amplitude of motion of the reproducing stylus differs from the recorded amplitude in the medium (N.A.B. 1949). The translation loss is a function of the record, the needle tip radius and the pickup. Usual values are from 8 to 16 db at 10 000 c/s at the inner groove.

Radius compensation (diameter equalization)

In order to reduce the loss of high frequencies during play-back some recording organizations boost the higher frequencies during recording, the degree of boosting increasing as the stylus approaches the innermost groove. It is important to remember that the purpose of radius compensation is to give, as nearly as practicable, constant output at all frequencies and at all positions along the groove, when played by a pickup with the recommended needle tip dimensions.

The R.C.A. automatic recording equalizer MI-11100 provides two degrees of radius compensation. The low setting gives 10.8 db at 8 inches diameter and 8 db at 9 inches, both for 10 000 c/s. The high setting gives 13.5 and 9.9 db respectively under the same conditions.

The B.C.C. have a maximum radius compensation of 10 db, but the frequency at which it reaches 10 db is decreased as the diameter becomes smaller (minimum 8-3/4 inches).

There is no doubt that with certain kinds of music it is impossible to apply the full N.A.B. pre-emphasis of 16 db at 10 000 c/s together with the necessary amount of radius compensation to provide a nearly level frequency characteristic without serious over-modulation and distortion. The only answer seems to lie in the use of fine groove recording.

References 4, 99, 189, 214, 227.

SECTION 10 : REFERENCES TO LATERAL DISC RECORDING

2. N.A.B. " Recording Standards " Comm. 22.8 (Aug. 1942) 20.
4. Lynn, R. A. " Factors contributing to good recording " RCA Rev. 6.4 (April 1942) 463.
7. Brooker, V.M. " Sound on disc recording " W.W. 43.26 (Dec. 29th 1938) 588.
8. " *Pick-up design* " W.W. 43.17 (Oct. 27th, 1938) 364. (Description of H.M.V. " Hyper-sensitive " model).
9. Andrews, H. " Home recording " W.W. (1) 43.2 (July 14, 1938) 24 ; (2) 43.3 (July 21, 1938) 50 ; (3) 43.4 (July 28, 1938) 73 ; (4) 43.5 (Aug. 4, 1938) 95.
10. Voigt, P.G.A.H. " Getting the best from records " W.W. (1) The recording characteristic 46.4 (Feb. 1940) 141 ; (2) " The pick-up " 46.5 (Mar. 1940) 177 ; (3) " More about tone correction circuits " 46.6 (April 1940) 210 ; (4) " The record has the last word " 46.7 (May 1940) 242.
11. Burt, A. D. " The reduction of record noise by pick-up design " Elect. 16.1 (Jan. 1943) 90.
14. Beers, G. L., & C. M. Sinnett " Some recent developments in record reproducing systems " Proc. I.R.E. 31.4 (April 1943) 138.
15. Brierley, J. " Pick-up accessories " W.W. 49.4 (April 1943) 100.
16. Hay, G. A. " Needle armature pick-up ; design giving good frequency response and low amplitude distortion " W.W. 49.5 (May 1943) 137.
17. Brierley, J. " A moving coil pick-up " W.W. 48.7 (July 1942) 154; G. A. Hay (letter) W.W. 48.9 (Sept. 1942) 222. J. H. Mole (letter) W.W. 48.8 (August 1942) 192.
21. Scroggie, M.G. " Gramophone needle scratch " W.W. 46.1 (Nov. 1939) 3.
24. Thrurrell, D. W., G. E. Horn, D. W. Aldous, A. S. Robb (letters) W.W. 49.6 (June 1943) 184.
25. de Soto, C. B. " How recordings are made " Q.S.T. (1) Principles of disc recording 26.7 (July 1942) 30 ; (2) The recording 26.8 (Aug. 1942) 56 ; (3) The amplifier 26.9 (Sept. 1942) 65 ; (4) Playback 26.10 (Oct. 1942) 54 ; (5) Tests and trouble shooting 26.12 (Dec. 1942) 51.
29. W.W. Brains Trust " Future of the Disc " W.W. 50.1 (Jan. 1944) 8.
30. Aldous, D. W. " *Defects in direct disk recording* " Electronic Eng. 15 (Nov. 1943) 233.
31. " Future of sound recording " W.W. 50.4 (April 1944) 114.
40. Devereux, F. L. " Gramophone needle buzz—an inherent form of distortion : Possible cures " W.W. 50.10 (Oct. 1944) 290.
41. Hunt, F. V., & J. A. Pierce " Distortion in sound reproduction from records " Jour. S.M.P.E. 31.2 (Aug. 1938) 157.
42. Lewis, W. D., & F. V. Hunt " Theory of tracing distortion in record reproduction" J. Acous. Soc. Am. 12.3 (Jan. 1941) 348.
45. Miessner, B. F. " Frequency modulation phonograph pickup " Elect. 17.11 (Nov. 1944) 132.
47. Parvey, J. C. " Vibratory momentum and groove skating in disc reproduction " Comm. 20.10 (Oct. 1940) 22.
50. Miessner, B. F. " Capacity phono pick-up " Radio Craft (Feb. 1945) 282.
52. Bauer, B. B. " Tracking angle in phonograph pickups " Elect. 18.3 (Mar. 1945) 110.
53. Glover, R. P. " A record-saving pick-up " Electronics, 102 (Feb. 1937) 31.
54. Bird, J. R., & C. M. Chorpening " The offset head crystal pickup " Radio Eng. 17.3 (March 1937) 16.
55. Knapp, D. G. " The offset head crystal pickup " Comm. 18.2. (Feb. 1938) 28.
56. Olney, B. " Phonograph pickup tracking error " Elect. 10.11 (Nov. 1937) 19.
57. Lindenberg, T. Jnr. " Moving coil pickup design " Elect. 18.6 (June 1945) 108.
59. Bauer, B. B. " Calculation of distortion due to phonograph needle wear " Elect. 18.77 (July 1945) 250 (based on J. Acous. Soc. Am. 16.4 April 1945 p. 246).
62. Bauer, B. B. " Crystal pickup compensation circuits " Elect. 18.11 (Nov. 1945) 128.
63. Brooker, V. M. " Some aspects of sound recording " Proc. I.R.E. (Aust.) 6.3 (Sept. 1945) 3.
65. Kalmus, H.P. " Pickup with low mechanical impedance " Elect. 19.1 (Jan. 1946) 140.
71. " A new moving coil pickup " (" Lexington ") Electronic Eng. 18.221 (July 1946) 224.
76. Rich, S. R. " *Torsional magnetostriction pickup* " Elect. 19.6 (June 1946) 107.
82. Scott, R. F. " Magnetostriction pickup " Radio Craft (Nov. 1946) 16.
83. Scott, H. H. " Dynamic suppression of phonograph record noise " Elect. 19.12 (Dec. 1946) 92.
84. Furst, U. R. " Periodic variations of pitch in sound reproduction by phonographs " Proc. I.R.E. 34.11 (Nov. 1946) 887.
85. MacDonald, G. E. " The reduction of tracking error " Comm. 21.1 (Jan. 1941) 5.
87. Smeby, L. C. " Recording and reproducing standards " Proc. I.R.E. 30.8 (Aug. 1942) 355.
88. Southey, R. V. " Things to come in sound recording and reproduction " Proc. I.R.E. (Aust.) 7.12 (Dec. 1946) 4.
89. Chinn, H. A. " Glossary of disc-recording terms " Proc. I.R.E. 33.11 (Nov. 1945) 760.
90. " A study of wows " Comm. 22.7 (July 1942) 42.
91. Martinson, B. K. " Phono pickups " Service 15.8 (Aug. 1946) 12.
92. Robinson, W. H. " Lateral Recording " Comm. 27.2 (Feb. 1947) 26. See also Ref. 99.
93. " *Two band phono receiver with variable reluctance pickup* " (G.E.), *Service*, 15.11 (Nov. 1946) 26.

94. Chinn, H. A. " Disc recording " Electronic Industries (Nov. 1946) 64.
95. Capps, I.L. " Recording styli " (for lacquer records) Electronic Industries (Nov. 1946) 65.
96. Germeshausen, K. J., & R. S. John " Phonograph pickup using strain gauge " Electronic Industries (Nov. 1946) 78.
97. Leidel, W. F., & N. E. Payne " Tuned ribbon pickup " (Audak) Electronic Industries, 5.10 (Oct. 1946) 67.
99. Robinson, W. H. " Lateral recording " Comm. 27.4 (April 1947) 38. See also Ref. 92.
103. Thompson, L. " Technics of sound methods ; recording with embossed groove " Tele-Tech. 6.5 (May 1947) 48.
105. Jorysz, A. " Bibliography of disc recording " Tele-Tech. 6.6 (June 1947) 73.
106. Queen, I. " Postwar features of phonograph pickups " Radio Craft 18.12 (Sept. 1947) 36.
109. Francis, E. H. " Moving iron pickups " W.W. 53.8 (Aug. 1947) 285.
110. Roys, H. E. " Intermodulation distortion analysis as applied to disk recording and reproducing equipment " Proc. I.R.E. 35.10 (Oct. 1947) 1149.
113. Rogers, G. L. " Simple rc filters for phonograph amplifiers " Audio Eng. 31.5 (June 1947) 28.
114. Scott, H. H. " Dynamic noise suppressor " Elect. 20.12 (Dec. 1947) 96. See also Ref. 275.
115. Olson, H. F. " Audio noise reduction circuits " Elect. 20.12 (Dec. 1947) 119.
116. Gordon, J. F. " A Vacuum-tube-type transducer for use in the reproduction of lateral phonograph recordings " Proc. I.R.E. 35.12 (Dec. 1947) 1571.
117. McProud, C. G. " High Frequency equalization for magnetic pickups " Audio Eng. 31.8 (Sept. 1947) 13.
119. Hayes, A. E. " A new phonograph pickup principle " Audio Eng. 31.9 (Oct. 1947) 14.
120. Wheeler L.J., & K. G. Lockyer " Crystal pickups ; basis of design for high fidelity reproduction " W.W. 53.11 (Nov. 1947) 412.
126. Savory, W. A. " The design of audio compensation networks " Tele-Tech 7.1 (Jan. 1948) 24.
127. McProud, C. G. " Transition frequency compensation " Audio Eng. 31.6 (July 1947) 10.
128. Mittell, B. E. G. " Commercial disk recording and processing in England " (Review) Audio Eng. 32.4 (Apr. 1948) 19.
131. Mittell, B. E. G. " Commercial disc recording and processing " (abstract) W.W. 54.2 (Feb. 1948) 67.
133. Goodell, J. D. " The dynamic noise suppressor " Audio Eng. 31.10 (Nov. 1947) 7.
135. Tillson, B. F. " Musical Acoustics " (5) Recording groove, Audio Eng. 31.9 (Oct. 1947) 25.
136. " Stylus " (letter) " Musical acoustics" (refers to recording frequency ranges) Audio Eng. 31.9 (Oct. 1947) 3.
137. Hull, A. G. " Limelight on quality " Australasian Radio World (May 1948) 5.
138. Cole, C. D. " Experimental noise suppressor " Audio Eng. 32.1 (Jan. 1948) 9.
140. McCracken, L. G. " Filter characteristics for the dynamic noise suppressor " Elect. 21.4 (April 1948) 114.
142. Kahr., A. " Torque-drive phono pickup " Service, 17.6 (June 1948) 32.
144. Burwen, R. S. " Feedback preamplifier for magnetic pickups " Audio Eng. 32.2 (Feb. 1948) 18.
145. Cook, E. G. " Noise modulation in recording " Audio Eng. 31.11 (Dec. 1947) 8.
146. Tillson, B. F. " Musical Acoustics " Part 7, Audio Eng. 31.11 (Dec. 1947) 23.
149. Canby, E. T. " Record Revue " (Scott noise suppressor) Audio Eng. 32.5 (May 1948) 24.
150. Price, S. L. " Balanced clipper noise suppressor " Audio Eng. 32.3 (March 1948) 13.
151. Cook, E. " Increasing volume level in disc recording " Audio Eng. 32.3 (March 1948) 17.
153. Maxfield, J. P., & J. K. Hilliard " Notes on pre-equalization for phonograph records " Audio Eng. 32.4 (April 1948) 15.
155. Pickering, N. C. " Misconceptions about record wear " Audio Eng. 32.6 (June 1948) 11.
157. " Ribbon pickup " (Brierley) W.W. 54.8 (Aug. 1948) 306.
158. " Modern crystal phonopickups " Radio Electronics 20.1 (Oct. 1948) 29.
159. Gernsback, M. H. " Microgroove phonograph records " Radio Electronics 20.1 (Oct. 1948) 30.
161. Dorf, R. H. " Frequency test records " Radio Electronics 20.1 (Oct. 1948) 46.
162. Queen, I. " New magnetic pickups " Radio Electronics 20.1 (Oct. 1948) 55.
163. Robinson, W. H. " Lateral recording " Comm. 28.9 (Sept. 1948) 34.
164. Olson, H. F., & J. Preston " Electron tube phonograph pickup " Audio Eng. 32.8 (Aug. 1948) 17.
165. McProud, C. G. " Simplified dynamic noise suppressor " Audio Eng. 32.8 (Aug. 1948) 22.
166. " Columbia LP microgroove records " Audio Eng. 32.8 (Aug. 1948) 24.
170. Harris, H. " Making phonograph record matrices " Audio Eng. 32.7 (July 1948) 14.
173. Scott, H. H., & E. G. Dyett, " An amplifier and noise suppressor unit " F.M.&.T. 8.3 (March 1948) 28.
174. Southey, R. V. " Modern practice in disc recording " Proc. I.R.E. (Aust.) 9.11 (Nov. 1948) 16.
178. Hector, L. G., & H. W. Koren " Ceramic phonograph pickup " Elect. 21.12 (Dec. 1948) 94.
179. " Design of L-P records " Elect. 21.12 (Dec. 1948) 110.
181. Smith, O. J. M. " Polyethylene phonograph records " Audio Eng. 32.9 (Sept. 1948) 13.
182. Canby, E. T. " Record revue " (3 types of noise suppressors) Audio Eng. 32.9 (Sept. 1948) 33.
183. Baruch, R. M. " The LP microgroove record system " Service 17.11 (Nov. 1948) 14 ; 17.12 (Dec. 1948) 16.
184. Dyett, E. G. " Three tube dynamic noise suppressor " Service 17.11 (Nov. 1948) 26.
185. " Recorder specifications " Tele-Tech. 7.8 (Aug. 1948) 40.
187. Douglas, A. " The G.E. variable reluctance pickup " Electronic Eng. 21.251 (Jan. 1949) 21 (based on G.E. catalogue data).
188. McProud, C. G. " Elements of residence radio systems " (3) Audio Eng. 32.11 (Nov. 1948) 20.
189. Viol, F.O. " Some problems of disc recording for broadcasting purposes " Proc. I.R.E. (Aust.) 10.2 (Feb. 1949) 42. Reprinted Proc. I.R.E. 38.3 (March 1950) 233.
193. " Proposed standards for the measurement of distortion in sound recording " Jour. S.M.P.E. 51. (Nov. 1948) 449.
194. Nicholas, W.R. " Some aspects of phonograph pickup design " Proc. I.R.E. (Aust.) 10.3 (March 1949) 63.
195. " Supersonic high fidelity " W.W. 54.1 (Jan. 1948) 23.
197. Hilliard, J. K. " Factors affecting pre-and post-equalization " Comm. 32.9 (Sept. 1943) 30.
198. Savory, W.A. " The design of audio compensation networks " Tele-Tech 7.2 (Feb. 1948) 27.
199. Haines, F.M. " High fidelity bass compensation " Electronic Eng. 18.216 (Feb. 1946) 45.
205. Tillson, B. F. " Musical acoustics " Part 6 Audio Eng. 31.10 (Nov. 1947) 31.
209. Ellis, J. " Bass compensation " W.W. 53.9 (Sept. 1947) 319. See also Ref. 278.
210. Griffin, E. E. " Embossing at constant groove speed—a new recording technique " Elect. 13.7 (July 1940) 26.
211. McProud, C. G. " Experimental volume expander and scratch suppressor " Audio Eng. 31.7 (Aug. 1947) 13.

212. Begun, S. J., & T. E. Lynch "The correlation between elastic deformation and vertical forces in lateral recording" Jour. Acous. Socy. Am. 13.3 (Jan. 1942) 284. Correction 13.4 (April 1942) 392.
213. Pierce, J. A., & F. V. Hunt "On distortion in sound reproduction from phonograph records" Jour. Acous. Socy. Am. 10.1 (July 1938) 14.
214. Davies, H. "The design of a high-fidelity disc recording equipment" Jour. I.E.E. Vol. 94 Part III No. 30 (July 1947) 275.
215. Scott, H. H. "Dynamic noise suppressors" Service 17.9 (Sept. 1948) 16.
216. Henney, K. (book) "The Radio Engineering Handbook" (McGraw-Hill Book Co., **New York,** & London, 3rd edit. 1941) Sec. 21.
218. Aldous, D. W. "Manual of Direct Disk Recording" (Bernards, Publishers, Ltd. London, 1944).
219. "N.B.C. Recording Handbook" National Broadcasting Co. Inc., Engineering Department.
220. O'Brien, E. J. "High fidelity response from phonograph pickups" Elect. 22.3 (March 1949) 118
222. Le Bel, C. J. "Properties of the dulled lacquer cutting stylus" J. Acous. Soc. Am. 13.3 (Jan. 1942) 265.
223. Reid, J. D. "A large radius stylus for the reproduction of lateral cut phonograph records" J. Acous Soc. Am. 13.3 (Jan. 1942) 274. Review W.W. 49.1 (Jan. 1943) 5.
224. Sepmeyer, L. W. "Tracing distortion in the reproduction of constant amplitude recordings" J. Acous. Soc. Am. 13.3 (Jan. 1942) 276.
225. Goldsmith, F. H. "A noise and wear-reducing phonograph reproducer with controlled response" J. Acous. Soc. Am. 13.3 (Jan. 1942) 281.
226. Savory, W. A. "Design of audio compensation networks" Tele-Tech 7.4. (April 1948) 34.
227. Kornei, O. "On the playback loss in the reproduction of phonograph records" Jour. S.M.P.E. 37 (Nov. 1941) 569.
228. Baerwald, H. G. "Analytic treatment of tracking error and notes on optimal pick-up design" Jour. S.M.P.E. 37 (Nov. 1941) 591.
229. McLachlan, N. W. (book) "The New Acoustics" (Oxford University Press, 1936) p. 88.
230. Dorf, R. H. (book) "Practical Disc Recording" (Radcraft Publications Inc., New York, 1948).
231. Axon, P. E., & H. Davies "A study of frequency fluctuations in sound recording and reproducing systems" Jour. I.E.E. Part III 96.39 (Jan. 1949) 65.
232. "Columbia LP record specifications" Tele-Tech 7.10 (Oct. 1948) 63.
233. Roys, H. E. "An improved lacquer disc recording head" Audio Eng. 33.2 (Feb. 1949) 21.
234. Bachman, "Phonograph reproducer design" E.E. 65.3 (March 1946) 159.
235. Mittell, B. E. G. "Annexure to recorded talk on disc-recording standards" delivered to I.R.E. (Australia) Convention at Sydney, Australia, Nov. 3, 1948.
236. Aldous, O. W. "American microgroove records" W.W. 55.4 (Apr. 1949) 146.
237. "N.A.B. Recording and reproducing standards" Engineering (May 16, 1949)
238. "Stylus", "Characteristics of the new 45 r.p.m. record" Audio Eng. 33.3 (March 1949) 6.
239. St. George, P. W., & B. B. Drisko "Versatile phonograph preamplifier" Audio Eng. 33.3 (March 1949) 14.
240. Van Beuren, J. M. "Cost vs quality in af circuits" F.M. & T. 9.2 (Feb. 1949) 31.
241. Scott, H. H. "Audio developments: observations on the quality of records made here and overseas" F.M. & T. 9.1 (Jan. 1949) 23.
242. Morse, M. "Sound embossing at the high frequencies" J. Acous. Soc. Am. 19.1 (Jan. 1947) 169.
243. Hornbostel, J. "Improved theory of the light pattern method for the modulation measurement in groove recording" Electronic Eng. 19.1 (Jan. 1947) 165.
244. McClain, E. F. "A distortion reducing stylus for disk reproduction" J. Acous. Soc. Am. 19.2 (March 1947) 326.
245. Duffield, A. W. "Improvements in disc records through constant amplitude recording" Comm. 20.3 (Mar. 1940) 13.
246. Bomberger, D. C. "A continuously variable equalizing pre-amplifier" Audio Eng. 33.4 (Apr. 1949) 14.
247. Maxfield, J. P., & J. K. Hilliard "Notes on pre-equalization for phonograph records" Audio Eng. 32.4 (Apr. 1948) 15.
248. Fleming, L. "Notes on phonograph pickups for lateral-cut-records" J. Acous. Soc. Am. 12.3 (Jan. 1941) 366.
249. Bauer, B. B. "Pickup placement" Elect. 22.6 (June 1949) 87.
250. McProud, C. G. "General purpose 6AS7G amplifier" Audio Eng. 32.6 (June 1948) 24.
251. Aston, R. H. "A dynamic noise suppressor" Radiotronics No. 132 (July/Aug. 1948) 73.
252. Williams, A. L. "Further improvements in light-weight record reproducers" Jour. S.M.P.E. 33 (Aug. 1939) 203.
254. Data kindly supplied by Radio Corporation of America, R.C.A. International Division.
255. Data kindly supplied by William S. Bachman, Director of Research, Columbia Records Inc.
256. Data kindly supplied by R. V. Southey, E.M.I. (Australia) Pty. Ltd.
257. Hunt, F. V. (in discussion on "What constitutes high fidelity reproduction?") Audio Eng. 32.12 (Dec. 1948) 8
258. Frayne, J. G. & H. Wolfe (book) "Elements of Sound Recording" (John Wiley and Sons, New York; Chapman and Hall, Ltd., London 1949).
259. Langford-Smith, F. (Letter) "Recorded supersonic frequencies" W.W. 55.7 (July 1949) 275.
260. R.M.A. (U.S.A.) Standards and other data REC-103 (Oct. 1946): Dimensional characteristics—phonograph records for home use.
REC-105 (June, 1947): Disc home recording.
REC-125-A (July 1949): Phonograph pickups.
REC-126-A (Oct. 1950): Playback needles for home phonographs.
REC-128 (May, 1949): Standard frequency test records.
261. Andrews, D. R. "Importance of groove fit in lateral recordings" Audio Eng. 33.7 (July 1949) 18.
262. Goldmark, P. C., R. Snepvangers & W. S. Bachman "The Columbia long-playing microgroove recording system" Proc. I.R.E. 37.8 (Aug. 1949) 923.
263. Carson, B. R., A. D. Burt & H. I. Reiskind "A record changer and record of complementary design" R.C.A. Rev. 10.2 (June 1949) 173.
264. Corrington, M. S. "Tracing distortion in phonograph records" R.C.A. Rev. 10.2 (June 1949) 241.
265. Roys, H. E. "Analysis by the two-frequency intermodulation method of tracing distortion encountered in phonograph reproduction" R.C.A. Rev. 10.2 (June 1949) 254.
267. Institute of Radio Engineers, U.S.A. "Standards on radio receivers—methods of testing amplitude-modulation broadcast receivers" (1948).
268. Sterling, H. T. "Simplified preamplifier design" Audio Eng. 33.11 (Nov. 1949) 16.

269. Yenzer, G. R. " Lateral feedback disc recorder " Audio Eng. 33.9 (Sept. 1949) 22.
270. Williamson, D. T. N. " High quality amplifier—new version " W.W. 55.8 (Aug. 1949) 282 ; 55.10 (Oct. 1949) 365 ; 55.11 (Nov. 1949) 423.
271. " Disc recording system developments—solutions of many problems to bring about a fidelity range of 20 KC " Tele-Tech. 9.1 (Jan. 1950) 14.
272. Begun, S. J. (book) " Magnetic Recording " (Murray Hill Books Inc. 1949).
273. Haynes, H. E., & H. E. Roys " A variable speed turntable and its use in the calibration of disk reproducing pickups " Proc. I.R.E. 38.3 (March 1950) 239.
274. Briggs, G. A. (book) " Sound Reproduction " Wharfedale Wireless Works, Bradford, Yorks., England, 1949.
275. Scott, H. H. " The design of dynamic noise suppressors " Proceedings of the National Electronics Conference, Chicago, Illinois, Nov. 3-5, 1947, Vol. 3. p. 25.
276. Brierley, J. H. " Reproduction of Records—1 " booklet published by J. H. Brierley (Gramophones and Recordings) Ltd., Liverpool, England.
277. Data supplied by J. H. Brierley of J. H. Brierley (Gramophones and Recordings) Ltd., Liverpool, (England).
278. Fleming, L. " Equalized pre-amplifier using single stage feedback " Audio Eng. (Mar. 1950) 24. See also Ref. 209.
279. Reid, J. D. " Universal phonograph styli " J.A.S.A. 21.6 (Nov. 1949) 590.
280. Warren, H. G. (letter) " Pre-amplifier circuit " W.W. 46.6 (June 1950) 238.
281. Bauer, B.B. " All-purpose phonograph needles " Elect. 23.6 (June 1950) 74.
282. Wood, G. H. H. " Record and stylus wear—advantage of compliant stylus mountings " W.W. 56.7 (July 1950) 245.
283. Mallett, E. S. " The determination of gramophone pick-up tracking weights " Electronic Eng. 22.267 (May 1950) 196.
284. Woodward, J. G. " A feedback-controlled calibrator for phonograph pickups " R.C.A. Rev. 11.2 (June 1950) 301.
285. Roys, H. E. " Determining the tracking capabilities of a pickup " Audio Eng. 34.5 (May 1950) 11.
286. " Playback standards " Audio Eng. 34.7 (July 1950) 4.
287. Fleming, L. " Equalized pre-amplifier using single stage feedback " Audio Eng. 34.3 (March 1950) 24.
288. Bachman, W. S. " The Columbia hot stylus recording technique " Audio Eng. 34.6 (June 1950) 11.
289. Wortman, L. A. (Summary of discussion) " Heated stylus recording technique " Audio Eng. 34.7 (July 1950) 24.
290. Marcus, E. J. & M. V. " The diamond as a phonograph stylus material " Audio Eng. 34.7 (July 1950) 25.
291. Fine, R. S. " An intermodulation analyzer for audio systems " Audio Eng. 34.7 (July 1950) 11.
292. Roys, H. E. " Recording and fine-groove technique " Audio Eng. 34.9 (Sept. 1950) 11.
293. Moyer, R. C., D. R. Andrews & H. E. Roys " Methods of calibrating frequency records " Proc. I.R.E. 38.11 (Nov. 1950) 1306.
294. Godfrey, J. W. " Reproduction of discs and records for broadcasting " B.B.C. Quarterly 4.3 (Autumn 1949) 170.
295. Terry, P. R. " The variable-disc-speed method of measuring the frequency characteristics of pick-ups " B.B.C. Quarterly 4.3 (Autumn 1949) 176.
296. Anderson, L. J. & C. R. Johnson " New broadcast lightweight pickup and tone arm " Audio Eng. 35.3 (March 1951) 18.
297. Moir, J. " Recorders and reproducers " FM-TV 11.1 (Jan. 1951) 14.
298. Weil, M. " Phono facts " Audio Eng. 35.6 (June 1951) 20.
299. Dutton, G. F. " Gramophone turntable speeds " W.W. 57.6 (June 1951) 227.
300. " Frequency test records—Calibration methods discussed by B.S.R.A. " W.W. 57.6 (June 1951) 227.
301. Kelly, S. " Piezo-electric crystal devices " Electronic Eng. 23.278 (April 1951) 134 ; 23.279 (May 1951) 173.
302. Shirley, G. (letter) " Diamond vs sapphire " Audio Eng. 35.8 (Aug. 1951) 6.
303. John, R. S. " A strain-sensitive phonopickup " Radio and TV News 43 (Feb. 1950) 40.
304. Roys, H. E. " Recording and fine groove technique " Broadcast News No. 60 (July-Aug. 1950) 9.
305. West, R. L., & S. Kelly " Pickup input circuits " W.W. 56.11 (Nov. 1950) 386.
306. Goodell, J. D. " Problems in phonograph record reproduction " Radio & TV News 44.5 (Nov. 1950) 39.
307. " AES Standard playback curve " Audio Eng. 35.1 (Jan. 1951) 22.
308. " British long-playing records " W.W. 57.1 (Jan. 1951) S7.
309. Pollock, A. M. " Thorn gramophone needles " W.W. 56.12 (Dec. 1950) 450 ; correspondence 57.3 (March 1951) 121 ; 57.4 (April 1951) 145.
310. Kelly, S. " Intermodulation distortion in gramophone pickups " W.W. 57.7 (July 1951) 256. (b) Letter L. J. Elliott, 57.9 (Sept. 1951) 370.
311. Bachman, W. S. " The application of damping to phonograph reproducer arms " Proc. I.R.E. 40.2 (Feb. 1952) 133.
312. Discussion on hum in moving coil and ribbon pickups : H. J. Leak, W.W. 56.4 (Apr. 1950) 132 ; J. H. Brierley, 56.6 (June 1950) 238 ; 57.2 (Feb. 1951) 81 ; P. J. Baxandall and R. L. West 57.4 (Apr. 1951) 146, 147.
313. Anderson, L. J., & C. R. Johnson " New lightweight pickup and tone arm " Broadcast News No. 64 (May-June 1951) 8.
314. Weil, M. (letter) " Tracking efficiency " Audio Eng. 34.8 (Aug. 1950) 2, also front cover.
315. " Hot stylus technique " W.W. 58.2 (Feb. 1952) 50.
316. Read, O. (book) " The recording and reproduction of sound " (Howard W. Sams & Co. Inc. Indianapolis, Indiana, 2nd ed. 1952).
317. Parchment, E. D. " Microgroove recording and reproduction " Jour. Brit. I.R.E. 12.5 (May 1952) 271.

Additional references will be found in the Supplement commencing on page 1475.