Practical Disc Recording

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By RICHARD H. DORF

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William Sterling Barker

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Preface

THE purpose of this book is to introduce the radio enthusiast to the art of disc recording and to explain in practical terms the elements of making high-quality records. Disc recording requires no more mechanical ability or knowledge than the average radioman possesses. It can be a fascinating and productive adjunct to radio, or a business or hobby in itself. Many hours of pleasure and profit can be spent in designing and constructing recording systems.

The owner of a well-built installation can readily acquire an excellent record library of music recorded from the radio and by artists at home, as well as history-making speeches, public events, and personalities. Musical backgrounds, with commentaries, can be provided for home movies. In addition, the serviceman will profit from a thorough knowledge of recording. More and more radios today are equipped to *make* records as well as play them.

It is expected that the reader has a fundamental knowledge of radio, but every detail of the recording process is described in this book. The recordist will find design and construction data for amplifiers, equalizers, and control equipment. The processes of adjustment and the steps in making a good recording are given in detail. Throughout, the hows and whys of recording are fully discussed, to give the reader a thorough knowledge of the subject.

The type of equipment to be purchased depends on two things: the use intended for the equipment, and the purchaser's pocketbook. It is possible to record radio programs with an initial expenditure of less than $25.00. The results, however, will not bear critical listening and may have little entertainment value. On the other hand, it is possible to spend several thousand dollars for the recording equipment. Naturally, few amateurs are willing or able to spend this kind of money on a hobby. But such an expenditure would not be excessive for some professional installations.

We can only suggest that you let your pocketbook and enthusiasm be your guides. Let us illustrate what we mean. Suppose you wish to make records purely as a hobby and plan to play them on your $45.00 table-model radiophonograph. The frequency response of such a machine *at best* is about 100-4,000 cycles. Harmonic distortion is probably in the order of 10% to 20%. There is little advantage to be gained from buying high-fidelity recording equipment. True, the high-fidelity recordings will sound a little better, but not enough better to warrant the extra cost. On the other hand, those who enjoy music and have a phonograph capable of reproducing wide-range records should consider high-fidelity recording equipment (if they can afford it). They probably would be dissatisfied with the results from low-fidelity equipment.

When recording for others, professionally, equipment must be as good as you can afford, since it is a business investment. Here, too, intended use supplies the answer to what to buy. Are the customers professional musicians who must have perfect recordings? Or are they less critical average people who are primarily interested in the novelty aspect of hearing their friends' and relatives' voices?

Having determined the ultimate use of the equipment, this much is sure: no two people will have to purchase the same items of equipment. One may have a suitable amplifier on hand, another a microphone, a third a heavy-duty turntable. In this book, we have attempted to evaluate each part of the whole with this in mind. The reader must determine which items he must get, and then balance cost against intended use in determining how much he spends for each part. Naturally, the goal is the best results for the smallest expenditure.

It is our hope that this book will provide the answers to all the important problems encountered by the recordist, and that it will be of continuing value as a ready reference.

The publishers acknowledge with thanks the cooperation of the following manufacturers in supplying illustrations for this book: Figs. 201, 306, 308, 1401—From book "How to Make Good Recordings"—Audio Devices, Inc.; Fig. 1111—Cinema Engineering Co.; Figs. 803, 804—Electro-voice, Inc.; Fig. 303—Fairchild Camera & Instrument Corp.; Fig. 403—General Industries Co.; Figs. 304, 401, 406, 408, 502, 1103, 1112—Presto Recording Corp.; Fig. 405—Rek-O-Cut Co.; Fig. 802—The Turner Co.; Fig. 402—Wilcox-Gay Corp.; Figs. 503, 605, 805—Brush Development Co.; Fig. 102—Cook Laboratories.

Chapter 1

Recording System Elements

DISC recording involves the engraving of a spiral groove in a flat disc of semisoft material. The groove is a precise spiral during periods of no modulation; but when an audio signal is recorded, the path of the groove varies from side to side in accordance with the positive and negative variations of the impressed audio. Fig. 101 shows a portion of one groove. In Fig. 101-a the groove is unmodulated—no signal has been recorded. The groove takes a perfectly spiral path around the disc. In Fig. 101-b a signal has been recorded. The path of the groove fluctuates from side to side (that is, *laterally*) within narrow limits, in accordance with the signal. (In the drawing, the lateral variations are much exaggerated.) Fig. 102 is an actual microphotograph of a small area of a recorded disc. The 3 wavy grooves are recordings of a 1,000-cycle sine wave, while the 2 at each side are unmodulated grooves.

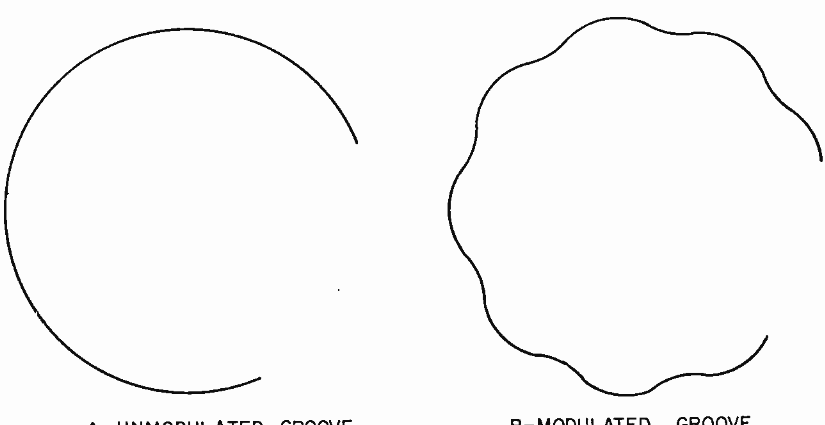


Fig. 101—a—Grooves without signal recorded; b—with signal recorded.

In playing back, the phono pickup needle, traveling in the groove, is deflected from side to side by the variations in the groove path. This lateral movement is translated by the pickup into an audio voltage corresponding to the fluctuations.

This recording method is known as *lateral* recording because the groove varies in a lateral direction. There is a second method, *vertical* or "hill and dale" recording, so called because the variations occur in a plane vertical to the disc surface. In this system, audio fluctuations vary the *depth* of the engraved groove rather than its lateral path, which remains a perfect spiral throughout. The early Edison records were recorded by the vertical method, and today many broadcast transcriptions are made in this manner because of certain inherent advantages. Vertical recording being confined to a very few large transcription

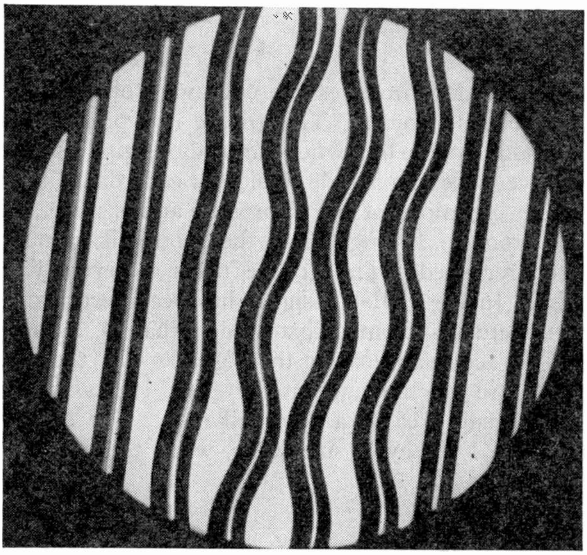


Fig. 102—Actual microphoto of grooves with and without modulation.

manufacturers and the equipment not being generally available, we will confine ourselves to lateral recording.

The elements necessary to produce a lateral disc recording are:

1. A flat disc with a surface suitable for engraving;
2. An engraving tool or point (the *stylus*);
3. A means of converting electrical energy into mechanical movement of the engraving tool (a *cutter* or *cutting head*);
4. A means of rotating the disc under the engraving tool (*motor and turntable*);
5. A method of moving the engraving tool slowly and uniformly along the radius of the disc, to produce the spiral feed;
6. An amplifier to supply audio power to the cutter.

Chapter 2

The Disc

THE discs used in making *instantaneous* records—those which can be played back immediately without processing, the type with which we are concerned—are all basically similar. The best quality discs consist of a flat aluminum base, coated with a special composition. This composition used to be misnamed "acetate" (it is usually cellulose nitrate, actually), and the discs are still popularly known as acetate discs. Fig. 201 shows a typical recording disc. Note the extreme smoothness and regularity of the surface.

Cardboard and similar materials are often used as bases in smaller sized discs for reasons of economy. These materials do not provide a hard enough backing to allow good cutting of the higher frequencies.

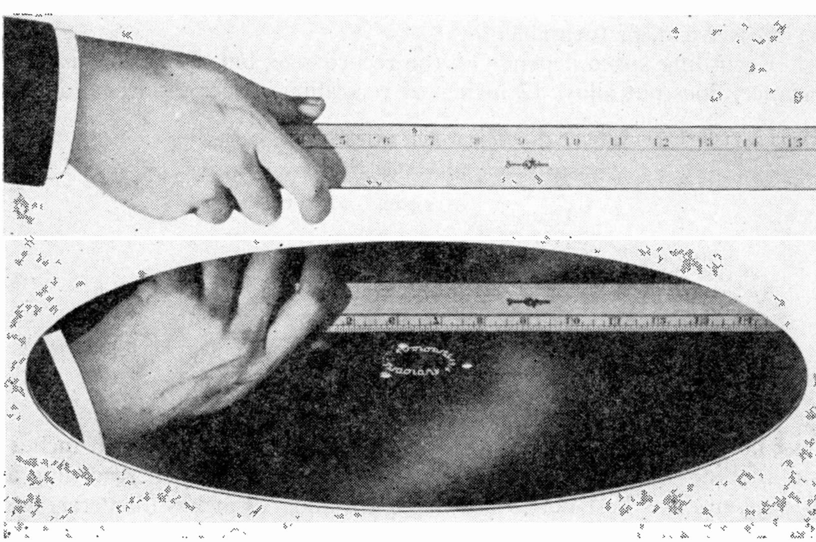


Fig. 201—Typical mirror-smooth recording disc.

They are porous, and their comparatively coarse texture makes a smooth coating almost impossible. This causes surface noise. Generally, they

Table 2-1 — Recording time in minutes.

Disc Diam. inches	Lines per Inch					
	78 r.p.m.			33-⅓ r.p.m.		
	96	112	120	96	112	120
6	1:14	1:26	1:54	—	—	—
8	2:28	2:52	3:48	—	—	—
10	3:42	4:18	5:42	2:10	2:31	2:42
12	4:56	5:44	7:36	5:03	5:51	6:18
16	—	—	—	10:48	12:36	13:30

are used only for voice recording in cases where audio quality and durability are not important.

Tables 2-1 and 2-2 show disc diameters and recording times available at the standard turntable speeds of 33⅓ and 78 r.p.m. (see Chapter 3) and at various pitches of the lead screw (see Chapter 4). For any other conditions than those listed, use the formula:

$$T = \frac{NS}{R}, \text{ where}$$

T is recording time in minutes;
N is feed screw pitch, in lines per inch;
S is recording space, in inches;
R is r.p.m. of turntable.

Recording space depends on the record size, but a 12-inch disc, for instance, does not allow 12 inches of recording space. At least ¼ inch

Table 2-2 — Recording space (S) in inches.

Disc Diam.	78 r.p.m.	33-⅓ r.p.m.
6	1	—
8	2	—
10	3	0.75
12	4	1.75
16	-	3.75

must be left around the rim; the label usually takes up about 3 inches; and another ¼ inch must be left around the label. When recording at 33⅓ r.p.m., it is best not to use the space under 8 inches diameter, due to loss of high frequencies (see Chap. 11). Values in Table 2-1 have been figured on this basis, and Table 2-2 gives recording space for each size of disc at each speed. When using the formula, substitute the value shown in Table 2-2 for the factor S. Diameters over 12 inches should not be recorded at 78 r.p.m., because the speed of the disc as it passes the stylus becomes so great that the stylus will be quickly worn down.

Each manufacturer makes several grades of discs. They vary principally in type and thickness of base and thickness of coating. Where cost is important, the second-best grade will usually be entirely satisfactory for all but the highest-quality professional work.

It is wise to try several brands and grades, since preference varies with individuals. Except for occasional amateur special purposes, however, no base material but aluminum is acceptable. Never use unbranded or factory-reject discs. Coating is usually uneven, and the cutting stylus is very likely to be ruined. Be sure the discs will lie flat on the turntable.

Chapter 3

Motor and Turntable

PROBABLY no part of the recording system is so capable of doing harm as a poor motor and turntable, because, if it is inherently unsatisfactory, there is just no way to "make it do." The 2 most important requirements are *sufficient power* and *constant speed.*

As the stylus bites into the disc coating, it creates drag on the revolving turntable—a drag many times greater than that of a pickup needle. Most turntables made only for *playing* records would stop

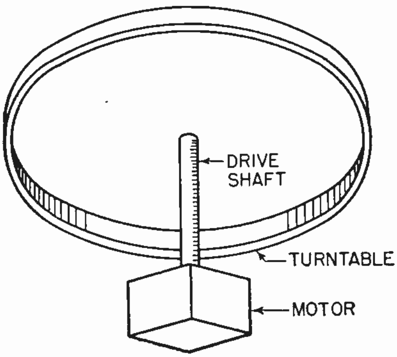


Fig. 301—Simple direct-drive turntable.

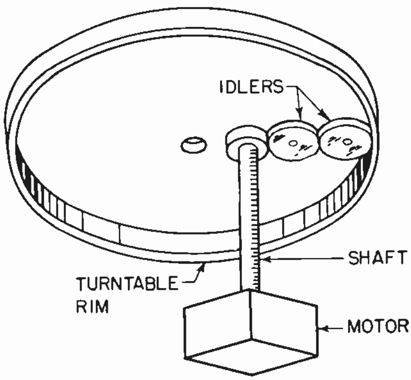


Fig. 302—Rim-driven turntable.

if a recording stylus were lowered to the surface of a disc on them. Never use a turntable not specifically designed for *making* records.

When a phonograph turntable varies its speed, the musical tones appear to waver or "wow." This is because the tones produced depend on the rate at which the groove variations pass under the pickup needle. If they do not pass at a steady rate, the tone will be unsteady. Similarly, if the speed of the *recording* turntable is not constant, the tones will waver when played back on a good phonograph.

Speed of a typical good recording (or playback) table is constant to within ½ of 1%, and, within any single revolution, within ¼ of 1% *when under load (cutting a record)*. Since the human ear can detect

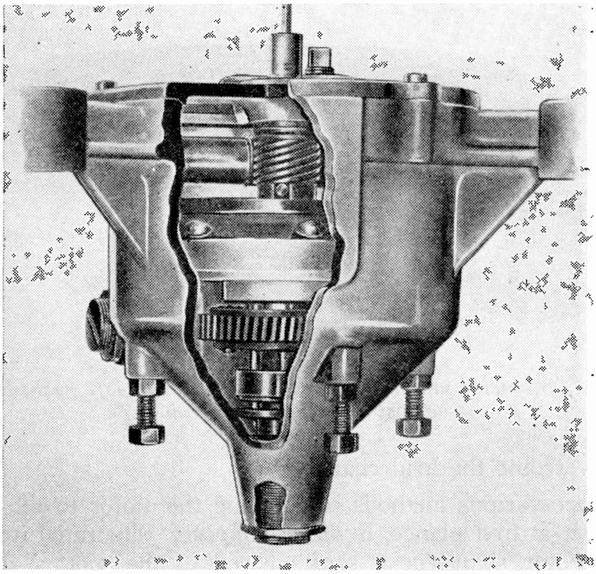


Fig. 303—Precision built direct-drive assembly.

with great discomfort variations of even 1% in musical pitch, it is clear that there is not much room in a recording system for inferior turntables!

Recording Speeds

The speed of the turntable must be not only constant, but also standard. The 2 standard speeds are 78.26 r.p.m. (the speed of standard phonograph records) and 33 1/3 r.p.m. (used in most broadcast transcriptions). If the recording turntable revolves faster than the playback table, the groove variations will not be passing under the pickup needle as fast as they passed under the recording stylus. The music will then be lower in pitch when it is played back than it was in the original. Conversely, if the recording table is too slow, the pitch will be raised in playback.

If a.c. lines are available, the recording motor should always be of the *synchronous* type. Speed of these motors depends only on the line frequency (usually 60 cycles) and not on the line voltage.

Another source of wow is the signal peak. When a high-level passage is recorded, the stylus swings laterally a greater distance. It bites into a larger amount of the disc coating in a given time than when low-level passages are in progress. The amount of drag caused by the stylus depends, not only on the weight of the cutter and the hardness of the disc coating, but also on signal level, which changes momentarily. It is very important that the motor have sufficient reserve

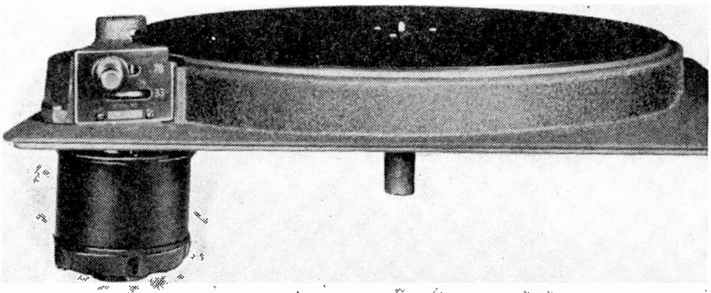


Fig. 304—An outside rim-driven turntable. Lever at left pushes idler against the rubber-tired rim.

power to overcome the load changes.

There are various methods of coupling the motor to the turntable. The simplest, at first glance, is *direct coupling,* illustrated in Fig. 301. Here, the motor shaft—or a shaft geared to the motor—is fastened directly to the center of the turntable.

Direct drives are reliable only in the most expensive and precisely built units of the type shown in Fig. 303.

The method most commonly in use today for all grades of units is

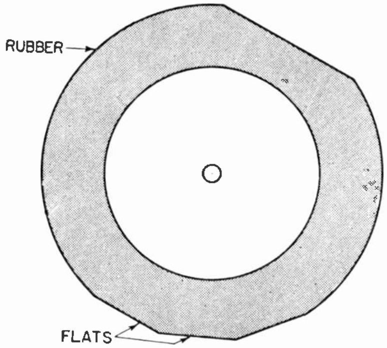


Fig. 305—Idler wheel may develop flat spots.

rim drive, shown in Fig. 302. Here the motor shaft friction-drives a rubber-edged wheel. The rubber wheel contacts the inside edge of the turntable, either directly, or through one or more idler wheels of similar construction. Rim driving requires less torque from the motor, although motor speed must be higher for a given turntable r.p.m. than for direct drive. Since speed is cheaper to incorporate into a motor than torque, a good rim-drive table can be purchased for much less

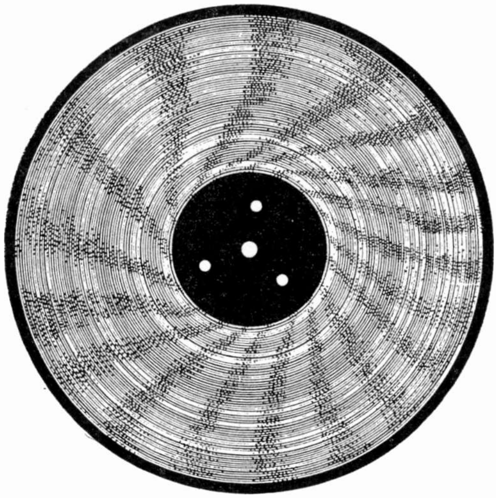


Fig. 306—Spoke pattern, result of idler "flats".

than a direct-drive arrangement giving comparable results.

There are variations in rim-drive arrangements. Frequently several idler wheels are provided to reduce turntable rumble (vibration transmitted from the motor) and to allow for 2-speed operation by selecting the proper idler combination. Often the idlers and the motor shaft are placed outside the perimeter of the turntable, as in the unit shown in Fig. 304. In this unit, the lever at the left is placed in either of 2 slots to select the proper idler for the desired turntable speed. A significant advantage is a third position of the lever, which removes all idlers from contact with the turntable when the unit is not in use.

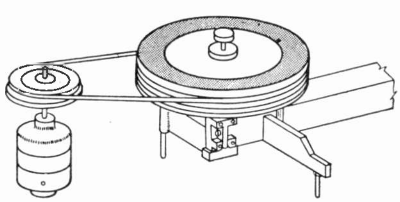


Fig. 307—Simplified belt-driven turntable.

In tables which do not include such an arrangement, it is good practice to perform the same operation by hand. A piece of rubber pressed against a metal object will tend to assume the shape of the metal object after a time. When the turntable is revolving, the pressure is evenly distributed around the idler wheel, but if it is allowed to stand for long periods, the idler will develop a "flat," as shown in Fig. 305. There-

Fig. 308—Moiré pattern, resulting from motor vibration or worn idlers.

after, turntable revolution will be uneven and poor recordings will result. Records cut on a motor with a flatted idler will frequently have a visible spoke pattern similar to that in Fig. 306.

Belt drive is used in a few high-quality systems (see Fig. 307). The chief value of belt drive is the mechanical insulation of the motor from the turntable.

The 3 types of units, then, are direct drive, rim drive, and belt drive. Of these, rim drive is the least expensive. When well built, it is satisfactory in every way. Rim-drive recording assemblies are sold in a wide price range—from about $15 to over $150. Even the cheaper ones will give satisfactory results if the standard of performance demanded is not too high. For high-fidelity work and professional applications, it is always best policy to use a good, substantial turntable.

Direct drives are inherently the most precise of the three types. But this is true only when the machining is exact, the shaft very hard, and the gears (if any) very carefully made and aligned. Low-priced direct drives are seldom satisfactory.

It is necessary to use some method of mechanical insulation. Every motor has some vibration, and if transferred to the turntable as rumble, a low-frequency hum will be recorded. Records made on a table with insufficient mechanical insulation will appear like those in Fig. 306 or Fig. 308. The moiré pattern of Fig. 308 can be caused also by worn rubber idlers or amplifier hum.

Another important factor in choosing a turntable is its speed. At 33 1/3 r.p.m., a given size disc will give longer recording time, a good feature. However, most of the inexpensive tables are made for 78 r.p.m.

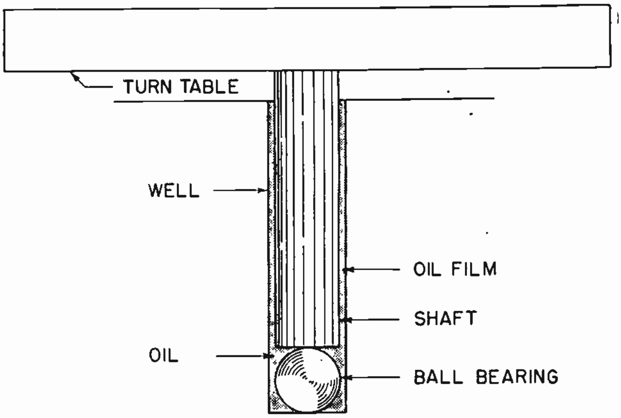


Fig. 309—Typical bearing of a rim-driven turntable.

only. At 33⅓ r.p.m., more power and less speed are required of the motor; but in terms of actual speed variations, regulation must be better than at 78 r.p.m. since 0.5% of 33⅓ represents a smaller allowance for variation than 0.5% of 78. A 2-speed table, for that reason at least, will cost more than a straight 78 of comparable quality. However, 2-speed tables, especially those 16 inches in diameter, are recommended.

The turntable itself may be of iron, steel, aluminum, or an alloy. The principal considerations are its flatness and rigidity—a requirement not present in playback tables, where ribbed construction is often used—and its weight. It should be as heavy as the torque of the motor will allow. A heavy table has a high moment of inertia—it acts as a weighted flywheel—which is very valuable in smoothing out small speed variations caused by changes in audio level.

But do not look for weight alone. A few makers have presented very heavy turntables with motors of insufficient power to drive them. Unless it is accompanied by an adequate motor, a weighted table is a liability.

Bearings of a recording table should be substantial and as nearly frictionless as possible. A typical bearing used in a medium-priced recording table is shown in Fig. 309.

Turntable diameters range from 10 inches to slightly over 16 inches. Although some 10-inch tables are made for dual-speed operation, good practice does not allow 33 1/3 r.p.m. recording at diameters under 8 inches, so not much is gained with a 10-inch disc. It is unwise to purchase a 2-speed table smaller than 12 inches in diameter. For ideal 2-speed results, a 16-inch table is the best choice. *Never attempt to use a disc larger than the turntable.*

Chapter 4

The Feed Mechanism

THE feed mechanism controls the available recording time on a disc of given diameter, the direction of cut (outside-in or inside-out), the precision with which the grooves are spaced, and the general convenience with which the mechanical operations can be performed. The mechanism determines, to a great extent, the quality and consistency of recording results.

Two principal types are in present-day use, the *swinging arm* and the *lathe* (see Figs. 403, 405, 406, and 407.) They may be distinguished by the location of the *lead screw,* which is usually underneath the motor

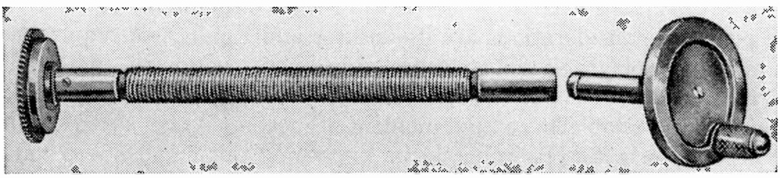


Fig. 401—*Lead screw, with spiraling crank.*

board of swinging arm recorders and above the board on lathe mechanisms.

The lead screw is a threaded rod which is geared to the turntable and mounted parallel to the table, on the mechanism. The cutter mount is engaged with the lead screw, and the revolution of the screw pushes cutter and stylus radially across the disc as recording proceeds. This causes the groove to spiral instead of remaining a perfect circle, as it would if cutter and stylus were not moved across the record. A lead screw is shown in Fig. 401.

Swinging-Arm Mechanisms

Fig. 402 shows a complete recording and playback instrument using a typical swinging-arm mechanism. The arm on the right is

Fig. 402—Complete recorder with swinging-arm mechanism; cutter is at right

quite similar in appearance and function to a pickup arm. A cutter is mounted in its forward end instead of a pickup cartridge.

Fig. 403 shows the feeding method of this type of mechanism. The lead screw (seen under the motor board) is geared to the motor. The cutter arm may be moved over the disc just like a pickup. The arm and rod A are rigidly connected together. When the arm is lifted from its rest and the stylus placed on a blank disc, the 2 flat pieces, B, of

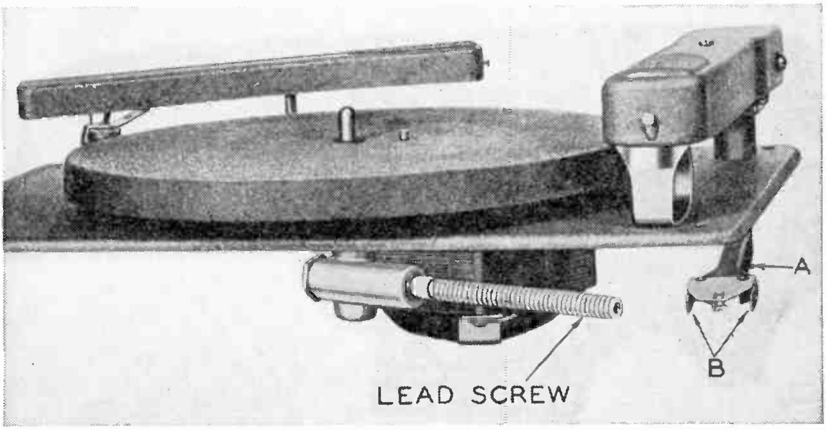


Fig. 403—A swinging-arm recording chassis

metal rest between threads of the lead screw. By ordinary screw action, the turning of the lead screw forces B along the length of the screw. With B go rod A and the cutter arm. Thus, the stylus is slowly and

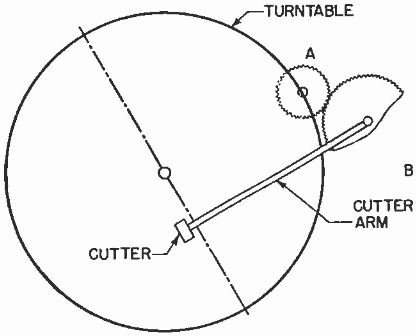


Fig. 404—Swinging-arm feed; Gear A driven by motor or turntable; gear B, on cutter arm, meshes with A, causing the arm to swing.

evenly pushed across the disc and a spiral groove results. When cutting is ended, the arm may be lifted. B then rises off the lead screw and the arm is free to be placed back in its rest, where it is shown in the photograph.

There are variations of the swinging-arm feed. One of these is shown in Fig. 404. Gear A is driven by the motor or turntable (through a reduction gear train to attain slow speed). The teeth of gear B, which

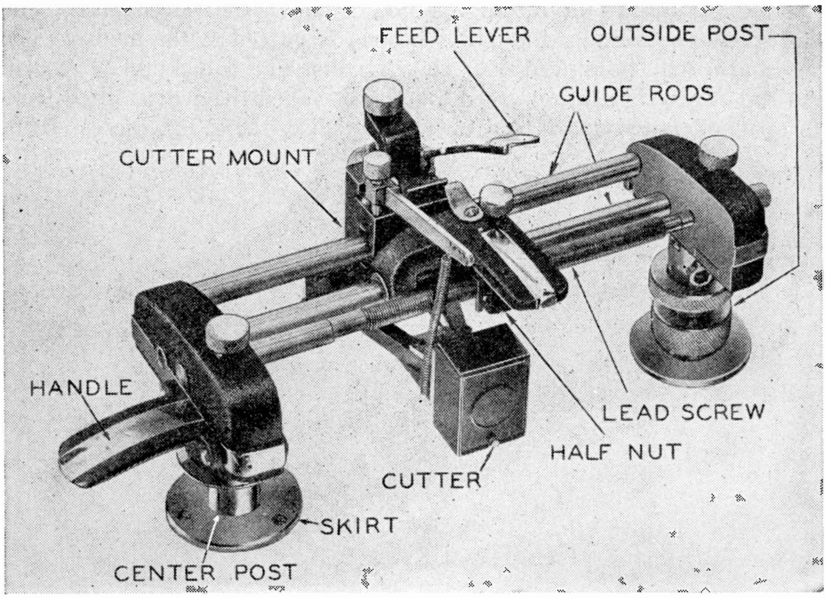


Fig. 405—An overhead lathe mechanism.

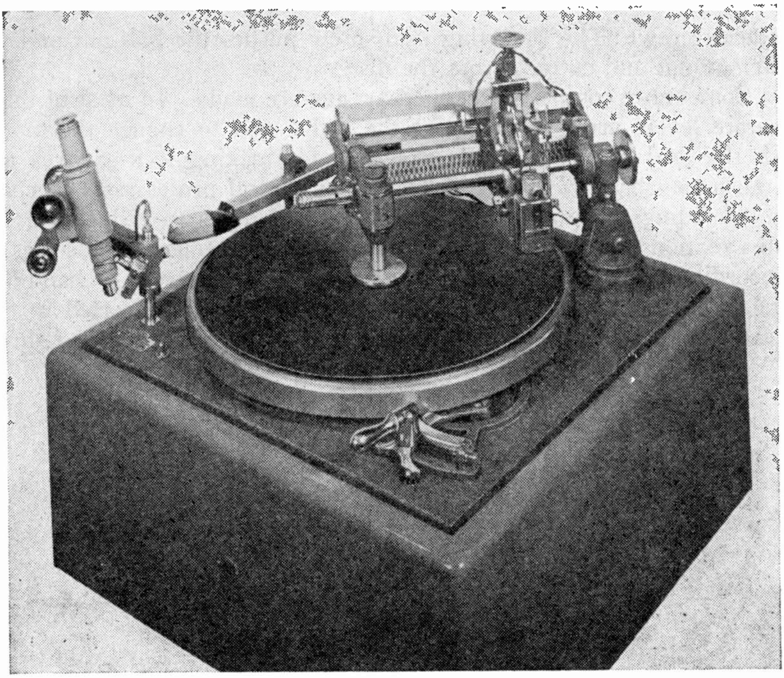


Fig. 406—A fairly elaborate overhead lathe recording table.

is rigidly fastened to the cutter arm, engage with those of gear A, causing the arm to swing. Swinging arms are also made with friction drives, rather than lead screws or gears.

Lathe Mechanisms

Fig. 405 shows a mechanism of the lathe type. The *outside post* (the vertical support at right) is fastened permanently to the motor board. The mechanism may be raised by using the handle at the left, since there are horizontal and vertical pivots on top of the outside post.

To record, the *center post* at left, is placed over the center pin of the turntable. A small locking pin extends upward through most recording turntables. Both disc and center-post *skirt* are so oriented that the pin goes through 1 of the 3 holes in each. This locks turntable, center post, and disc together, so that one cannot rotate without the others.

When the turntable and disc revolve, the center post also revolves. The top of the center post and the left end of the lead screw are connected by a worm gear, so that the lead screw also revolves, though at a much slower speed. The cutter is rigidly fastened to the cutter mount, which slides freely along the smooth guide rods. When cutting is to begin, the feed lever is operated, engaging a half-nut in the mount with the lead screw. The revolving lead screw pushes the half-nut and the cutter mount and cutter across the disc.

Some more complex lathe mechanisms are made. In most of them, separate levers are used to lower the stylus and to engage the mount with the lead screw. This is desirable for making lock-grooves and spirals (see Chap. 12). Fig. 406 shows a typical professional mechanism, including a liquid (dash-pot) vertical damper to reduce vertical stylus motion due to vibration. It has such convenient accessories as a recording time scale, a crank for turning the lead screw by hand and a calibrated microscope. Various lead screws may be inserted in this mechanism to vary pitch (explained later in this chapter) and direction of cut. There is, in all these mechanisms, some arrangement—often a simple spring—to regulate stylus pressure.

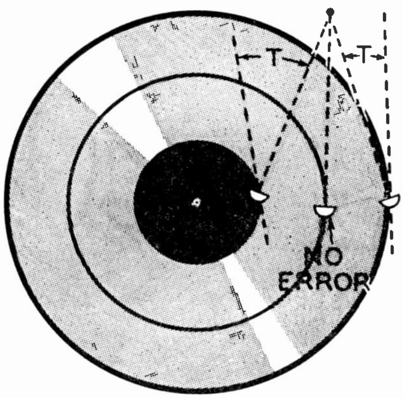


Fig. 407—Why tracking error occurs with the swinging-arm feed mechanism.

Purchasing a Mechanism

Swinging-arm mechanisms are almost always cheaper than lathes, largely because they are simpler in construction. Because their operation is also simpler, they are more suitable for the layman. However, as can be seen from Fig. 403, before the motion of the lead screw reaches the stylus, it has to pass through 2 fairly long levers, rod A and the arm. These levers have a small amount of flexibility and the grooves, therefore, will not always be as evenly spaced as the lead screw alone would permit.

Another disadvantage is the *tracking error* introduced. Fig. 407 shows a cross-sectional view of the stylus tip. At one point, the flat cutting face of the stylus is perpendicular to the groove, which is correct. But as the arm moves in, the stylus cutting face is at an odd angle with respect to the groove. This distorts the groove shape and, to a certain extent, impairs record quality. Tracking error is invariably present to some degree in pickups, but since playback needles are round, not flat on one side, the needle contour presented to the oncoming groove is almost always the same, regardless of small tracking errors; the error in a pickup, therefore, is not of such great importance. Tracking error in a cutter will not produce ideal records, although, for nonprofessional use, it is not too serious a defect.

Swinging-arm units are satisfactory for amateur use if they are solidly constructed. They are definitely indicated where expenses must be kept down, since excellent swinging arms are available at prices under

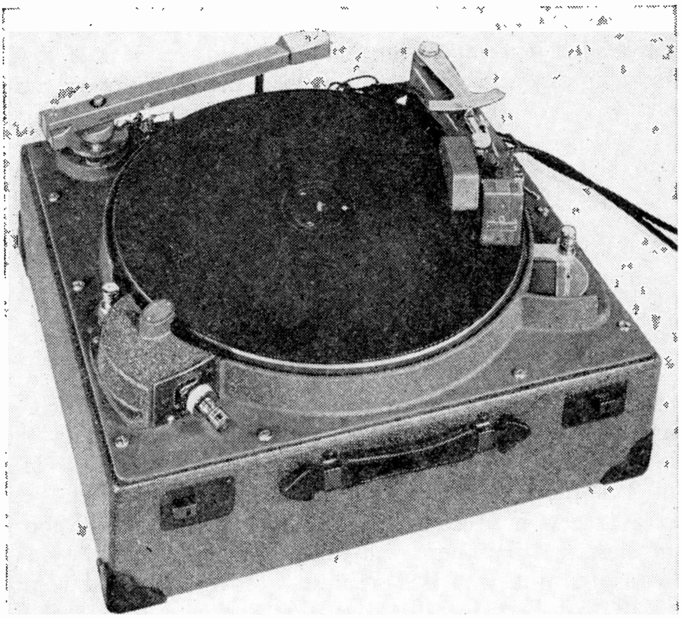


Fig. 408—A high-quality swinging-arm mechanism.

$50, although more expensive ones, such as that in Fig. 408 are also made.

The lathe mechanism will usually space the grooves with accuracy, depending entirely on the precision of the lead screw threads. Since the parts are usually heavier, lathes are generally more solidly constructed than swinging arms, and will give more consistent results.

They are available at prices beginning under $100 and extending upward to several hundred. In deciding how much to spend on a lathe mechanism, the use to which it will be put is important. For making records and transcriptions for broadcasting or for reproduction by pressing (see Chap. 13), nothing but the finest is permissible. This means highly accurate lead screws and precisely machined parts allowing no excess play. If records are to be played on home phonographs, the requirements are less severe.

Units with time scales, vertical dampers, interchangeable lead screws, lead screw cranks, and other convenient accessories are desirable, but these conveniences are expensive and not by any means necessary. Even an inexpensive lathe, carefully adjusted and properly used, will give excellent results. No lathe, however, should be operated by a novice, and for that reason, if the recorder is to be used by a layman. swinging-arm feed is a better choice than a lathe.

Pitch and Direction

Lead screws come in a variety of *pitches*. The pitch at which the screw is threaded determines the number of *lines per inch* (l.p.i.) cut in the disc. To determine pitch of a record, place a ruler on the diame-

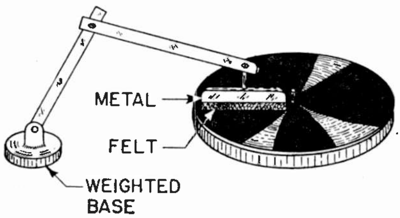


Fig. 409—*One type of brush to sweep away the "chip".*

ter and count the number of grooves appearing within 1 inch. Usual pitches are between 96 and 130 l.p.i. Of course, the higher the pitch the more recording time available on a given size disc. However, higher pitches mean smaller separation between grooves. A more accurate lead screw is necessary and audio volume must be more carefully controlled, so that there will not be enough excess stylus movement to cause cutting into the adjacent groove. A good compromise is 110 or 112 l.p.i. For recording times at various pitches, see Chap. 2.

Recordings may be made either inside-out or outside-in. Standard phonograph records are always cut outside-in, and most instantaneous records and transcriptions are made the same way.

During cutting, the stylus cuts a thread of material (known as the *chip*) out of the record coating. The chip is thrown inward by the stylus. When recording outside-in, some provision must be made for clearing away the chip before the stylus gets entangled in it. Several brushes are sold which may be laid on the record surface. They will automatically clear away the chip as it appears and wind it up around the center post. One of these is shown in Fig. 409. Many commercial recordists use a small tube, attached to the cutter, leading to a suction motor. Suction is the most convenient and safest way to remove chip, but the motor must be filtered for r.f. and a.f. interference.

Chapter 5

The Cutter

THE function of the cutter is to transform the electrical (audio) energy furnished by the recording amplifier into mechanical movement of the stylus. There are 2 common types: the *magnetic* and the *crystal.*

Magnetic Cutters

The magnetic cutter is similar in design to the moving-coil pickup. But the pickup is used to convert mechanical movement to electrical

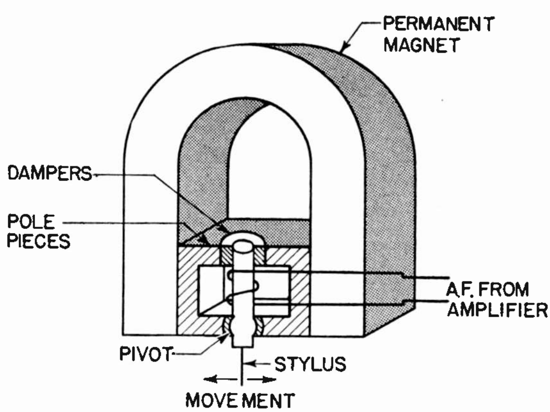


Fig. 501—*Simplified sectional view of magnetic cutting head.*

energy, while the cutter does the opposite. Fig. 501 is a simplified drawing of the working parts of a cutter. A permanent magnet, shaped like an inverted U, supplies a magnetic field which is concentrated by the split pole pieces into a small area. The armature, mounted between sets of dampers of rubber or similar material, pivots between the lower portions of the pole pieces. The upper end of the armature is free to move laterally, and the cutting stylus is fastened to the lower part.

The audio output of the amplifier is fed to the coil, producing a polarity at the ends of the armature. This polarity, of course, changes with each alternation. When the top of the armature has the same polarity as the left pole piece, it will be repelled and will travel to the right. During the next alternation, the polarity will be reversed, and the armature will be attracted to the left pole piece.

Since the armature pivots near its lower end, the stylus which is

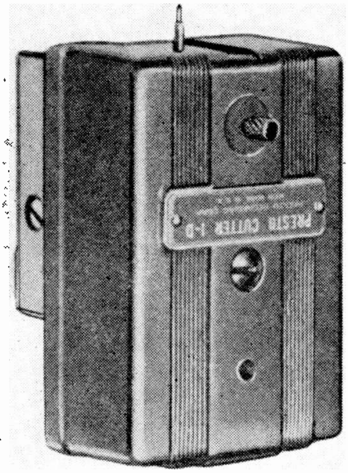


Fig. 502—A magnetic cutter.

attached to the lower end will always move in a lateral direction opposite to that taken by the armature's top. If the stylus is in contact with a revolving disc of suitable material, the path of the groove it engraves will vary laterally in accordance with the motion of the stylus.

In playback, the needle of the reproducer, of which Fig. 501 is also a drawing, is moved laterally at an audio rate by the groove undulations. Movement of the needle causes the upper part of the armature to move; and the moving coil, cutting lines of force from the permanent magnet, has induced in it an audio voltage which can be amplified.

Crystal Cutters

The governing principle of the crystal cutter is the *piezoelectric effect.* A block of crystalline substances—notably quartz and Rochelle salts—will exhibit an electrical potential between its faces when the block is subjected to mechanical pressure or torsion. Conversely, when a voltage is applied to the faces, the crystal will twist or distort. This effect is used in crystal microphones, pickups, and frequency-control instruments as well as in cutters.

The usual crystal cutter is formed of 3 to 5 slabs or plys of Rochelle salt crystals. The stylus is mechanically coupled to the assembly, and an audio voltage is applied to the crystal faces. The mechanical distortion of the crystals produced by the voltage results in movement of the stylus. The direction and amplitude of the movement depend on the polarity and magnitude of the voltage.

The magnetic cutter was developed first, along with the moving-coil pickup, and both units are still used in most of the high-quality recording and reproducing systems, especially in broadcasting.

To give the best results, the magnetic cutter must be very carefully made. Most of the parts in the assembly are very small, allowing tolerances only in thousandths of an inch. This calls for skilled and expensive workmanship. The cutter may have one or more resonant points caused by dimensions of certain moving parts. In good magnetics, these are almost nonexistent. The rubber used for dampers dries out and must be periodically replaced. Distortion may occur on loud passages because of excessive compression of the dampers at the points of maximum armature travel. Magnetic cutters are available with frequency ranges as high as 10,000 cycles. These are very costly. One is shown in Fig. 502.

The ruggedness of the magnetic cutter makes it quite suitable for use by amateurs. It can take considerable overloads and can withstand a fair amount of knocking around without being damaged. It is practically unaffected by temperature.

The crystal, on the other hand, is sensitive to temperature and can easily be cracked by an overload or by being dropped. For low

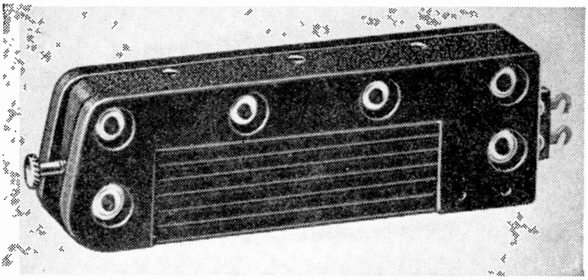


Fig. 503—A crystal cutter. Brush Model RC-20 cutter shown.

cost high-fidelity results, however, it is often preferred by semiprofessional users. The unit shown in Fig. 503 is flat from 50 to 9,000 cycles and costs about $15. Compare this with the magnetic in Fig. 502, which, with about the same frequency range, costs about $150.

Special circuits are required for connecting a crystal cutter to an amplifier if the usual phonograph record frequency response is desired. Magnetics are sold with popular impedances — 4-8, 15, and 500 ohms — and need only be connected to the amplifier's output transformer. However, more flexibility in selection of response curves is possible with the crystal.

Chapter 6

Constant Amplitude versus Constant Velocity

SOME records are cut with a *constant-velocity* response curve, others with a *constant-amplitude* curve. Still others—ordinary phonograph records, for instance—employ a combination or modification of these basic methods. What is meant by these two terms? What are the uses and comparative advantages of these methods of cutting? The frequency response of the entire recording system can be judged and measured correctly only when they are thoroughly understood and applied. Curves are meaningless unless the differences between constant amplitude and constant velocity are understood.

Constant Amplitude

First consider the action of the *crystal* cutter. In a piezo-electric crystal, the amount or *amplitude* of physical twist or distortion—and therefore the distance the stylus moves—is dependent on the value of voltage, regardless of frequency. In the crystal cutter, it is the groove width or *amplitude* which is directly controlled by the voltage. If the frequency is high and the voltage to the cutter terminals is kept constant, the amount of stylus travel is just as great as it would be at lower frequencies. If the stylus is to cut as wide a path at 2,000 cycles as it did at 1,000 cycles, it must, of course, travel faster. Stylus velocity, in a crystal, is therefore variable.

If stylus travel is dependent only on input voltage, with velocity changing as necessary to keep inches of travel constant, frequency will not be a factor. This is shown in curve A of Fig. 601. Since the vertical axis denotes amount or *amplitude* of stylus displacement, the curve will have to be flat if the input voltage is constant. We may then call the response of a perfect crystal cutter a *constant-amplitude* response.

A perfect crystal pickup has the same characteristic: output voltage depends entirely on *amplitude* of groove variations, without relation to frequency. Thus both crystal cutter and pickup are *constant-*

amplitude devices, and curve A in Fig. 601 is a constant-amplitude curve. The pickup's response complements that of an ideal crystal cutter. The pickup delivers a constant output voltage when playing a record cut by a constant-amplitude crystal cutter.

Constant Velocity

Now consider the *magnetic* cutter. Stylus movement is produced by movement of the armature, which, in turn, is produced by reaction of an electromagnetic field with a permanent magnet field (see Chap. 5). In a motor—which the cutter is—speed or *velocity* of movement of the coil and its armature is directly dependent upon the *magnitude* of the impressed voltage. Note that nothing is said about the total *amplitude,* or distance of the movement. A motor armature will con-

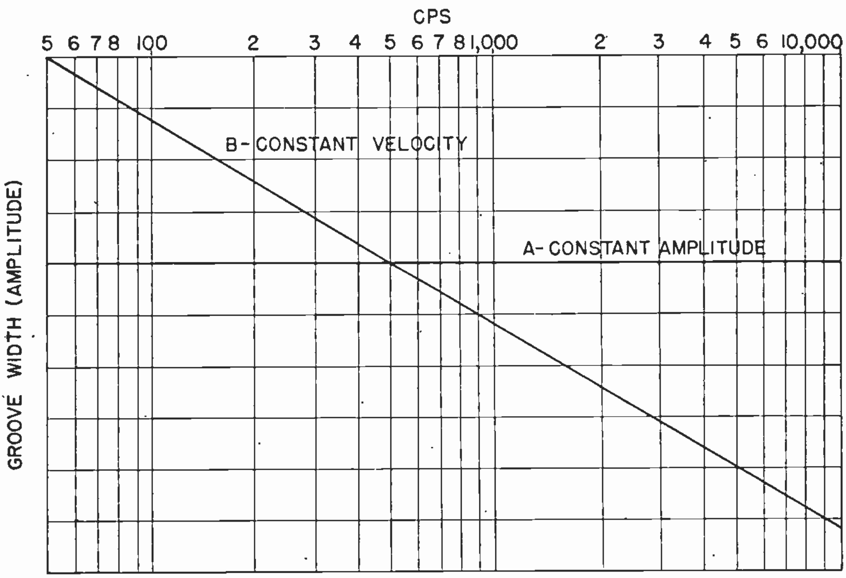


Fig. 601—Outputs of ideal constant-amplitude (A) and constant-velocity (B) record, reproduced on ideal constant-amplitude pickup.

tinue to rotate as long as voltage is applied to it. Only the *velocity* is affected by the voltage.

When we apply d.c. to the armature winding of a magnetic cutter, the stylus moves at a *velocity* determined by the *amount* of voltage. It will continue moving—in the same direction—until either the voltage is removed or the armature is physically restrained from moving further by the dampers and pole pieces. When we apply an audio voltage, the reversal of polarity at the end of each alternation limits stylus travel, just as removing the d.c. voltage did.

Fig. 602-a shows a 1,000-cycle sine wave of a certain voltage. If the entire cycle takes 1/1,000 second, then one-half the cycle will take 1/2,000 second and one-fourth the cycle will take 1/4,000 second. At

point A (the beginning of the cycle) the voltage is zero. Now look at the cutter in Fig. 602-b. Point A is the normal position of the stylus with zero applied voltage. During the first quarter-cycle AB, voltage will rise to maximum in the positive direction and velocity and direction of movement will be imparted to the stylus. *Velocity* at any instant depends on the instantaneous *magnitude* of the voltage, while direction

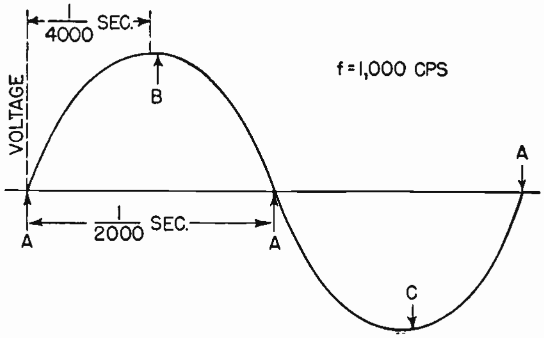


Fig. 602-a—A 1,000-cycle sine wave, showing time relations for ¼ and ½ cycle.

depends on the direction of electron flow in the coil. The velocity at the selected audio voltage is such that in the 1/4,000 second occupied by the first quarter-cycle, the stylus will have time to move from A to B (Fig. 602-b). At the beginning of the second quarter-cycle (point B on the graph), the direction of current flow reverses and the stylus begins to return to its center position A which it reaches just as the instantaneous voltage reaches zero. The same process is repeated, but in the opposite direction, for the second half-cycle.

Consider Fig. 603, drawn to the same scale as 602-b. As before, at the given r.m.s. voltage at 1,000 cycles, the stylus moves from A to B and back in the first half-cycle and from A to C and back in the second half. Now let us apply a frequency of 2,000 cycles at the same voltage. During the first quarter-cycle the stylus will travel toward B again, but at 2,000 cycles a quarter-cycle lasts only 1/8,000 second. The *voltage* and the *velocity* of the stylus movement have been kept constant, but the time allowed has been reduced to one-half of its former value. Therefore, the stylus can move only one-half the distance, to point D. During the second half-cycle at 2,000 cycles, the stylus travels in the reverse direction but has only time to reach point E before the polarity reverses. *When frequency is doubled, the distance of stylus travel, or stylus displacement, is halved.* The armature simply does not have time enough to go as far as it did at 1,000 cycles by the time polarity reverses.

We have simplified this explanation to avoid entanglement in such matters as phase difference in inductive circuits.

Velocity can be represented by the *slope* of the wave at its zero point. As Fig. 604 shows, to keep slope or velocity constant, amplitude must increase as frequency decreases, and vice versa. The 2 sine

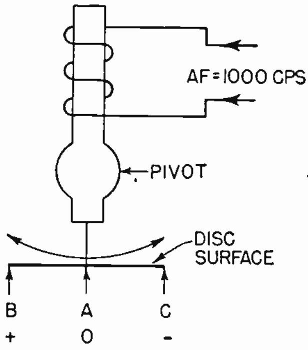


Fig. 602-b—Stylus moves back and forth, through point A, following voltage changes of Fig. 602-a.

waves have the same velocity, but their frequency ratio is 1 to 2 and amplitude ratio is 2 to 1.

In an ideal unequalized magnetic cutter, to which constant voltage is applied, *stylus displacement or amplitude is inversely proportional to frequency.* At any given frequency the stylus cuts a groove with width twice that of an octave above and half that of an octave below. (An octave is the interval between a given frequency and one either half or twice its value.) If frequency rises, stylus movement or amplitude decreases in proportion; if frequency drops, amplitude increases in proportion. This relationship between frequency and stylus movement is the crux of constant velocity and must be understood *fully.* The ratio of groove width at any frequency to groove

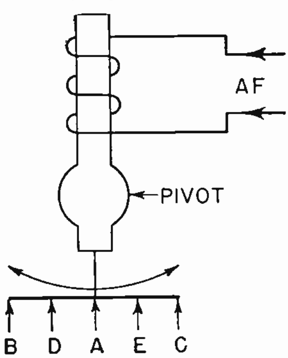


Fig. 603 — Stylus amplitude will decrease as frequency is increased.

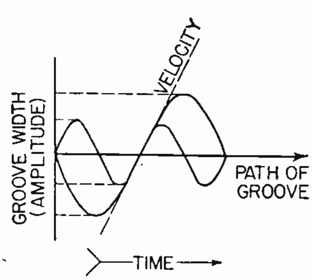


Fig. 604—To keep slope or velocity constant, amplitude must increase as frequency decreases, and vice versa.

width at one octave above that frequency is 2 to 1. We can evaluate the groove widths in terms of voltage. A voltage ratio of 2 to 1 is equal to a decibel gain or loss of 6. We can now be exact when speaking of the frequency response of a magnetic cutter: *output of the cutter decreases at the rate of 6 db per octave with increasing frequency.* Curve B in Fig. 601 shows this response.

The situation in a magnetic *pickup* is exactly opposite to that in the cutter. In the pickup, movement of the armature through the magnetic lines of force created by the magnet induces a voltage in the coil. The *velocity* of armature movement determines the magnitude of the voltage induced. Velocity depends on two things: the frequency being picked up, and the width of the groove. As frequency goes up, velocity of the pickup needle and armature increases. Increased velocity means increased output. We can also increase armature velocity (without changing frequency) by increasing groove width, for now the needle must travel a greater distance in the same period of time. Thus, pickup output (at any one frequency) increases as groove width is increased. But the magnetic *cutter* cuts narrower grooves as frequency is raised. This of course means lower velocity for the pickup armature. The effects of raising frequency and decreasing groove width (or vice versa) are exactly opposite and nullify each other. The result: pickup armature maintains constant velocity (and constant output) at all frequencies when playing a record cut with an ideal magnetic cutter.

In this discussion, the input voltage to the cutter terminals was assumed to be constant in value throughout. The frequency response of the magnetic cutter is the result of the fact that a constant applied voltage will produce a *constant velocity* of stylus movement. The response of magnetic pickups—exactly opposite to that of magnetic cutters—occurs because *constant velocity* of needle movement will produce constant output voltage. Any similar cutter or pickup curves are known as *constant-velocity* curves; and the devices which produce them are known as constant-velocity devices.

To summarize briefly the differences between the 2 types of cutter response: in constant-velocity cuts, groove width decreases (6 db per octave) as frequency goes up; while in constant-amplitude cuts, groove width remains the same for all frequencies. Stylus displacement versus frequency curve for each type of response must be memorized

Modified Constant Velocity

The patterns in Fig. 605 are enlarged drawings of record grooves showing variations in the width of the groove at various frequencies. Pattern 1 shows a perfect constant-velocity cut, the same as curve B in Fig. 601. Notice that the groove variations are very large at the low-frequency end and become progressively smaller as the frequency rises. The groove width at 100 cycles is about 100 times as great as at 10,000 cycles.

In practical recording, the distance of adjacent grooves from each other limits maximum groove width at low frequencies. If the stylus is allowed too much travel, it will cut into the next groove and ruin the recording. By limiting the audio signal level fed to the cutter, we can prevent this overcutting of adjacent grooves. However, groove width will be so slight at the high-frequency end of the audio range that the groove variations will be comparable to the random surface irregularities of the disc which produce scratch and surface noise. The noise will bury the signal. Under these conditions, the ratio of maxi-

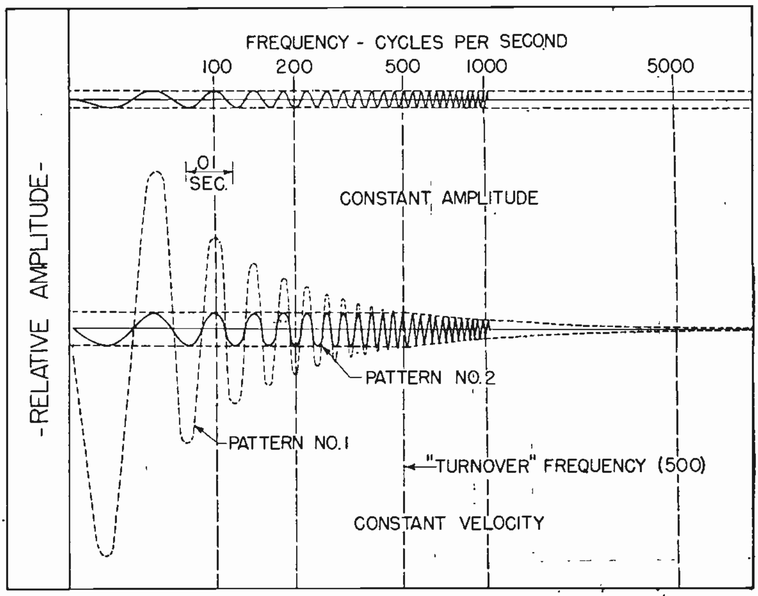


Fig. 605—Wave patterns for constant-amplitude, constant-velocity (pattern 1) and modified constant-velocity (pattern 2) recording.

mum groove width (at low frequency) to minimum groove width (at high frequency) is too great to be practicable.

There are 2 solutions to this problem. The first is the use of *constant-amplitude* recording. This is shown graphically in curve A of Fig. 601 and pictorially in Fig. 605. The groove variations are just the same at the low end as at the high end. Records can be and actually are cut in this manner, without any modification. Crystal cutters are used, and the records are played back on crystal pickups.

Phonograph records and most professional discs are not made constant-amplitude, however desirable it might seem. Phonographs and professional playback systems are still geared to the older type of recording, constant velocity, and manufacturers of records are still chary of changing their discs. The method of reducing the minimum-maximum groove width ratio in general use is to modify both types of curve and use a combination of them. The result is known as *modified constant velocity*.

Observe pattern 2 in Fig. 605. From 500 cycles upward, groove width decreases as frequency rises, just as in the perfect constant-velocity curve. But from 500 cycles downward, groove width remains *constant.* From the lowest frequency up to 500 cycles the pattern is the same as that for constant amplitude. The ratio between maximum and minimum groove widths is much reduced. If low-frequency stylus travel is increased to the allowable limit, high-frequency groove width will also be increased to a usable value.

This modified-constant-velocity curve is shown graphically in

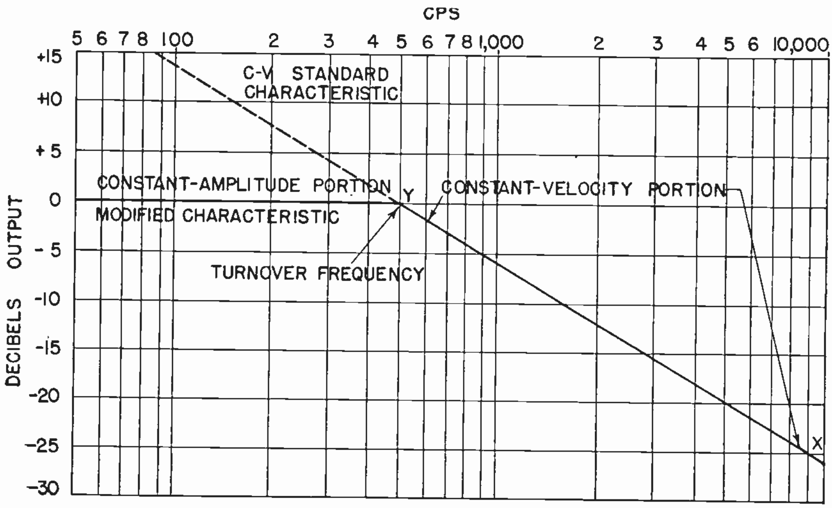


Fig. 606—Commercial modified constant-velocity record response, when pickup has constant-amplitude characteristic. Turnover is arbitrarily placed at 500 *cps.*

Fig. 606. This graph is plotted just as Fig. 601; the vertical axis may be thought of as stylus displacement or groove width. The curve is in 2 distinct parts: constant amplitude up to 500 cycles, and constant velocity beyond that. *Turnover frequency,* the point at which the change in type of response takes place, is usually 500 cycles in U.S. records, and has been 300 cycles in most European recordings. In some broadcast transcriptions it is 1,000 cycles. Since there is very little standardization, the turnover frequency may be any frequency arbitrarily chosen by the recordist. For discussion purposes, we will stick to 500 cycles.

Response Graph Conventions

The graphs we have shown so far have been based on groove width versus frequency. However, these are not the graphs commonly used or published by the industry.

Since the constant-velocity characteristic is the principal basis for recording today, it has been taken as the standard for comparison. In other words, specific cutters, pickups, and records are compared to the standard constant-velocity characteristic, shown in Fig. 601. Curves published do not actually show a picture of stylus displacement; they show the *difference* between the device or record being discussed and the standard characteristic.

To illustrate this point, compare Figs. 606 and 607. They both represent identical responses, the modified-constant-velocity response described above. However, Fig. 607 is drawn on a *constant-velocity basis,* which means that it is not a picture of anything real; it is only a comparison with the standard, ideal constant-velocity response.

The upper portion of the modified curve (between points X and Y of Fig. 606) corresponds exactly to the standard constant-velocity characteristic. Since the actual modified characteristic—shown in Fig. 606—agrees (from 500 cycles upward) with the standard, there is no difference between them. Therefore, when drawing a curve of *comparison,* all points from 500 cycles upward will have to be on the zero line, showing zero *difference.* See Fig. 607.

Below 500 cycles, however, the modified characteristic does show a departure from the standard. At 250 cycles, for instance, Fig. 606 is 6 db below the standard. Therefore, the 250-cycle point in Fig. 607 must be at -6 db.

Fig. 607 is the usual curve used in recording literature, and is a *comparison with the ideal* constant-velocity groove-width response curve. If, for instance, the graph shows response at 100 cycles to be at -14 db, it means, not that groove width has been reduced, but that actual pickup output voltage is 14 db less than would be obtained from a perfect constant-velocity record.

This curve, is, in fact, a graph of the output voltage obtained from a perfect magnetic pickup. We have seen why the low-frequency section is purposely reduced. If we use a magnetic pickup to play these records, we must insert an equalizer to boost the low frequencies, as Fig. 607 indicates.

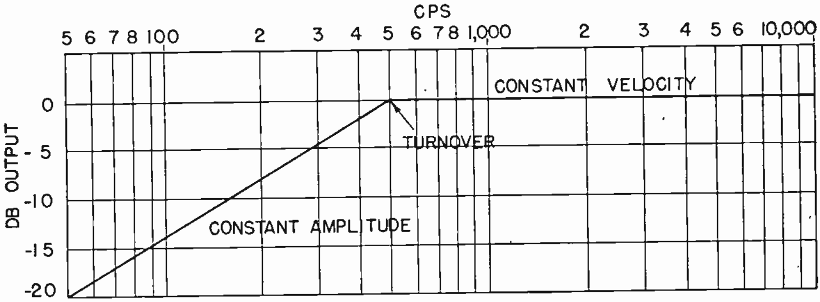


Fig. 607—Modified constant-velocity record response when played on perfect uncompensated constant-velocity pickup. This is the standard "velocity basis" type of curve, a comparison with the theoretical curve B of Fig. 601.

The modified curves in use by different manufacturers of records are not usually identical. While Fig. 607 illustrates the modified type of response, there are many variations of this. The high end may be increased, and other turnover frequencies may be used. They may, however, all be plotted just as Fig. 607 was plotted, as comparisons with the standard, or, speaking in a more practical manner, in terms of the output voltage obtained from a perfect unequalized magnetic pickup.

The modified characteristic is built into most commercial magnetic cutters by means of mechanical adjustments and rubber dampers. It is usually unnecessary to provide for the low-frequency drop by equalizing the recording amplifier.

When speaking of records which are cut completely *constant amplitude,* these curves of comparison with a constant-velocity standard are not used. The literature on constant-amplitude work shows crystal cutter curves merely as straight lines (or variations of that ideal). Fig. 608 might represent the response of a perfect crystal cutter. This curve does not have the same significance as those usually seen for *constant-velocity* devices. Here, it means that stylus displacement of the cutter is uniform over the range, and that an ideal *crystal* pickup will produce output as shown. Such curves are always accompanied by explanations unless they represent performance of crystal devices, in which case it can be assumed that they are curves of actual stylus displacement.

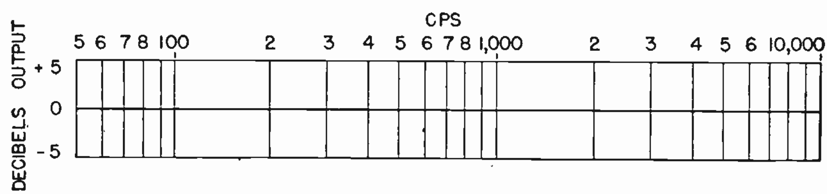


Fig. 608—Perfect crystal cutter response. This is NOT a comparison with the standard C-V curve.

Summary

The material in this chapter requires careful, thoughtful reading, but can be understood by the average radioman. Let us briefly summarize the points we have covered:

1. In the crystal cutter, stylus displacement is the same no matter what the frequency. Crystal pickups are identical. Curves showing crystal response show actual stylus displacement. The crystal characteristic is *constant amplitude.*
2. In the magnetic cutter, stylus displacement decreases as frequency rises, and vice versa, but velocity remains constant. In the magnetic pickup, velocity determines

output, and the resultant output is flat. The magnetic characteristic is *constant velocity.*

3. In practice a modified-constant-velocity characteristic is used, consisting of constant amplitude up to a turnover frequency between 300 and 1,000 cycles (usually 500 cycles in the U.S.A.) and constant velocity thereafter.
4. Conventional curves show, not actual stylus displacement, but output of a record as played on a perfect magnetic pickup. A flat cutter and pickup will therefore show output as a flat line.

Constant-amplitude recording has advantages. It is linear and there is no turnover frequency to worry about. The high-frequency groove width is made just as large as low-frequency width, and the signal-to-noise ratio is very good as a result. The record may be played back on a high-quality crystal pickup without any equalization. Results, even on a cheap crystal pickup, will usually be better than obtained from the usual records.

Crystal cutters are quite versatile. With very simple variations in the method of connection to the recording amplifier, many different recording curves, including the modified-constant-velocity characteristic used on phonograph records and shown in Figs. 606 and 607, may be obtained. The methods of varying crystal cutter frequency response are shown in detail in Chap. 11.

Remember that curves of crystal and magnetic devices cannot be mixed. If, for instance, the curve of Fig. 608 represented a crystal pickup and that of Fig. 607 a magnetic cutter, we would expect the output to be flat above 500 cycles. If it is remembered that Fig. 607 is plotted on the usual velocity basis while Fig. 608 is on an amplitude basis, representing stylus displacement, it will be clear that one or the other will have to be converted to the opposite basis before a true picture of output can be had.

Chapter 7

The Stylus

THE stylus is another highly important link in the recording chain. It is a specially shaped, precision ground and lapped tool. Fig. 701 shows a side view of the stylus tip. Note that the *cutting face* of the stylus is flat, while the *heel* makes an angle of about 60 degrees with the cutting face. Fig. 702 shows a front view of the tip, with the observer looking directly at the cutting face. Notice that the bottom is not a perfect point (except in a steel stylus) but is very slightly and symmetrically rounded. The radius of the tip is about .0022 inch. The angle of the V, approximately 88 degrees, is known as the *included angle*.

Fig. 702 shows 2 important facts: first, that the shape of the groove

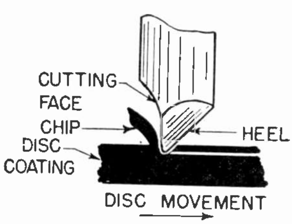
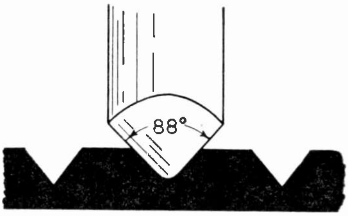


Fig. 701 — Side view of stylus tip.

Fig. 702—Front view of the tip and cutting face, showing included angle.



is the same as the stylus cutting face; and second, that the entire cutting face is not used. Fig. 702 shows that as the stylus cuts a deeper groove it cuts a wider groove. This bears directly on the matter of cutting pitch or number of lines per inch.

Fig. 703 shows several adjacent grooves. If the pitch remains constant and the grooves are cut deeper and therefore wider, the *land* separating the grooves becomes too narrow or disappears. The pickup then jumps grooves or becomes stuck in one groove and produces the familiar "broken record" effect of repetition. If stylus movement in one groove causes the walls of adjacent grooves to assume somewhat the same shape as the groove being cut, there will be an "echo." Because the playback needle traveling in any groove will reproduce, not only the sound recorded in that groove, but also (at a lower level) some of the sound in adjacent grooves, the name *echo* is appropriate. In practice, weight on the stylus is adjusted so that the depth of cut is between .0015 and .0025 inch for all pitches. Instructions for making this adjustment are given in Chap. 10.

During recording, the cutting face of the stylus must be absolutely

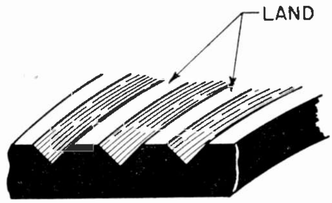


Fig. 703 — Several adjacent grooves, showing "land" between grooves.

vertical. Fig. 704 shows that a stylus in the wrong position will dig into the disc surface and tear the material rather than engraving, or will glide over the surface. This adjustment is also described in Chap. 10.

An irregularity in the stylus tip will affect the shape of the cut groove. Raggedness, caused by wear, will tear the record coating. Any stylus imperfection results in an increase in surface noise and a dull rather than a shiny cut.

Styli are made principally of 3 materials. The least expensive initially is the steel stylus (Fig. 705), made from a single piece of metal. The upper portion of the shank is flat on the side opposite the cutting face. When the stylus is inserted into the chuck of the cutter, the setscrew hits the flatted portion and automatically places the cutting face in the proper position.

Steel has at least two disadvantages. The first is a comparative softness. As it engraves, the frictional heat produced at the tip quickly dulls it and small ragged irregularities appear, which make the stylus worthless for further use. As a matter of fact, even the minute irregu-

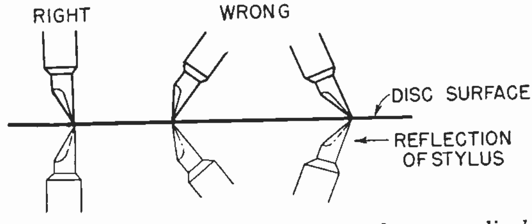
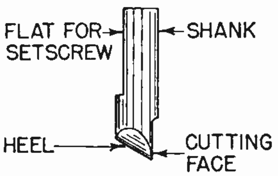


Fig. 704—Stylus cutting face must be perpendicular during recording.

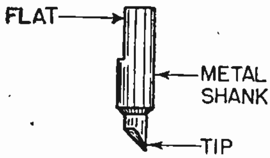
larities in the surface—for steel cannot be polished to a high degree of smoothness—make a noisy cut unavoidable. And since steel is flexible, at higher frequencies, the stylus, instead of conforming stiffly to the armature movements, sways and bends slightly. The cut groove does not vary its path as much as armature movement warrants and there is less response in the high-frequency range. The steel stylus is priced under 50¢, but cannot be used for more than 30 minutes of recording.

The sapphire (natural or synthetic), acknowledged the best material for recording, is almost as hard as diamond and can be polished to an almost unbelievable degree of smoothness. Fig. 706 shows a sapphire stylus. It consists of a sapphire tip mounted in a shank of hard metal.



← *Fig. 705—Steel stylus —note heel and cutting face.*

→ *Fig. 706 — Sapphire stylus, mounted in hard metal shank.*



The assembly is extremely stiff, and, when good discs are used, frequencies up to 10,000 cycles can be recorded without perceptible attenuation caused by stylus flexibility. Sapphire is especially valuable because its smooth edges polish the groove as they cut and the groove becomes extremely smooth and very quiet.

Sapphire styli are originally several times more expensive than steel ones. However, unlike the steel, sapphires can be resharpened at comparatively small cost and will give as good service as new ones. Generally, if the worn stylus is taken to the distributor, a new or sharpened one will be supplied for a moderate resharpening charge in exchange for the worn unit. Sapphire styli are economical for recording as little as 3 or 4 hours monthly, since the original cost plus occasional sharpening charges add up to less than the price of a new steel tool every half hour or less. Under proper conditions of adjustment, a sapphire will cut for several hours before it must be resharpened.

Sapphire is brittle, and a chipped stylus is a total loss. Therefore, take every precaution to see that a sapphire stylus is not dropped or hit against anything. When it is not in use, treat it with care. Usually a small plastic tube is furnished with each stylus, which will contain it safely. During recording, lower the stylus very gently onto the *rotating* record surface. *Do not start the turntable with the stylus resting on the disc!*

The stellite stylus is more economical than one of sapphire. Stellite, a metallic alloy which gives cutting characteristics almost as good as sapphire, lasts much longer than steel but not as long as sapphire. However, original cost and resharpening charges are less. Stellite tips are mounted the same as sapphires.

To determine whether a sapphire or stellite stylus needs resharpening, cut a few grooves with the stylus. Using a single light source, hold the disc so that the light is obliquely reflected to the eye. If the grooves are shiny, all is well. If they are dull, resharpen the stylus.

Chapter 8

The Sound Source

THE quality of a finished disc will be no better than the instrument which supplies program material to the amplifier. For that reason, a brief description of sound sources is given here.

There are 5 principal types of microphone in present-day use: Carbon, ribbon or velocity (the terms are interchangeable), condenser, dynamic or moving coil, and crystal (sound-cell or diaphragm type). Table 8-1 summarizes microphone characteristics. Fig. 801 shows the directivity of a ribbon microphone.

Table 8–1 — Microphone characteristic chart

Type	Frequency Range and Response	Output	Ruggedness	Available Impedances	Price Range	Remarks
Carbon	Poor	Very High	Excellent	D.B.:200 ohms S.B.:100 ohms	Low Very Low	Bad Hiss
Condenser	Excellent	Very Low (without Preamp)	Low to Medium	Very High (without Preamp)	High	Preamp. Must Be Built in Head
Ribbon (velocity)	Excellent	Low	Medium	Any	Medium to High	Useless for close Talking
Dynamic	Good to Excellent	Medium	Excellent	Any	Medium	Best Choice for Versatility
Crystal (Sound Cell)	Good to Excellent	Low to Medium	Medium	High	Medium	Heat-sensitive
Crystal (Diaphragm)	Good	High	Good	High	Low	Heat-sensitive

Phonograph pickups, important in re-recording and dubbing, are described in detail in Chap. 13.

Tuners and other amplifiers used to feed the recording amplifier

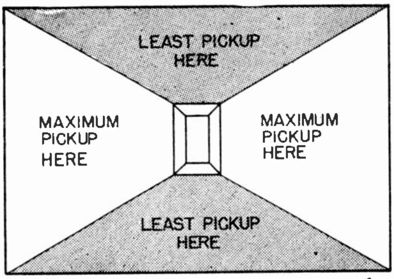


Fig. 801—Directivity pattern of a ribbon microphone.

should have good frequency response and very low noise level. Output impedances must be correct. For AM reception in areas where only local broadcasts will be recorded, special high-fidelity tuners, usually of the band-pass t.r.f. type, are desirable. These have better frequency range and lower distortion than superheterodynes, and they are almost universally used by professionals. Several are on the market as kits at reasonable prices. They usually have no audio sections and are fed directly to the recording amplifier input. See Chap. 12.

With the advent of FM, the recordist has an incomparable opportunity to make excellent records. The output of a good FM radio or tuner has less distortion and better frequency range than all but the

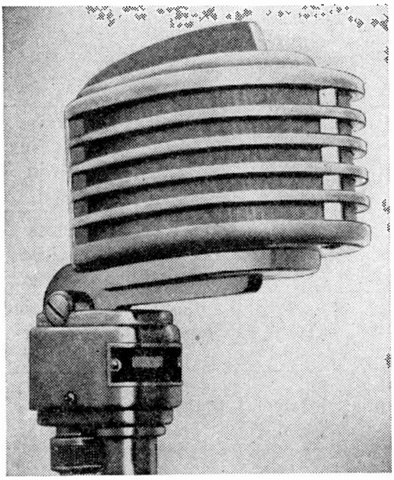


Fig. 802—Typical diaphragm type crystal microphone.

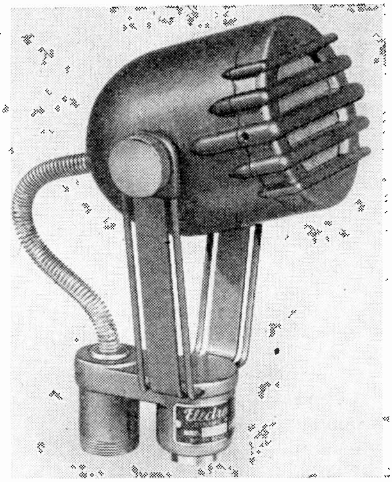


Fig. 803—A typical dynamic microphone.

best wire lines and should not even be mentioned in the same breath as AM radio. Records made of "live" FM programs will sound every bit as good as—and sometimes better than—those made in the recordist's own studio, and the opportunity for collecting a library of music by this means should not be passed by. Carefully handled and played on

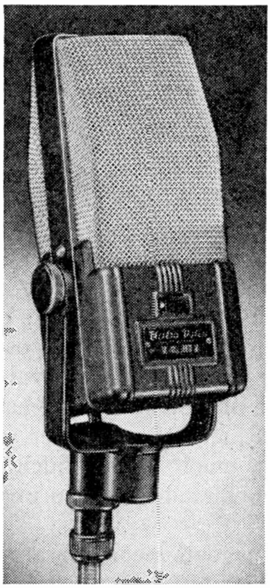


Fig. 804—*A typical ribbon (velocity) microphone.*

Fig. 805—*Typical sound cell crystal microphone.*

a light pickup with good needles, they will last long and will have no annoying surface noise.

In summation, any sound source should have optimum frequency response and lack of noise and distortion. Where equalization is necessary, it should be accomplished within the device or between it and the recording amplifier, never within the amplifier.

Chapter 9

The Amplifier

THE recording amplifier is important in determining record quality. It may be a completely conventional amplifier, but its quality must be far better than the usual public address or general purpose unit. There must be no hum, restricted frequency range, peaks and valleys in the response curve, harmonic distortion, or inadequate power-handling ability. A good record may be played on a mediocre amplifier, and an untrained listener may not be able to detect much lack of fidelity; but good quality can never be realized in a record made with an imperfect amplifier.

Briefly, here are the requirements for a good recording amplifier:

1. Flat (± 2.5 db) frequency response from 50 to *at least* 8,000 cycles is necessary. This may be subject to modification with equalizers but the amplifier should have a flat response curve to begin with.
2. Noise—hum and tube hiss—must be at least 40 db below normal program level. When the sound input is very low, the gain control must be advanced so that a usable groove is cut. Even under these conditions, hum and tube noise should be inaudible. Professional standards require hum level of 45 to 50 db below program level.
3. A full rated output of 10 times the normal power required for the cutter will take care of instantaneous peaks on crescendos. These will cause great distortion if the amplifier does not have sufficient power. For amateur work, 10 watts is a suitable compromise between expense and quality and for professional purposes, 30 to 50 watts is not too high. If speakers are to be connected with the cutter, the power rating must be increased proportionately.
4. Total harmonic distortion at full recording level should never exceed 5% for amateur use; and for ideal quality, it should be much less. In professional equipment, maxi-

mum distortion is 3% at *10 db above* normal recording level. Excessive distortion, plus that in the playback amplifier, will be very noticeable. While it is possible to iron out certain nonlinearities in frequency response by equalization in the playback system, harmonic distortion, once it is on the record, is there to stay!

5. The output stage should consist of triodes or feedback-stabilized beam or pentode tubes. A cutter varies its impedance with frequency. Unless the power stage of the amplifier has comparatively low effective plate resistance, the varying load impedance of the cutter will affect it.
6. Even though a high-output microphone is to be used, an amplifier gain of 110 db is not excessive. Lower-level devices may be used later.

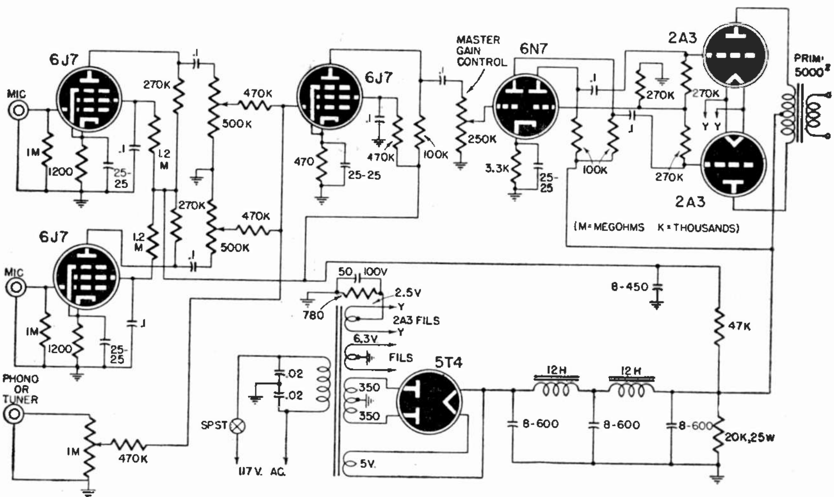


Fig. 901—Schematic diagram of a recording amplifier.

7. The system should have adequate gain controls and switching circuits, all of which must be noiseless. A volume indicator is necessary.

Figure 901 is a schematic diagram of a recording amplifier suitable for amateur use. If the power output stage is changed to allow higher-rated power output, it will also be suitable for professional use. The 2A3's shown are rated at 10 watts.

The input circuits allow for 2 low-level microphones and 1 high-level phonograph pickup or radio tuner. The microphone volume controls are placed after the preamplifier tubes in order to minimize the noise which may develop after a period of use. All 3 input gain controls are connected, through individual 0.47-megohm isolating resistors, to the grid of the 6J7. All discernible interaction between these controls is eliminated by the isolation resistor.

The use of a phase inverter of the self-balancing type, instead of an interstage transformer, eliminates the possibility of inductive hum pickup, has an inherently flat response curve, and saves the price of a high-quality transformer. The use of a master gain control (a potentiometer on grid No. 1 of the phase inverter) is very valuable in recording work when more than one microphone is in use. Fade-outs and fade-ins are possible. With the input controls in such a position as to give the best range of control, the master control may be set to give the proper recording level.

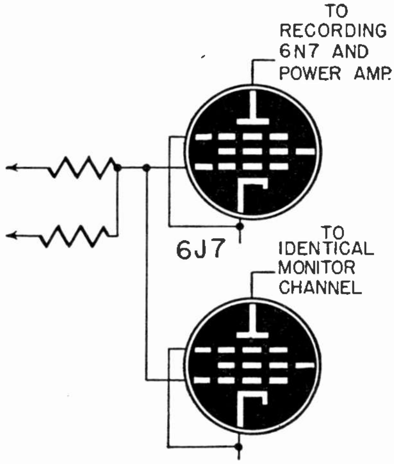


Fig. 902—Coupling monitoring stage for recording amplifier.

The power stage is a pair of push-pull 2A3's in class AB1, rated at 10 watts output. The naturally low plate resistance of triodes minimizes the effects of the changing cutter impedance. For higher power, any other output stage with the required power and harmonic distortion may be substituted. In normal use, beam tubes, such as 6L6's, have a higher power gain and increased over-all gain. But if beam tubes are used, feedback must be incorporated, and the power gain is about the same as that obtained with 2A3's. Total possible output will be greater, however, with beam tubes than with triodes.

It is essential that the highest-quality output transformer be used. All parts must be of the best quality—junk-box components are out of the question.

If more input channels are needed, they may be inserted without difficulty. Additional 6J7's may be used, with their output gain controls, similar to the ones shown and isolated by 0.47-megohm series resistors. If additional high-level inputs are needed, the phono input shown may be duplicated. There is a limit, of course, since the larger the number of inputs, using this system, the greater the possibility of interaction between them. Normally, 4 is the maximum.

In all professional recording systems, there must be facilities for monitoring while the recording is in progress. It is not a good idea to connect a loudspeaker to the same power stage which is feeding a cutter, because a voice coil also changes in impedance with frequency. Fig. 902 shows a very practical method of getting around this. A second 6J7 is connected to the grid of the second stage 6J7 in Fig. 901. It connects to an identical phase inverter and output stage. There can be no interaction between cutting and monitoring circuits, and the level of the monitor speaker can be controlled by its own potentiometer without affecting the recording. Since the power supply current requirements will be much greater, it is often advisable to use a separate power supply for the monitor channel. It may be necessary to insert some equalization in the recording amplifier to correct cutter deficiencies. In this case, a loudspeaker connected to the cutting amplifier would not show a true picture of the sound, and the separate monitor channel is a necessity, even if only for playing back the finished records.

Fig. 903 shows 2 different types of volume indicator. If a magnetic cutter is connected to the secondary of the amplifier's output transformer, the circuit of Fig. 903-a is probably the best. The value of resistor R1 should be at least 10 times the output impedance of the transformer. The exact value will have to be found by experiment. If a crystal cutter is used (connection methods are detailed in Chap. 11), a meter usually cannot be used across the amplifier output. In that case, the circuit of Fig. 903-b is probably the best. Although actual experiment is needed, the grid potentiometer of the 6E5 magic-eye tube probably can be connected to the first grid of the phase inverter in the amplifier of Fig. 902. If that is done, choose both controls so that the

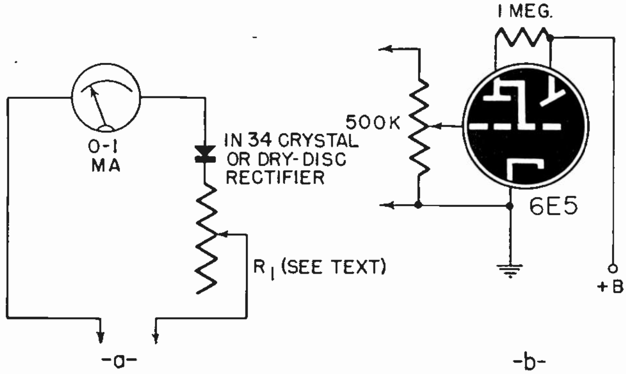


Fig. 903—Two types of volume indicator: (a) suitable for magnetic cutter; (b) crystal cutter hook-up.

total parallel resistance across the 6N7 grid, when the recording master gain control is wide open, is of the proper value. The value of the eye tube grid control is not critical.

When the circuit in Fig. 903-a is used, a constant tone is fed into the amplifier and the cutter at the proper level (given by the cutter manufacturer and measured with a voltmeter across the cutter). The variable resistor or potentiometer in series with the meter is varied until the needle points to about ⅔ scale. This point should be marked on

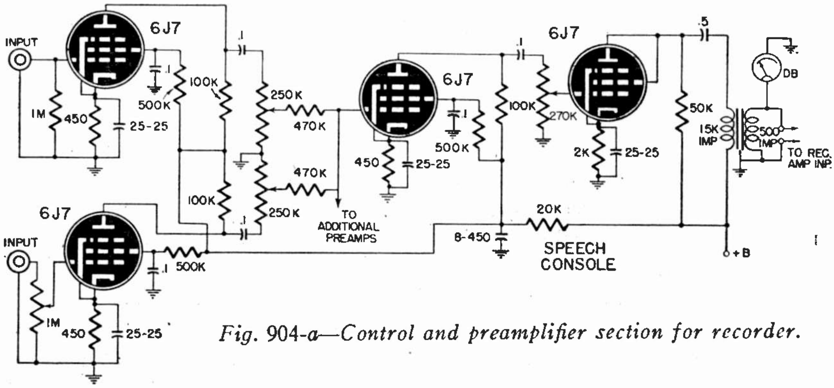


Fig. 904-a—Control and preamplifier section for recorder.

the meter scale. The meter then shows recording level, enabling the recordist to reduce gain if the sound is too loud.

When the circuit in Fig. 903-b is used, the tone should be fed in, and the 6E5 grid potentiometer adjusted until the eye just closes. The closing of the eye indicates maximum level, and gain can be adjusted accordingly during cutting.

Most professional studios and all broadcast stations use a system which is somewhat more flexible, though less compact. A typical setup of this type is shown schematically in Fig. 904. The first unit is the control and preamplifier section. Two high-gain inputs are shown, connected in the same manner as in the amplifier previously discussed. The tubes used are pentodes, 6J7's. As before, tubes may be eliminated and high-level devices connected directly to volume controls, if the inputs need not have preamplifiers. Fig. 904-a shows the first unit.

The output stage is a triode-connected 6J7, feeding into a tube-to-line transformer, whose secondary impedance is 500 ohms. The output level is generally zero db (6 milliwatts) or zero VU (1 milliwatt in 600 ohms) if the newer type of volume indicator is used.

A master gain control is provided at the grid of this 6J7. The control and preamplifier unit—usually called the *speech console*—is complete in itself, with its own power supply (housed in a separate case to eliminate hum pickup) and mounted in a sloping-panel steel cabinet.

The recording amplifier (Fig. 904-b) is a separate unit; it is similar to the amplifier of Fig. 901, but it lacks the input stages. Although a 500-ohm-to-grid input transformer may be used, none is needed. A 6C5 has been used as the input stage, with a 500-ohm resistor connected across its grid. The 6C5 makes up the gain which a step-up transformer would have given, but it is not frequency-discriminating though cheaper than a good transformer. The 500-ohm grid resistor provides the proper impedance for terminating the line from the console.

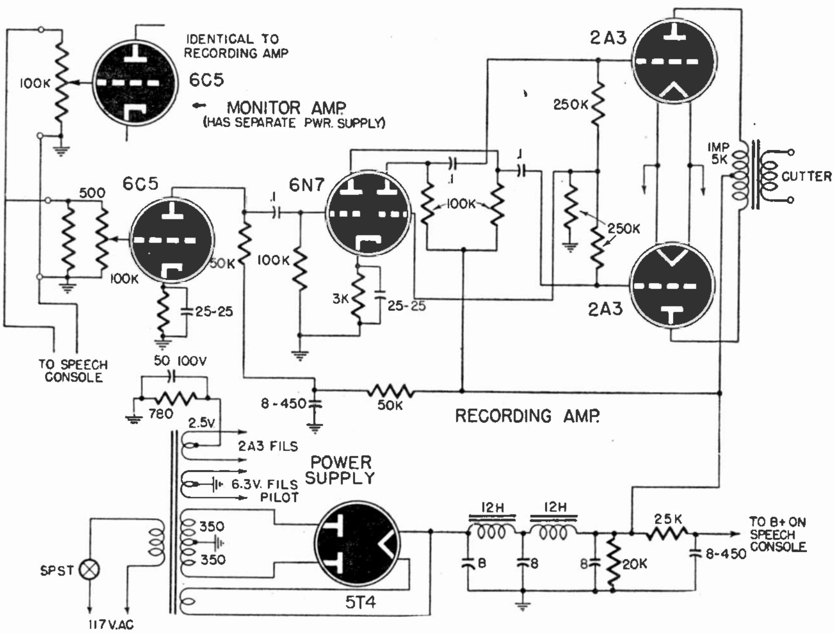


Fig. 904-b—Recording amplifier section; to be fed from preamplifier.

A system like this is flexible for several reasons. A professional recording firm may have several studios. If each studio has a console, simple switching will connect the proper console to the proper recording amplifier. If equalization is necessary, an equalizer may be inserted in the line between console and recording amplifier or in the recording amplifier. Since the 500-ohm line may be much longer than a high-impedance line, the performers and control point may be at almost any distance from the recording machine. A standard decibel or VU meter may be connected directly across the line as it is in the diagram, and it will show actual db or VU, rather than the arbitrary units which must be used in the two other volume indicators previously described.

In addition to console and recording amplifier, a monitor amplifier is shown in Fig. 904-b. This monitor amplifier is similar to the recording amplifier, except that there is no 500-ohm grid resistor in the first stage. The high-impedance grid circuit placed directly across the line is known as a bridging input.

This entire system makes use of unbalanced lines, that is, one side of each line is grounded. In most broadcast stations, *balanced* lines in which a center tap of each transformer is grounded are used. The balance results in less cross-talk and hum pickup. In most small-size installations, this is not necessary. In broadcast equipment, since low-impedance microphones are used, inputs to the console are usually low-impedance to grid transformers. Wherever the microphone must be more than 15 feet from the console, this is desirable, since lengthy high-impedance lines pick up hum and attenuate higher frequencies.

In this system, input and master gain controls are always adjusted to keep program level at or below zero db or VU (whichever type of meter is used). This is known as the *reference level.* The input gain control in the recording amplifier is adjusted to give proper output to the cutter—and then left alone. A reference-level reading on the console

Fig. 905—A fairly elaborate homemade recording and playback console used in a small professional recording studio.

meter assures the operator that the cutter is being fed at the proper power.

It should be emphasized that the 2 systems shown are only examples. If its characteristics satisfy the requirements, any conventional PA amplifier may be used. Usually some modification of the control circuits is desirable for convenience in operation.

Chapter 10

Preliminary Adjustments

AFTER the mechanism has been mounted and the amplifier and control system constructed, some mechanical adjustments must be made before setting the equalization as described in the next chapter. Make these adjustments *before* cutting discs for *any purpose,* because improper alignment of any of the mechanical parts can injure or destroy some part of the system.

The exact order in which the adjustments are made is a matter of choice, but we suggest that the following order be adopted.

Feed Mechanism Alignment

If an overhead feed mechanism is used, check its alignment with the top of the turntable. The assembly should rest on a level surface. Gravity plays a part in the functioning of the mechanism, particularly the resting of the cutter and stylus on the record. Use a carpenter's spirit level to determine that the top of the turntable is level.

Next, be sure that the horizontal portions of the feed mechanism—especially the trolley on which the cutter mount travels, and the lead screw—are parallel to the top of the turntable. In most cases, the height of the center post is fixed, determining the height of the inside end of the lead screw and trolley above the turntable. Using either the trolley or the lead screw as the reference, measure this height carefully. Use dividers or inside calipers, *not* the eye. Then make certain that the *outside* end of the trolley or lead screw is exactly the *same* distance above the rim of the turntable. Almost all overhead type table machines are provided with a height adjustment for the outside post, to allow parallel alignment with the table.

With swinging-arm mechanisms, the important consideration is that the shaft which goes through the motor board and supports the rear end of the cutter arm be absolutely vertical.

Be sure to have a typical blank disc on the turntable during parallel adjustment of overhead mechanisms, since the thickness of the disc on which the center post rests will cause a slight misalignment if adjustment is made without it.

See that the outside post of the mechanism is tightly fastened to the motor board at the *right* place. A small error in its placement will throw the entire mechanism out of line and create unnecessary friction. If the outside post is correctly placed, the center post can be lowered onto its position over the turntable easily. It should *never* have to be forced down over the center pin.

Lubrication

The next step—and one that should be repeated at frequent intervals throughout the life of the equipment—is to see to lubrication. Secure the manufacturer's instructions for motor, turntable, and feed mechanism, and follow them religiously. Too much friction at any point will destroy the speed regulation and wows will result in the finished recordings. Improper or insufficient lubrication can damage such parts as the turntable bearing, making complete replacement unavoidable. A small amount of oil on the smooth rods or trolleys on which the cutter mount travels and on the lead screw is necessary. Wipe them with an oil-soaked rag. Do *not* drop oil on them directly, since it will drip onto the turntable and the disc. Unless the manufacturer recommends another type of oil, light machine oil is suitable.

Stylus Angle

Now insert a good stylus in the cutter. Unless steel styli will be used for all recordings, make the adjustments with a sapphire or stellite stylus. Be sure the *flatted portion* of the shank is in contact with the end of the setscrew. An error here will damage both stylus and disc.

With the motor off, lower the cutter and stylus gently on the surface of a disc of the type and quality to be used during future operations. Be certain that there is no appreciable vibration in the room and that neither you nor the equipment is jarred.

With the eye on the level of the turntable, look past the stylus toward the center of the turntable. Observe the cutting face of the stylus tip and its reflection in the shiny surface of the record. If the stylus and its reflection make a straight line, the cutting face is perpendicular to the disc; and good results can be expected. (See Fig. 1001.) If the stylus and its reflection are not a straight line, adjustment must be made. It is true, however, that many manufacturers recommend that the stylus be canted very slightly in the direction shown in Fig. 1001-b. The angle should be so small that a casual glance will create the impression that the stylus is vertical. Follow the manufacturer's recommendations.

There are 2 means in general use for adjusting the stylus angle. In many mountings, the cutter may be raised or lowered, or spacers may be inserted between cutter and mounting. If no such adjustment is provided, a stylus of different length must be used—shorter if the situation is as in Fig. 1001-b, longer if as in Fig. 1000-c. Styli are normally sold in 2 standard lengths, known simply as "short" and "long." If neither size is satisfactory, the shank of a long stylus may be clipped off a little with a pair of diagonal cutters. *This is a last resort only.* Clip very carefully and observe the result after each cutting. Occasionally, the height

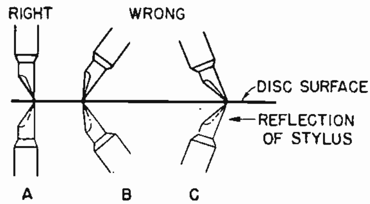


Fig. 1001—*Stylus and its reflection should form a straight line (A). If not (B or C), adjustment must be made.*

of the entire mechanism can be adjusted; but be sure that it is parallel to the turntable.

Depth of Cut

The next adjustment is for *depth* of cut. Start the turntable, engage the lead screw with the cutter mount; and, with no signal applied, lower the stylus gently on the disc. (*Never* start the turntable with the stylus resting on the record.) After a few revolutions, raise it again and observe the chip. It should be about the thickness of a very coarse human hair, and should have no tendency to crumble. Since the cross-section has the shape of an isosceles triangle, it is impractical to measure the thread with a micrometer. It would be impossible to know whether the micrometer was reading the groove depth or width.

It is possible, however, to measure the groove width with a calibrated microscope. If this method is used, groove width should be set at .006 inch. With an uncalibrated microscope, the "land" between grooves should be roughly ⅔ the width of a groove at normal pitches.

The adjustment for cutting depth can be made by varying the tension of a counterweighting spring. A knurled thumbscrew is usually provided. If no adjustment is provided or its range is inadequate, additional weight can be added. Small pieces of solder can be twisted around some convenient portion of the cutter (*NOT* the setscrew). The spring may be stretched; or if none is provided, one can be installed. Whatever the method, cutter weight must be adjusted for proper groove depth and width. If grooves are too shallow and narrow, the pickup needle will not track and will skid across the disc. If they are too deep and wide, overcutting into adjacent grooves may take place, or the stylus tip may hit the base material and break. Make the adjustments in very small steps and check and readjust if necessary at any time.

Turntable Speed

The speed of the turntable is important. If the motor is synchronous, its initial speed is controlled by the line frequency. Its motion, however, is impeded by the drag of the stylus through the disc coating and, with all but the most powerful motors, the table revolves more slowly while cutting than without load. To determine the speed of the table during cutting, procure a stroboscope disc.

Slip the stroboscope disc over the turntable center pin, on top of the blank disc. The black lines are so spaced that, when the turntable is running at 78.26 r.p.m. under a fluorescent or neon light fed by a 60-cycle power source, persistence of vision will make the lines appear to stand still. If the table is revolving too fast, the lines will appear to turn clockwise; if too slowly, they will move counterclockwise.

With no cutting in progress, all but the most expensive tables will run slightly fast—perhaps 80 to 82 r.p.m. With the stylus on the revolving disc (cutting), the stroboscope lines should appear to stand still, indicating that table speed has been reduced to 78 r.p.m.

Before worrying too much about speed variations, check to see that low speed is not caused by a dull stylus, a bad blank disc, or too great a depth of cut. High speed can be caused by too shallow a cut and sometimes by dried-out discs.

In rim-driven turntables, a thumbscrew is usually provided for adjusting the pressure of the idler against the turntable rim. Within a small range this adjustment will also vary the speed.

Thread Disposal

Control of the thread or chip resulting from cutting a disc should be decided upon during the initial adjustments. If recording is done from inside-out no precautions need be taken. The average stylus usually throws the thread inward. But if outside-in recordings are made, a brush will have to be procured. One of these is shown in Fig. 409. A strip of felt rests on the disc and sweeps the thread toward the center, where it winds up around the center post. A suction motor may be connected to a hose, the end of which is fastened to a metal tube mounted on the cutter assembly so that the mouth of the tube is beside the stylus tip. In such an arrangement, the motor must not create a.f. or r.f. interference.

It is also possible to use a soft camel's-hair brush to sweep away the thread during recording, but this requires the constant attention of the operator who—even though he is not the performer—has more important duties elsewhere. A brush should be on hand, however, for no method of automatic thread disposal is infallible and occasionally a thread will have to be removed from accidental entanglement with the stylus. This is a delicate operation at best and must be done gently so the stylus is not made to jump over the thread.

CAUTION! Dispose of the thread—*all* of it—in water or in a closed metal container which is used for no other purpose. Most disc coatings are cellulose nitrate compounds, and nitrate is a prime ingredient of *explosives!* The disc is fire-resistant, but the thread is *highly inflammable.*

Chapter 11

Equalization

In professional recording work, there are 2 principal reasons for the use of equalizer circuits. First, discs cut at $33\frac{1}{3}$ r.p.m. lose some high-frequency response as the stylus nears the center of the record. Second, the recorder may want special response curves, such as Orthacoustic, Columbia Transcription and NAB Standard. In amateur and semiprofessional work 2 more reasons for equalization often appear. If the response of the cutter is not linear, some compensation can be made. If a crystal cutter is used, special connection circuits must be used, and its response will depend on how it is fed by the amplifier. Frequency-response control for *playback* of finished discs is discussed in Chap. 13.

The recording amplifier system *must* have a flat frequency response. If there are peaks or if the amplifier curve drops off excessively on the high- or low-frequency end, equalization is *not* the cure. It is easy to build a flat amplifier (50 to at least 8,000 cycles) if proper attention is paid to high-quality components and circuit wiring. If the amplifier does not turn out well, *do not insert equalizers to correct the original frequency response of the amplifier.* Experimentation with the amplifier is indicated.

Making Frequency Runs

It is a good idea to make a frequency run on the amplifying system before equalization is attempted. For those who are unfamiliar with this procedure, the following detailed outline is given. This method of determining response curves is valuable in any audio work and will be necessary in equalizing the system.

The materials needed are:

1. An a.f. test oscillator with frequency variable from 50 to 10,000 cycles. Output voltage should be sufficient to be readable on a meter, and output impedance should be 5,000 ohms or higher. There should also be a selection

of low impedances. Any commercial audio test oscillator will suffice.

2. Unless the oscillator has a built-in output meter or is of the constant-output, R-C type, a meter should be provided. Oscillator output must be kept constant at all frequencies.
3. A dummy load resistor of the same value as the output impedance of the amplifier system, with a wattage equal to the maximum capability of the amplifier.
4. A high-resistance (1,000 ohms-per-volt or better) a.c. voltmeter to measure amplifier output. A vacuum-tube voltmeter or one using a crystal rather than a dry-disc rectifier is ideal because it will not have frequency discrimination in the audio range.
5. Pencils and plenty of paper.
6. A good supply of graph paper (semi-log paper with 3 cycles by 70 divisions).

Connect the oscillator to one of the inputs of the amplifier system. Set its output high enough so that some indication can be seen on the amplifier voltmeter. Usually, a vacuum-tube voltmeter must be used

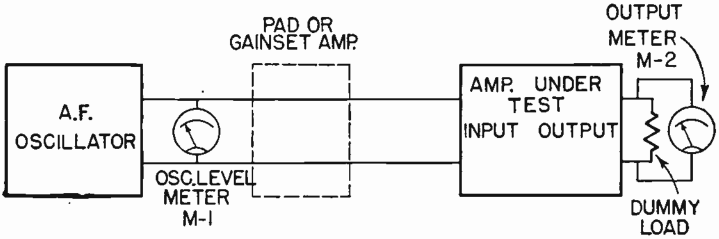


Fig. 1101—Frequency run setup. Oscillator output should not be high enough to overload the initial amplifier stages, but sufficient to give a reading on meter M-1.

to show oscillator output when impedance is high because the low resistance of ordinary meters interferes with operation of the test setup.

Disconnect the amplifier output from the cutter and substitute a dummy load resistor of the same impedance as the amplifier output. Across the dummy load resistor connect the output meter. Now the frequency run can be made, as shown in the following steps:

1. Adjust the oscillator to a reference frequency, such as 1,000 cycles.
2. Adjust amplifier and oscillator gain controls so that the amplifier output meter indicates some convenient value near center scale. Be sure that the oscillator output is not so high as to overload the initial amplifier stages, and that oscillator output is sufficient to give a reading on the meter across its terminals, if one is used. If a low-impedance, high-gain input is being fed, a pad may be inserted between

oscillator and amplifier to reduce actual input while still putting out enough level to actuate the oscillator output meter. The setup is shown in Fig. 1101.

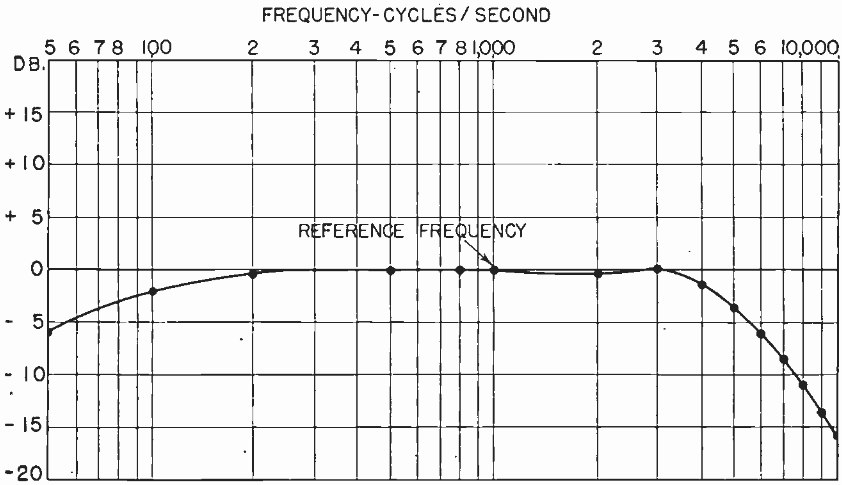


Fig. 1102—Typical response curve of a poor amplifier.

3. Make a note of both meter readings. For all future steps, adjust only *oscillator output* to keep the reading of M-1 (Fig. 1101) at this same point. *Don't touch amplifier gain control during these steps. This is most important.*
4. Adjust the oscillator to each of the following frequencies, adjusting the oscillator output to keep it constant and making a note of the reading on the amplifier output meter M-2: 50, 100, 200, 500, 800, 1,000, 2,000, 3,000, 4,000, 5,000, 6,000, 7,000, 8,000, 9,000, and 10,000 cycles. The voltage output of the amplifier for each frequency should be tabulated on a sheet of paper.
5. Calibrate a sheet of the graph paper as shown in Fig. 1102. The horizontal lines represent decibels and the vertical lines represent frequency. Select a horizontal line in the center of the sheet and mark it 0 db. In the left margin, mark the lines above plus and below minus.
6. Make a pencil dot at the point where zero db intersects the chosen reference frequency (1,000 cycles in Fig. 1102).
7. On a separate sheet of ordinary paper, calculate the decibel relationship between the output at the reference frequency and that at 50 cycles. To do this, divide the larger voltage by the smaller. For instance, if output at the reference frequency 1,000 cycles was 6 volts and at 50 cycles was 3, dividing the 6 by 3 (6/3) gives 2. This is the *voltage ratio* of 50-cycle output to 1,000-cycle output. To con-

vert to decibels, look up 2 in the column headed "Voltage Ratio" in Table 11–1. Read decibels under the column headed "Decibel Gain or Loss." In this case, a voltage ratio of 2 equals a decibel gain or loss of 6. Since 50-cycle output was *lower* than 1,000-cycle output, this must be a 6 db *loss*. Make a dot on the graph where 50 cycles intersects with minus 6 db.

Table 11–1 — Abbreviated decibel table.
Voltage ratios are those found in step 7 in text.

Voltage Ratio	Decibel Gain or Loss	Voltage Ratio	Decibel Gain or Loss
1.06	.5	3.35	10.5
1.12	1.0	3.55	11.0
1.20	1.6	3.76	11.5
1.26	2.0	3.98	12.0
1.35	2.6	4.22	12.5
1.41	3.0	4.47	13.0
1.50	3.5	4.73	13.5
1.58	4.0	5.01	14.0
1.68	4.5	5.31	14.5
1.78	5.0	5.62	15.0
1.88	5.5	5.96	15.5
2.00	6.0	6.31	16.0
2.11	6.5	6.68	16.5
2.24	7.0	7.08	17.0
2.37	7.5	7.50	17.5
2.51	8.0	7.94	18.0
2.66	8.5	8.41	18.5
2.82	9.0	8.91	19.0
2.99	9.5	9.44	19.5
3.16	10.0	10.00	20.0

8. Follow this same procedure for each of the other frequencies used in the test. For instance, in Fig. 1102, voltage output at 3,000 cycles was the same as that at 1,000 cycles. The dot at 3,000 coincides with the zero line. At 10,000 cycles output was only 1 volt. Dividing 6 (output at the reference frequency) by 1 gives 6. The nearest figure to that in Table 11–1 is 5.96. The equivalent db is 15.5 The

10,000-cycle dot coincides with the line for minus 15.5 db.

NOTE: Do not interpolate with this table. Values are not linear and results will be incorrect. Decimal accuracy is not necessary.

9. After all the dots are made and rechecked, join them with a solid line.

Interpreting the Curve

The curve of Fig. 1102 shows the frequency response of an amplifier, obtained as shown above. An inspection quickly shows that the high-frequency response is far from satisfactory. For good results, there

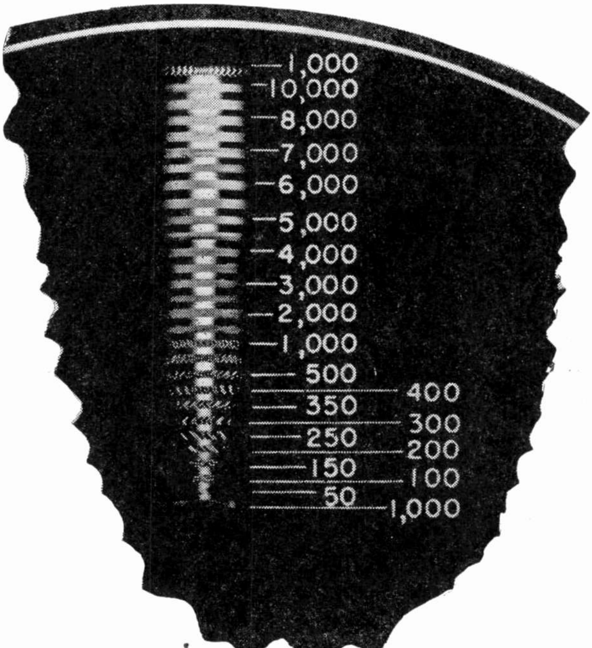


Fig. 1103—Light pattern of disc cut by a very high quality cutter, showing an almost perfect frequency response.

should not be much dropoff up to 8,000 cycles. Eleven db, as shown here, is far too much. The unit should be reworked to eliminate stray capacitances in the wiring. Perhaps too much shielded wire has been used. Perhaps circuit design is faulty. After modification, this whole process of taking a frequency run should be repeated. When the curve is practically flat (within 2 db) from 50 to at least 8,000 cycles, the amplifier can be called suitable. For professional work 1.5 db, or better, from 30 to at least 10,000 cycles is required.

Using Magnetic Cutters

If a magnetic cutter is used, the actual recorded frequency curve to be achieved will be modified constant velocity, or some variation of that characteristic. There are 2 methods in common use for measuring the frequency response of a disc cut in this way.

The first and quickest is the light method:

1. Connect the audio oscillator to the amplifier input as before, with provisions for keeping its output level constant.
2. Cut a disc at 78 r.p.m., recording a series of frequencies

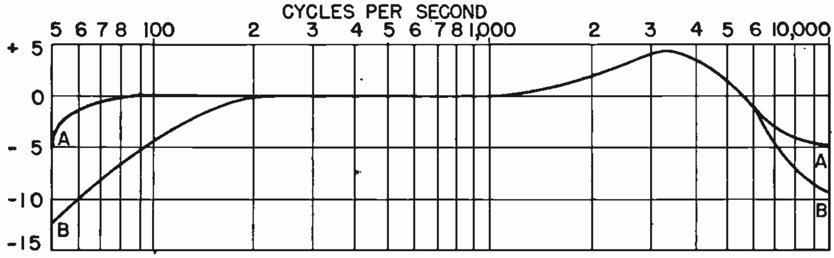


Fig. 1104—*Output of standard frequency record (curve A) and output of recorded test disc (curve B).*

   from 10,000 cycles down to 50 cycles. If the cut is made outside-in, start with the highest frequency; if it is made in the other direction, start with the lowest. Record each frequency for about 5 seconds, then leave an unmodulated space of about 3 or 4 seconds. Make a careful list of the frequencies to be used.
3. Now hold the finished disc obliquely under a single light source and observe the "Christmas tree" pattern of the cut grooves. Adjust the positions of the disc, light source, and eye until something like the picture of Fig. 1103 is seen.
4. A disc with a practically perfect frequency response will appear like the one in the photo; the bands from the highest useful frequency down to the turnover frequency will be about the same width. From turnover downward, the bands will gradually become narrower.

This method does not lend itself to very exact measurement, but it is an excellent way to make a quick preliminary check on the high frequencies. From turnover upward, the width of the light band is in direct proportion to the recorded voltage. Measurement can be made with a ruler, and the voltage ratios can be translated into decibel gain or loss, just as in actual voltage measurements. This is *not* true below turnover. Incidentally, this check will show almost the exact turnover frequency mechanically built into the cutter.

After a quick look at the "Christmas tree" pattern, more exact measurements can be made to determine the exact equalization required (if any) to correct cutter deficiencies. Procure one of the standard-frequency records on the market. These discs have a series of tones recorded on them with a perfect modified-constant-velocity characteristic similar to Figs. 605, 606 and 1103. Get one such as Columbia #10004-M, with a 500-cycle turnover. We propose to measure cutter response by comparing the records it cuts with the standard-frequency records, so a good playback pickup will be needed, together with a separate amplifier. The pickup-amplifier system should be of good quality. It can be adjusted with the standard-frequency record, according to the instructions in Chap. 13. Refer to that chapter and adjust the playback system before going ahead with the rest of this process.

Assuming that the playback system is reasonably good, play the frequency record on it and make a graph of output, just as shown earlier in this chapter. The only difference will be that the tone source is now a record and pickup instead of an a.f. oscillator. Amplifier gain controls, once set, should be left alone during this test. The graph thus made might be like curve A in Fig. 1104. The fact that this curve is not flat shows that the pickup-amplifier arrangement is not quite flat, but this does not matter if we are concerned only with cutter calibration.

Now play, on the same playback system, the frequency record which was made on the new recording machine. Chart its output in the same manner. In both charts, use the 500-cycle turnover frequency as the reference frequency, so that the 500-cycle point on both graphs will coincide on the 0-db line. Plot the curve of the new disc on the same piece of graph paper. Curve B in Fig. 1104 is an example of a new disc.

Now compare the two. In the example, the test-record level at 50 cycles is obviously 7.5 db lower than that of the standard disc. At 10,000 cycles it is 4.5 db lower. Curve A, representing the standard record, is the ideal, and we can easily draw a new graph showing the *differences* between our disc and the ideal. Fig. 1105 shows the difference in the example chosen. As we have pointed out, the 50-cycle test record level was 7.5 db lower than that of the standard record; therefore, in curve A of Fig. 1105 the 50-cycle level is shown as — 7.5 db, and so on.

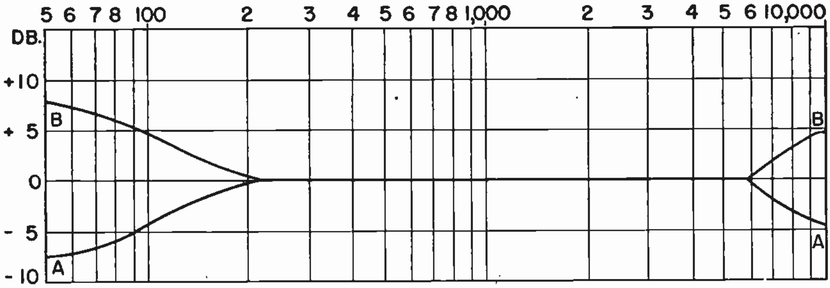


Fig. 1105—*Difference between test disc and ideal (curve A). Curve B shows equalization necessary.*

Now insert enough equalization to *counterbalance exactly* the drop-off on each end of the frequency range. In other words, use an equalizer that will raise the 50-cycle level of the recording system by exactly

7.5 db, etc. The work the equalizer must do is shown in curve B of Fig. 1105. The graph makes equalizer selection easy; thus in the example it is obvious that a bass booster is needed. For anything but high-fidelity professional work, we would probably leave the high end alone, since the dropoff of 3 db at 8,000 cycles is not serious.

Choice of Equalizer Circuit

The next step is to choose the equalizer circuit. The best practice is to build into the amplifier a versatile equalizer allowing either boost or attenuation of both highs and lows separately, such as the one shown later in this chapter; but if space is left on the chassis, the equalizer may be selected after the amplifier has been built.

Most high-quality professional installations do not include equalization within the recording amplifier. Invariably, in such systems, the setup shown in Fig. 904 is used. Since high-fidelity, expensive cutters are incorporated, equalization to compensate for cutter deficiencies is unnecessary. What equalization is needed for other purposes is usually placed in the 500–600-ohm line between console and recording amplifier. However, in less elaborate installations, it is permissible to have the equalizers within the recording amplifier. Several equalizers are shown at the end of this chapter.

After the equalizer has been selected and installed, refer to the original graph showing the final response of the amplifier *without equalization*. Replace the cutter with the dummy resistor, connect the a.f. oscillator to the recording amplifier input, and make new frequency runs. The object now will be to adjust the equalizer to obtain an amplifier response which will be the same *as before, but with the addition of the necessary equalization*. For example, if the amplifier was originally flat from 50 to 10,000 cycles, the equalizer now should be adjusted so that the response looks like curve B in Fig. 1105. Whatever the amplifier response was, the 50-cycle response should now be raised by 7.5 decibels (in our example), and so on.

Next, reconnect the cutter and make a new test record. Compare this again with the standard disc. If the complete procedure has been followed faithfully and accurately, the two should be very similar. If not, make a new graph of the difference and re-equalize.

Setting the frequency response of a recording system is not a quick, offhand operation. It is, on the contrary, a job requiring patience, time, and attention to detail. It is very unlikely that the disc cut will match precisely the characteristics of the standard record; but if they are within 3 or 4 decibels throughout the range up to 10,000 cycles, the recordist will be entitled to a vast amount of pride. Even up to 7,500 or 8,000 cycles will be very creditable, producing discs with as good a response as most commercial phonograph records — often better!

Caution: some inexpensive cutters have an effective cutoff as low as 6,000 cycles. Do not attempt to *extend* the response greatly by equalization, since this will only result in a sharp and unpleasing peak at the top of the cutter's normal range. A sharp cutoff at the end of the range is much more desirable. Most AM broadcast stations put out very little response above 5,000 cycles, yet most people are quite used to and satisfied with this. But anything which cuts off below about 8,000 cycles cannot be considered high fidelity, and even this is a very indulgent limit.

Crystal Cutters

The crystal cutter, inherently a constant-amplitude device, can be made, however, to cut modified constant velocity very simply. With crystals, the turnover frequency can be varied at will merely by selection of the proper method of connection to the amplifier. Constant-amplitude records may, of course, be cut, too.

The crystal is a primarily capacitive device, and its capacitance remains, for all practical purposes, fairly constant at usual room temperatures. It has a definite (and different) impedance at different frequencies just as has a condenser. If the impedance of the crystal always exceeds, even at the highest frequencies, the impedance of the source of power

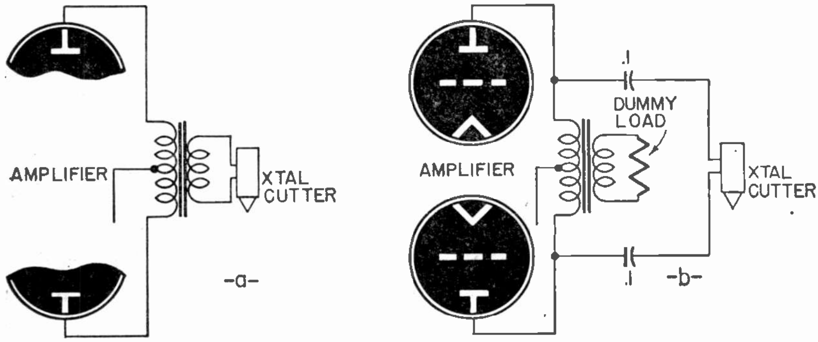


Fig. 1106—*Two methods of connecting crystal cutter for constant-amplitude recording.*

which drives it, then the voltage across the cutter will be constant for all frequencies, and the cut will be constant amplitude. As an example the following specific data refers to the Brush RC-20 crystal cutter.

The RC-20 has a capacitance of .007 μf. From the capacitive reactance formula: $X_c = \frac{1}{2\pi FC}$, it is seen that the impedance is approximately 225,000 ohms at 100 cycles, and about 2,500 ohms at 9,000 cycles. To cut *constant amplitude,* the driving source (output transformer secondary or tube plates) should have an impedance about that of the cutter at the highest desired frequency. If, with the RC-20, the highest frequency desired is 9,000 cycles, the source impedance should be 2,500 ohms although 4,000 ohms is adequate with this particular cutter. Two methods of connection for constant-amplitude recording are shown in Fig. 1106. The transformer-secondary (a) or the plate-to-plate (b) impedance should be equal to or less than X_c at the top frequency. The maximum signal voltage across the cutter is specified by the manufacturer of each crystal cutter. For the RC-20 operating under these conditions, it is about 50 volts. Use a vacuum-tube voltmeter to measure this.

If, when using the crystal cutter, the impedance of the driving source is made equal to the impedance of the cutter at any frequency, the cutter response drops at the rate of 6 db per octave *above* that frequency. The impedance of the .007 μf capacitance of the RC-20 cutter for instance, is approximately 44,000 ohms at 500 cycles. If it is fed by a 44,000-ohm source, response (stylus movement) will be constant for all frequencies below the 500-cycle point of equal impedances; but, as the frequency rises, it will be reduced at the rate of 6 db per octave. Under these conditions, the response is exactly the same as a magnetic cutter cutting modified constant velocity! Merely by adjusting the source impedance we can adjust the characteristic for any desired turnover frequency or we can cut constant amplitude, which is merely a characteristic in which the turnover frequency is above the usable frequency range, and so, practically speaking, does not exist.

In Fig. 1107 2 methods are shown for connecting the crystal cutter to obtain the modified-constant-velocity response. In (a), the transformer-secondary impedance and the resistance of R *each* should be equal to ½ the impedance of the cutter at turnover frequency. In (b), the plate-to-plate impedance should be low (triodes or feedback-stabilized beam tubes should always be used and these will have a low plate-load impedance). R should equal cutter impedance at turnover.

In Fig. 1106-b or 1107-b the transformer-secondary load resistor may be replaced with a loudspeaker for monitoring, provided no equalization exists in the amplifier. However, the speaker alters the plate-load impedance with varying frequencies and so should not be used *at the same time* cutting is in progress. An ideal use for the speaker for playback of finished records is made possible by a simple switching arrangement.

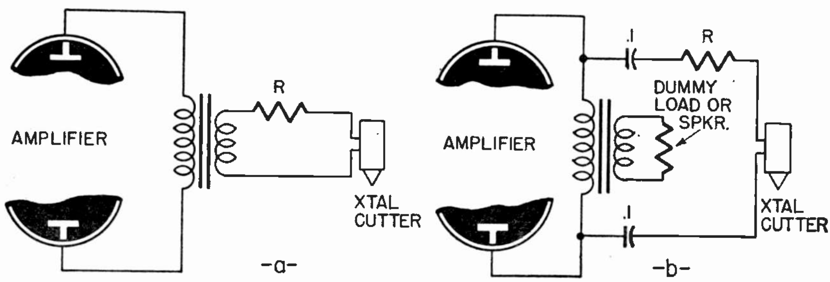


Fig. 1107—Crystal cutter connections for modified constant-velocity recording.

In Fig. 1106-b or 1107-b the blocking condensers have a very high voltage rating, to prevent d.c. leakage to the cutter.

When modified-constant-velocity response is cut with a crystal cutter, driving voltage may be increased. With the RC-20, a turnover of 500 cycles will permit driving voltage of 150. Voltage overloads must be carefully avoided, or the crystal may be cracked.

After the crystal cutter is connected and the turnover frequency checked by observing the light pattern on a test record, the system is treated as though a magnetic cutter were used. Most crystal cutters do

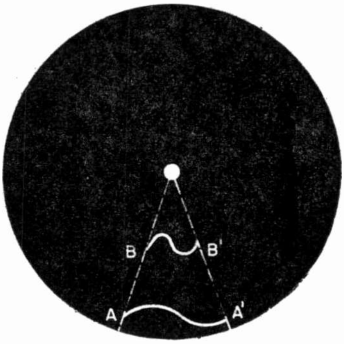


Fig. 1108—*One cycle will occupy a much longer path on the disc at A-A*[1], *than at B-B*[1], *with its more acute bends. Refer to Fig.* 1109.

not have a flat frequency response. Excessive drop-off on either end, or a serious peak, may be corrected by equalization. The procedure is exactly the same as previously described for magnetic cutters.

High-Frequency Pre-Emphasis

After a good standard modified-constant-velocity response has been obtained, some thought can be given to special curves. Commercial phonograph records are made of a shellac compound, an abrasive included in it causing surface noise or scratch. Many phonograph users turn down the tone control to eliminate this, but, in so doing, they eliminate much of the high-frequency range of the record as well. For this reason, record manufacturers boost the high end of the range in recording. When this is done, using a tone control to reduce high-frequency surface noise brings down the boosted highs to the proper value. While this is not necessary with instantaneous discs because of their very low noise level, the recordist may want to try high boost on the premise that many cheap phonographs lack good high-frequency response. Experimentation is fairly simple, if the equalizer in the amplifier is sufficiently versatile. One record manufacturer, for instance, raises the high frequencies at the rate of 2½ db per octave, beginning at turnover. This results in a 10-db boost at 8,000 cycles after which he cuts off the response very sharply. Many phonographs are excessively boomy, so experiments with a bass attenuator may be fruitful.

In cutting discs at 33⅓ r.p.m. we encounter an additional problem in equalization. Any cutting system which is properly equalized for

78-r.p.m. recordings, according to the outline given in this chapter, will cut at the slower speed just as successfully *when cutting near the outside of a 16-inch disc.* When the diameter of the groove nears 12 inches, however, further treatment is necessary.

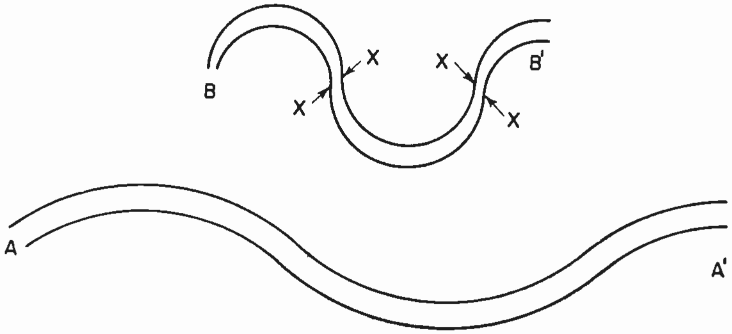


Fig. 1109—Grooves of same frequency at different disc diameters; note pinching of groove at points X-X.

Fig. 1108 is a schematic drawing of a disc surface. When the disc revolves under the cutting stylus at a constant speed of 33⅓ r.p.m., the stylus will take the same amount of time to travel from A to A′, if it is near the outer edge of the disc, or from B to B′, if it is near the center, since each of these distances represent the same fraction of a revolution. However, the actual *linear distance* travelled at BB′ – with the cutter near the disc center – is much smaller than that traveled from A to A′, when the stylus is near the edge.

The drawing is much out of scale, but assume that the stylus travels each of these distances in 1/5,000 second. If the tone being recorded is 5,000 cycles the stylus will trace out 1 cycle in each case, as the drawing shows. Notice that the 1-cycle groove at AA′ takes up a compara-

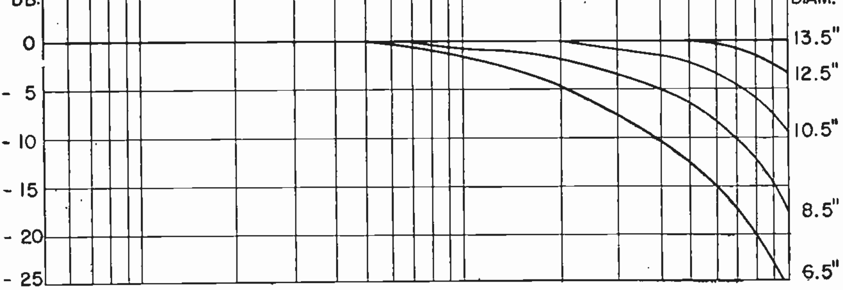


Fig. 1110—Approximate attenuation in playback due to "pinch effect" at various diameters.

tively long distance and its undulations are fairly gradual. But at BB′ the same cycle will have to be traced in a much shorter distance and its undulations are much sharper and its bends more acute.

Fig. 1109 is an enlarged view of each of these grooves. Notice that in AA′ the *width* of the groove is fairly constant at all points. A reproducing needle of the proper size and shape will fit nicely into this groove and reproduce its variations faithfully. But in BB′ the steeper bends of the engraved wave cause the groove width at points X to be perceptibly narrower than normal. Because of this, the playback needle will be forced up out of the groove somewhat; it will not track properly, and the output volume of the pickup will be decreased.

This pinch effect will occur to some extent no matter what the frequency. But, because the higher the frequency and the slower the disc r.p.m., the more the number of cycles engraved in a given distance, the effect is noticeable at 33⅓ r.p.m. and at higher frequencies. In practice, pinch effect is not bothersome at frequencies much below 1,000 cycles, but if the playback needle is a little larger than optimum at its point, it

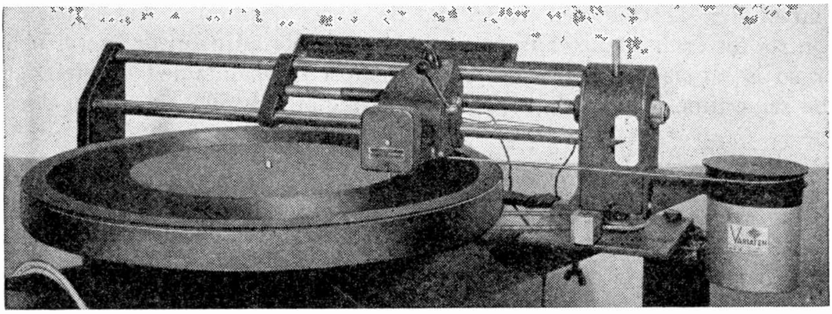


Fig. 1111—*One type of automatic diameter equalizer mounted on overhead lathe. The cutter pulls the string which regulates the equalizer setting.*

will attenuate frequencies even lower than this. While the actual attenuation due to pinch effect in playback varies with the particular pickup and needle used, the curves in Fig. 1110 are typical.

Under a diameter of about 8 inches, the pinch is so great that little correction is possible; but from 8 to about 13 inches, where the effect begins to be noticeable, *diameter equalizers* are used to correct the response. These high-boost (or low-pass) equalizers have 2 functions. First, they boost the amplitude of high frequencies fed to the cutter (or attenuate the lows), the boost (or attenuation) increasing as the stylus travels inward on the disc. Second, they maintain over-all cutter level constant.

A number of amateur and semiprofessional recordists and all professionals use *automatic* diameter equalizers in which a variable control is geared to the cutter mount, so that as the cutter moves inward, equalization is automatically increased. Fig. 1111 shows one automatic equalizer, mounted on a recording assembly. A cord attached to the cutter mount turns the control within the cylindrical case. This unit, priced in the neighborhood of $75, is designed for insertion into a low-level, 500-

ohm line, such as that between the console and the recording amplifier in the unit of Fig. 904, Chap. 9. Another type, priced considerably higher, is shown in Fig. 1112. The long flat box is mounted on the mechanism, parallel to the feed screw. A metal arm projecting from one of the long sides is attached to the cutter mount. The arm, moving with the cutter, contacts metal studs within the flat case. The studs are wired to the other box, which contains the actual equalizer. This unit is also designed for insertion in a low-level, 500-ohm line.

Diameter equalization can also be performed by hand. First, a high-boost or low-pass equalizer with a variable control is built into the system. Then a number of large discs are cut (without equalization) at various diameters with different frequencies. The playback response at each diameter and at each frequency is charted and compared with the response of a good 78-r.p.m. disc. A graph similar to that of Fig. 1110 is then made, and the exact position of the equalizer control for each diameter is determined. Usually adjustment every inch or so is satisfactory. The cutter level must be maintained constant at the same time. Doing this job manually is not only inexact, but it does

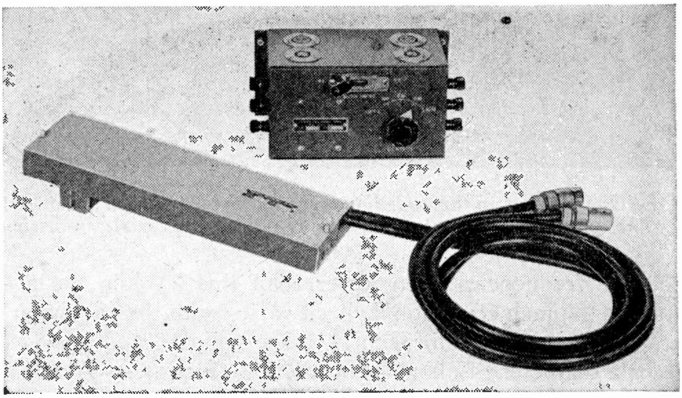


Fig. 1112—*Another automatic diameter equalizer. The flat box is installed on the lathe.*

not allow the recordist the freedom necessary to attend to other things. An automatic equalizer can be made by ingenious constructors after a little thought and several tests.

Practical Equalizer Circuits

In the commercial line, a very popular low- and high-frequency-type equalizer is the resonant type allowing independent boost of highs and lows, with adjustable resonant frequencies. These are quite expensive but very suitable for high-quality professional installations. Some types give attenuation at both ends of the range. Typical of these are the UTC 3A and 3D.

Thordarson offers a dual tone control of the nonresonant variety. The kit consists of 2 special dual potentiometers and an a.f. choke. The circuit permits either boost or attenuation of both ends of the range independently. The actual Thordarson circuit may be found in the Thordarson Amplifier Manual, but it is actually an adaptation of a very useful idea — using degeneration for equalization.

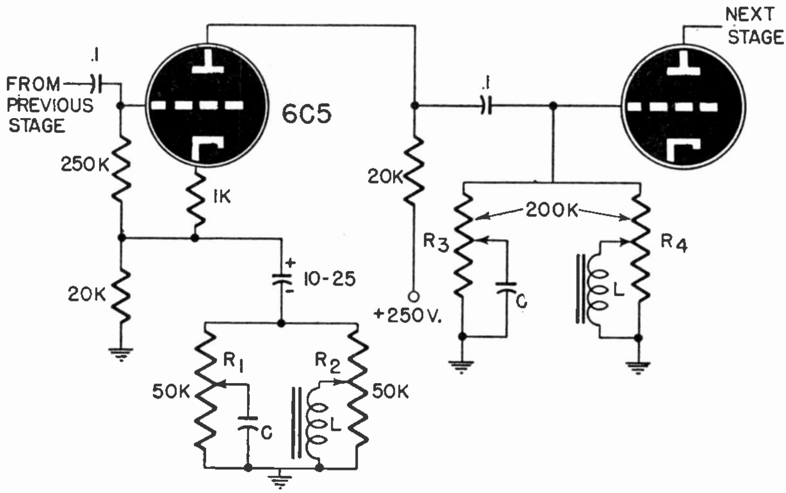


Fig. 1113—*Circuit for universal equalizer.*

Fig. 1113 shows a similar and very effective circuit which can be built without special parts. The 6C5 equalizer tube gives no gain unless either end of the range is boosted. It is to be inserted in an amplifier somewhere after the preamplifier stages.

When the arm of R1 rises, highs are boosted; when it is lowered to ground, highs become normal. When the arm of R2 is raised toward the cathode, the lows are boosted; when it is grounded, lows are normal. When the arm of R3 is grounded, highs are normal; when it is raised, highs are attenuated. R4 controls attenuation of lows in the same manner.

Values of the condensers C and chokes L are not given because they should be determined by experiment and will depend on just what equalization is needed. The values will determine which portions of the range are affected. For example, with very small condensers, only the highest parts of the spectrum will be raised or lowered. If quite large values are used, the high controls will affect frequencies as low as 500 cycles. The *amount* of boost or attenuation is controlled only by the potentiometers. L and C determine the *frequency range* affected. In practice careful measurements of the results *must* be made. Do not confuse the functions of the components. This excellent, all-around equalizer is to be inserted into the amplifier while it is being built, since, no matter what correction is later found necessary when cutting tests have been made, it is almost always possible to adjust the values of C and L and the settings of the controls for just the right effect. This unit will not take care of peaks in the range except at either end.

Resonant equalizers are most useful where very sharp boost or attenuation is required around a certain frequency. Usually the simpler nonresonant circuit will satisfy the needs of most recordists; but where sharper curves are wanted, circuits similar to that of Fig. 1114 may be

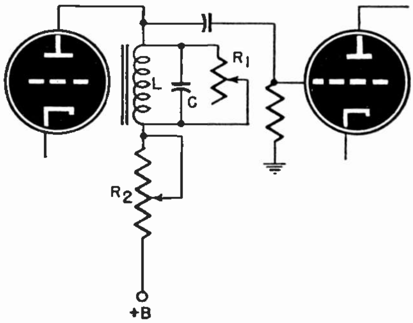


Fig. 1114—*A resonant equalizer circuit.*

used. L and C are resonant at the desired frequency, and R1 adjusts the amount of equalization. R2 compensates for the change in level which occurs when equalization is varied. Two L-C combinations may be connected in series for equalization at 2 different frequencies.

It is seldom advisable to use resonant equalizers to compensate for peaks in cutter response. The peaks encountered in most units are not so sharp as to warrant elaborate L-C filters, and, when they are used for this purpose, an undesirable hangover effect makes all tones of the resonant frequency appear to linger for a period and die away gradually. This effect is present whenever the cutter has a peak, but, while the equalizer may flatten the peak according to tests using an a.f. oscillator and an output meter, the hangover will still appear. It may even be accentuated.

Equalizers for use across low-impedance lines are hard to make because they must have a fairly good Q if they are of the resonant type. Such units can be bought, however, from transformer manufacturers. If control of frequency response is desired in a low-impedance line, the least expensive solution giving the most versatility in use is a small gainless amplifier inserted in the line. Any of the various high-impedance equalizer circuits which are presented in technical magazines, or the excellent one described here, may be used in this amplifier.

Reference to magazines and other literature is, in any case, a good way to discover many special-purpose equalizer circuits for particular requirements. While only one complete equalizer has been described in this chapter, it is by no means the only suitable one. Equalizers especially designed for record playback will be found in Chap. 13. See also the Gernsback Library book, Amplifier Builder's Guide.

Chapter 12

Making a Good Recording

WE come now to the crucial phase of recording—the moment when all the effort and expenditure of time and money are to be vindicated by producing actual recordings of as good quality as possible.

Some manufacturers, particularly those who make the less expensive "home" recorders, make much of the fact(?) that making a good recording is easy for anyone, whether or not he has any knowledge or experience. "Just turn up the volume," they say, "and lower the recording arm to the disc, and you will have perfect results."

This statement is not true. Even with modern developments it is emphatically not that easy. Recording is, on the contrary, a painstaking precision job requiring knowledge and experience. There is little physical labor connected with recording, but adjustments — mechanical and electrical — must be made correctly and frequently checked. Volume must be controlled accurately; microphone placement and radio tuning must be done with care, and every other detail must be scrupulously carried out. When the recordist learns to do these things — and they can be learned — recording will be pleasurable and uncomplicated. If he does not take the time and trouble to learn, his records will be amateurish — suitable, perhaps, for party entertainment or as a sort of toy, but they will never really satisfy anyone.

Recordings of very satisfying quality can be made on almost any equipment, even the least expensive home recorder, but particularly on custom-made jobs such as the average radioman can build with the help of information in this book.

At this point it is assumed that the system has been bought or built, that tests and final adjustments described in the preceding chapters have been made, and that a final frequency run and listening check have been completed satisfactorily. The recording procedures given are applicable to almost any type of equipment.

The average recordist will not have an acoustically treated studio;

probably a living room will be pressed into service. But its acoustics can be markedly improved very simply. Human hearing is *binaural.* Our ears being separated by a small distance, we can judge, not only how far we are from a sound, but also the *direction* from which the sound is coming. If sound is coming from our left, for instance, the left ear will hear it with slightly greater volume than the right. Through experience we have learned to detect this slight difference in volume and to interpret it automatically in terms of direction. The situation is somewhat analogous to the stereoscopic effect obtained with two eyes.

The microphone is *monaural,* the equivalent of only a single ear (just as the camera is a single eye), and the stereoscopic effect is not present. The microphone, therefore, cannot distinguish *direction,* although it can reveal distance by relative volume.

In the average room, bare walls, floors, and wood furniture all reflect sound waves and cause small echoes. To normal binaural persons these echoes are almost unnoticeable; they come from diverse directions and appear natural and are automatically taken into account when determining the direction of a sound. But to a microphone all these echoes seem to come from the same direction; they present a miscellaneous conglomeration of repetitions of the same sound which, in the loudspeaker, appears as a multiplied echo, an unnatural and often an annoying one.

In building sound studios most of the small echoes are eliminated and the remainder are diminished. Some, of course, are left so that the sound will not appear to be coming from a telephone booth or from the grave. The amount of echo which a studio of a room contains is known as its *liveness.* The opposite effect, that of considerably less echo than normal, is known as *deadness.*

In early broadcasting, rooms were usually completely lined by sound-absorbent material such as heavy draperies and they were almost completely dead. Today, the advances in the science of acoustics have led to elaborate treatments to control desired degrees of liveness and deadness.

Treatment for almost any room other than a large hall is neither difficult nor expensive. First, determine the condition of the room by having someone speak into the microphone from at least 3 or 4 feet away, raising his voice to get about the same microphone output as for normal microphone distance of 6 to 12 inches. Listen critically on a loudspeaker *in another room,* a normal room. If any excess echo is apparent, it can be reduced by hanging heavy cloth over bare wall surfaces, or by putting rugs on bare floors. Often, however, some particular portion of the room will be found satisfactory as is. When treating a room, do it by slow degrees. First cover some obvious cause of echo, then listen again; repeat this procedure until unnatural effects are eliminated, but stop before the room becomes unnaturally dead. The amplifier and loudspeaker used should, of course, have as good characteristics as the recording equipment. If desired, small record cuts may be made for each test and played back — not in the treated room, but in a normal one!

Once the room has been treated and found satisfactory, it can generally be left the same for all future recording. However, the same tests and treatment may be gone through each time a different program type or musical group is to be recorded. If this is done, use as the test the particular material to be recorded. Generally, musical recordings are benefited by greater liveness than that required for speech alone. Notice that the very best phonograph records are those in which there is a perceptible echo, giving a "large hall" effect. European symphonic and operatic records are particularly excellent in this respect.

Microphone Placement

Microphone placement is a subject on which very few exact rules can be formulated. The first cardinal principle, however, agreed upon

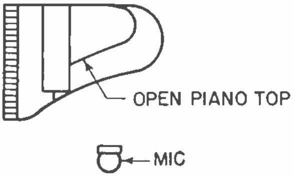


Fig. 1202—*Microphone placement for piano recording.*

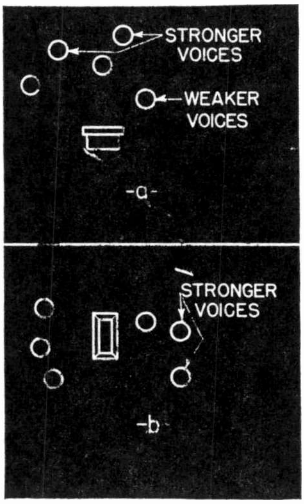


Fig. 1201-*a*—*Placement of several speakers with dynamic microphone; b—with ribbon microphone.*

by all modern broadcast and recording technicians, is that, no matter how many tempting amplifier input channels and microphones are on hand, no more microphones should be used than the minimum necessary to do the job. It used to be fashionable, for example, to use a separate microphone for each section of the orchestra and for each soloist. Today it is agreed that very few run-of-the-mill programs need more than 2 microphones for the actual program material. Not only is it difficult to use several microphones in the same room without appreciable interaction among them, but, by having the musicians control their own expression and the speakers do their own fading, the performers themselves have a more accurate idea of how they sound. In addition, a recordist has enough to do without having to watch constantly the mixing of several channels.

When recording speech, the speaker should be at least 12 inches from most ribbon or velocity microphones, and at least 6 inches from any other type. Microphone technique is simple but important. For instance, if the speaker raises his voice momentarily to make a point he should bring his head back slightly rather than depending on the operator and the gain controls to keep average level constant.

If several speakers are to be recorded, they must be arranged before the microphone in accordance with their vocal volume. Except for special effects, everyone should speak at natural volume, neither shouting or whispering. In radio and recording, emphasis and expression can be achieved most effectively by controlling the *pitch* of the voice and the *pauses between particular words,* as well as variation of speaking *speed.* The late President Roosevelt was perhaps one of the finest exponents of this technique.

In recording several persons, place the weakest voice where normal gain setting gives normal volume indicator level. Then place each additional speaker at a distance which will produce the same indication — far, if his voice is loud, and near if it is soft. This balancing should be done with care. Once the positions have been set, each person must maintain his position. If necessary (and possible), mark Xs' on the floor with chalk. It goes without saying that all persons must face a live side of the microphone. Typical setups for several speakers, using dynamic and ribbon microphones, are shown in Figs. 1201-a and b.

Certain special effects may be obtained by purposely varying the speaker's position. For instance, if the speaker is supposed to be leaving, he can gradually turn his face away from the microphone as he speaks the last few words, and even walk away slightly. This is called a *fade.* If the voice is to be lowered, as in a confidential tone, the speaker should lean forward into the microphone. To call someone at a distance, the voice should be raised and the face turned half away. All these and many other effects will be discovered in practice, but each should be rehearsed carefully, with the recordist watching the volume indicator.

For recording a grand piano, standard technique is to open the top and place the microphone a few feet from the piano and facing the uplifted sounding board, as shown in Fig. 1202. The distance should be determined by trial, both from a quality as well as from a volume standpoint. Generally, increasing the distance will increase the echo effect; this is usually undesirable with piano. For upright and spinet pianos, there is no standard technique and proper positioning must be determined by experiment. In most cases results will not be as good as with grands, but acceptable results may often be secured by opening the top or removing the large front board beneath the keyboard. If this is done, there will usually be some frequency discrimination, depending on whether the microphone is placed at the left or the right of the piano.

For piano recordings, the volume indicator is not as effective as for other recordings. Except for magic-eye types, there is a small lag between the beginning of a sound and the full registration of the meter and, since the piano is a percussion instrument (for electronic purposes only), the initial percussive impact of the hammers on the strings will create an instantaneous peak which will not be shown on the indicator. As a result, piano records cut at normal indicator reading will often distort on these percussive peaks because of cutter overload — especially with crystal cutters — and experiments should be made to determine the proper gain setting for reduction of this effect.

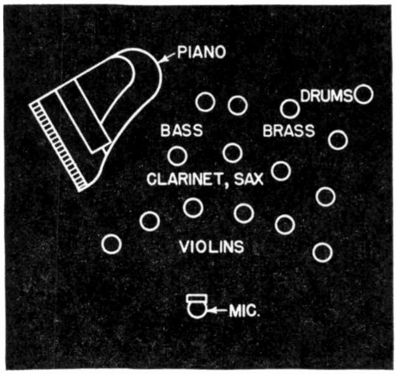


Fig. 1203—*A typical dance band setup.*

The largest amount of experimentation must be done with musical groups. Standard orchestra seating for public playing does not necessarily agree with recording requirements. The horns, for instance, must be far enough from the microphone to prevent their comparatively high level from overriding the strings or soloists. It is often good practice for soloists to use the same microphone as the band or orchestra, in which case the relative distances must be carefully determined for proper balance.

Usually, the best place for the microphone is in front of and slightly above the orchestra. A single microphone almost always will be sufficient. Introducing others may cause interaction troubles, where the microphones may be so connected that the sound output of one is exactly 180 degrees out of phase with the other and cancellation is produced. In special cases where the piano is used for solo passages but is combined with the orchestra for most of the playing, a separate microphone may be located over the piano. When that is done, the recordist or control operator must be something of a musician, for he will determine the musical balance whenever this microphone is used. Highly directional types are best for this work. When the piano is used for solo work only, it can be placed in front of the orchestra and an extra microphone is unnecessary. A typical dance band setup is shown in Fig. 1203.

Singers are also a special problem. Distance from the microphone is a question of vocal power. Never place a powerful singer close and then reduce gain very greatly. Gauge distance by leaving microphone gain at normal setting and moving the singer.

When more than one microphone must be used, locate them some distance apart with their directional patterns either opposing or at right angles, the object being to avoid picking up sound on one microphone which is intended for the other. Fig. 1204 illustrates typical right and wrong positions.

Making the Cut

Use a monitor system, if one is available, in arriving at these placements and balances, then check by making test cuts. The following is recommended procedure for all cutting, tests as well as complete recordings:

1. Select a good stylus and test it by following cutting instructions 2 to 6 below (without feeding any audio to the cutter), then playing back the blank grooves on a phonograph. The cut should be silent, and the grooves should be shiny under a single light source.
2. Place a good blank on the turntable and position the mechanism over the turntable. Place the cutter over the beginning of the record (or whatever surface has not been used, in the case of test cuts), but not nearer to the perimeter than ¼ inch. (When recording inside-out start at least ¼ inch out from the label for 78 r.p.m., or at least 4 inches from the center at 33 1/3 r.p.m.)
3. Start the turntable and give it a few seconds to attain speed.
4. Engage the cutter mount with the lead screw (unless this happens automatically at some point).
5. *Gently* lower the stylus onto the revolving disc.
6. Check immediately to see that the chip is being disposed of properly. One result of lowering the cutter too quickly can be the improper throwing of the first part of the chip, and its entanglement with the stylus. If this happens, brush it away carefully.
7. Open gain controls or switches to feed audio to the cutter. The best practice is to use variable controls rather than switches, for this. There is almost always a small amount of general air noise and agitation in a room, and, if it is abruptly switched in, it is noticeable on playback. Fade in smoothly.
8. Signal the performers to begin. Note that this procedure has given the cutter time to engrave a few blank grooves at the beginning of the disc — which is desirable.

9. Do whatever input mixing is necessary throughout the record, and keep one eye glued on the volume indicator. Do not try to keep all material at the same level, but any reasonably large rises or drops in program level should be compensated for to some extent by operation of the appropriate gain control. *Keep the indicator reading at reference level on peaks and somewhere between minimum and reference reading at other times.* Over-all level should be kept as high as possible to produce a good signal-to-noise ratio in the finished disc, but do not overcompensate to the extent that normal musical expression will be completely wiped out. This monitoring process is known technically as *manual compression,* and that is exactly what it is. (The slang term is *riding gain.*) Volume changes are compressed into smaller variations, but not eliminated. It is unfortunate that this must be

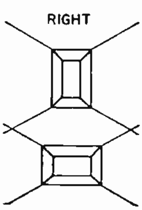
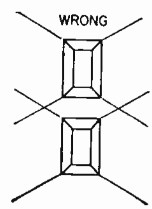


Fig. 1204—Right and wrong ways to place two ribbon microphones for best pick-up.



done because some realism is sacrificed (which is why volume expanders are used in some playback amplifiers), but the cutter must be neither overloaded nor fed so low a level that no appreciable stylus movement will occur.

10. Keep an eye on the chip. (With one eye on the volume indicator and one on the chip, the recordist will run out of eyes, but most people manage anyhow!)
11. As the end of the record draws near, signal the performers. Do not cut closer than ¼ inch to the label at 78 r.p.m., nor closer than about 4 inches from the center at 33⅓ r.p.m. (If recording inside-out, don't cut closer than ¼ inch to the rim.)
12. As the performance ends, close the gain controls, let the stylus cut a few blank grooves, then conclude with a lock groove if the machine is capable of it. If not, simply lift the cutter after cutting the blank grooves.

Here are some important cautions. They can, of course, be disregarded on occasion, but generally they apply:

1. *Never* start or stop the turntable while the stylus is resting on the disc. (This rule must never be broken or the stylus will be!)
2. Never use a bad stylus.

3. Always make at least 2 test cuts before each recording. The first should be made blank to test the stylus, and the second should be modulated with a sample of the program material. Where special effects or balances are necessary, make a test cut of each one. Using discs for test purposes

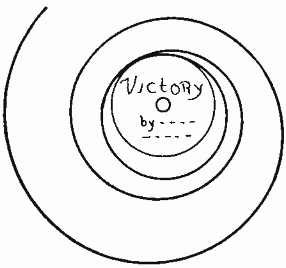


Fig. 1205 — *Eccentric groove at end of commercial phonograph record.*

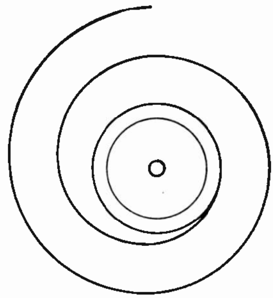


Fig. 1206—*Appearance of lock groove at center of disc.*

is cheaper in time, temper, and money, than ruining complete recordings through improper balances and placements.

4. Use the same type of disc and stylus for the tests as for the final job.
5. Never allow volume to exceed the no-distortion limits of the cutter and amplifier.
6. Never allow anyone to touch a live microphone during cutting.
7. Never place a microphone on a piano which is to be played or on any vibrating surface.
8. Never allow anyone to handle the recording equipment unless he knows all about it (self-protection, and better than an insurance policy).
9. Make sure that all preliminary adjustments made according to the procedures detailed in previous chapters are still effective before cutting.

Lock Grooves

Anyone who has ever played a record made by an inexperienced person is familiar with the action of the pickup when it reaches the end of the record. The needle reaches the end of the last spiral groove and, having no place else to go, flies out into the center of the turntable, plowing up the label and, if there is no mechanical stop, digging up the grooves on the opposite half of the surface. Commercial phonograph records have a so-called eccentric groove at the end (Fig. 1205), but this is made during processing and is impractical for instantaneous recordings.

There is, however, a very simple way of making a *lock groove* with any mechanism which allows the cutter to be disengaged from the lead screw without being raised from the record. Fig. 1206 shows the last few grooves of a disc so treated. The grooves are perfectly spiral until the last groove. Then the cutter has not moved inward as usual, and a perfect circle results. When the playback needle reaches the circular groove, it rides around in it until the pickup is removed. There is no possibility of the disastrous effects mentioned above.

To make a lock groove, allow the turntable a few extra revolutions after the program material has ended; then disengage the lead screw so that cutter movement stops. Allow the turntable *slightly more than one additional revolution,* and then raise the cutter off the record *without* engaging the lead screw. To perform this operation successfully requires a little practice, but the technique is not difficult. Don't allow the turntable much more than one revolution with the lead screw disengaged because each time it traverses the same groove the stylus cuts deeper and will eventually reach the base material and blunt itself. If less than one revolution is allowed, the circle will be incomplete, and the attempt at a lock groove might as well have been omitted.

If the particular mechanism at hand does not allow lock-grooving, let the cutter make as many blank grooves as room allows at the end of the disc. That will give the playback operator time to lift the pickup before the pickup arm flies off.

Spiraling

Another allied technique is *spiraling.* On many records, especially the large ones made at 33⅓ r.p.m., several selections or announcements may be recorded on the same side. It is desirable to separate these, so that selected ones may be played without having to hunt for them.

The spiraling technique is this: allow a couple of blank grooves at the end of a selection, then disengage the lead screw *without lifting the cutter. Immediately* push the cutter by hand about ¼ inch inward and immediately re-engage the lead screw, proceeding with the next selection. Do not push the cutter too fast: about 6 or 7 times the speed at which it is normally actuated by the lead screw is sufficient.

Spiraling is difficult to do manually, since it is very easy inadvertently to create a lock groove by failing to perform the "immediate" operations immediately. Some machines are provided with a spiraling crank at the outside end of the lead screw. (Such a recorder is shown in Fig. 406, chapter 4). To spiral, simply turn the crank by hand. This makes the lead screw turn faster than normal and there is no possibility of error. Hand-spiraling requires practice, and because of the chance of error, it should be done only when absolutely necessary.

Making Radio Recordings

Recording radio programs, speeches, or musical selections is an excellent way to build a library. Most radios can be connected to the recording amplifier input in either of 2 ways. The first method involves placing the amplifier input directly across the speaker voice coil of the receiver, as shown in Fig. 1207. If the speaker is to be disconnected or switched out for any reason during recording, a dummy load resistor equal to the voice-coil impedance should be substituted. This bridging allows the high-impedance input of any amplifier to be fed by any low-impedance source which is properly terminated in its characteristic

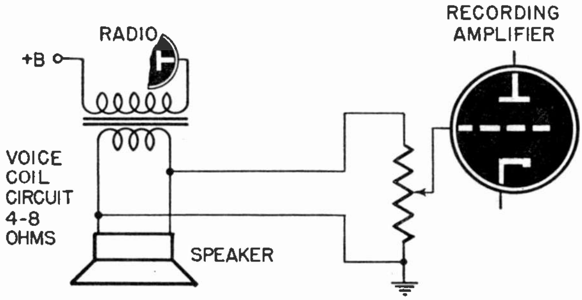


Fig. 1207—*One method of coupling radio receiver to recording amplifier.*

impedance. The very large loss of level in this process explains why the high power level normally used for a loudspeaker may be coupled directly to an amplifier input. High frequencies may be lost with this arrangement, and any distortion in the audio system of the receiver will be passed on.

The second, and better method, is to connect the amplifier input directly to the output of the second detector load resistor, as in Fig. 1208. Here the recording amplifier simply replaces the receiver's audio section. (See also Chap. 8).

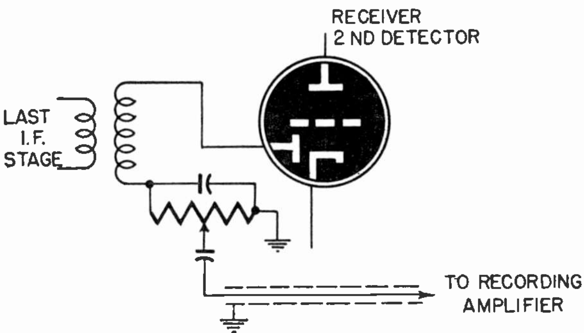


Fig. 1208—*Another radio connection, which bypasses receiver audio system.*

With either of these arrangements, a.c.-d.c. receivers are not recommended, since their chassis are often tied to one side of the power line. They are also usually of poor fidelity, which is another good reason for not using them. If such a set must be used, insert a 1 to 1 ratio isolating transformer between it and the recording amplifier or use .05 μf condensers in series with *both sides* of the audio line.

Chapter 13

Record Playback and Duplication

THERE are many occasions when it is desirable or necessary to make copies of either original discs or commercial phonograph records. Often you will want to keep a copy of a particularly interesting recording made for someone else, or several persons will want copies of a cut. The opportunities for duplication of recordings are many, and no recordist who is interested in the work should be without duplication facilities.

There are 2 methods of *duplication.* The first is generally known as *re-recording* or *dubbing,* and the second is the factory pressing process.

Re-recording and Dubbing

Dubbing is a slang term which has come to mean the same as re-recording. It is a process of playing back the original disc with a

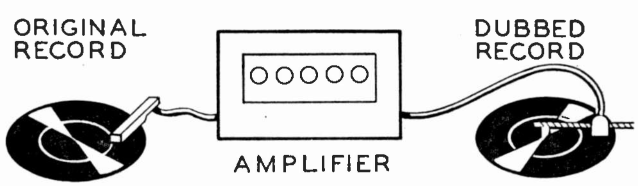


Fig. 1301—*Setup for dubbing or making a copy of a recording.*

standard phonograph pickup whose output is fed into the recording amplifier, and thence to the cutter. The cutter engraves a new recording which is (ideally) an exact copy of the original (Fig. 1301).

Offhand, the operation appears extremely simple and, as far as the actual physical manipulations are concerned, it is. But here again, we run into the problem of *audio quality.* In previous chapters we have shown how the amplifier-cutter combination has been equalized to make records of a standard characteristic when sound is fed into the system.

In dubbing and re-recording we must again perform an equalization process since the sound output of the pickup playing back the original record must be of the same quality and character, as the sound the microphone or radio tuner furnished for the original recording. In other words, the pickup characteristics must exactly complement those of the cutter to produce a resultant flat output to be applied to the amplifier. This brings us up squarely against the problem of record reproduction. Heretofore, we have concentrated on *making* the product; now we must play it back properly.

Since the entire system, from input to stylus, has already been equalized on the basis of a flat sound source, *the placement of any corrective equalization must be limited to that portion of the circuit which lies between the pickup and the amplifier input.* We cannot equalize at any point beyond the grid of the first amplifier tube without upsetting the adjustments already made. Moreover, the input used for the re-recording and playback pickup will be used probably for other pickups and for radio tuners; it would obviously be unwise to tamper with the amplifier itself.

Equalizing the Pickup

From the standpoint of calculating curves, pickup equalization is usually the simplest process involving frequency correction in the entire recording chain. For dubbing purposes, the object is to obtain from any record a flat output. For playback of records into a loudspeaker, it may be desirable, however, to adjust tone controls by ear to obtain the sound most pleasing to the listener. And pleasing sound, to the average listener, as some listening tests have shown, may not make a full-range frequency curve desirable. However, as stressed in the beginning of Chap. 11, when *producing* a disc, the full frequency range should be placed on the record, no matter what the source of the sound. When the disc is played back, the listener is free to adjust his tone controls; but if the full range is not recorded in the first place, the ultimate listener is restricted in his choice of playback response. Discs should represent, as nearly as possible, the original sound. Surface noise is not a consideration. Instantaneous discs introduce very little if any scratch; if, in re-recording a commercial phonograph record we try to eliminate noise, we will also eliminate a part of the range. The entire object, therefore, in equalizing a pickup is to obtain a disc *as nearly like the original* as possible in every respect.

For making copies of original discs made on our own system, the pickup should produce a flat output from those discs. To accomplish this, first make a frequency record. As described in Chap. 11, this is a process of recording a series of tones from an audio oscillator, keeping the oscillator output constant throughout. This disc will always be valuable for showing the system's characteristic, and it should be carefully preserved.

Now provide a means of measuring while playing this record the output of the pickup by connecting a vacuum-tube voltmeter across the grid of one of the tubes following the amplifier input tube. Select a stage where the voltage is sufficient to actuate the meter, and — this is most important — *a stage preceding which there is no equalization.*

Connect pickup to amplifier and play the record. Leave all gain controls alone, once set. Note the voltage registered on the meter for each frequency played. Then, following the instructions in Chap. 11, make a graph of the pickup response.

If the pickup used is a magnetic with a perfect (constant-velocity) frequency response, and if the recording system characteristic is the standard modified-constant-velocity with 500-cycle turnover, the graph will resemble curve A in Fig. 1302. The upper portion will be flat because the characteristic of the perfect magnetic pickup exactly complements that of the perfect magnetic cutter (with a flat amplifier). But in *modified*-constant-velocity recording, groove width remains constant be-

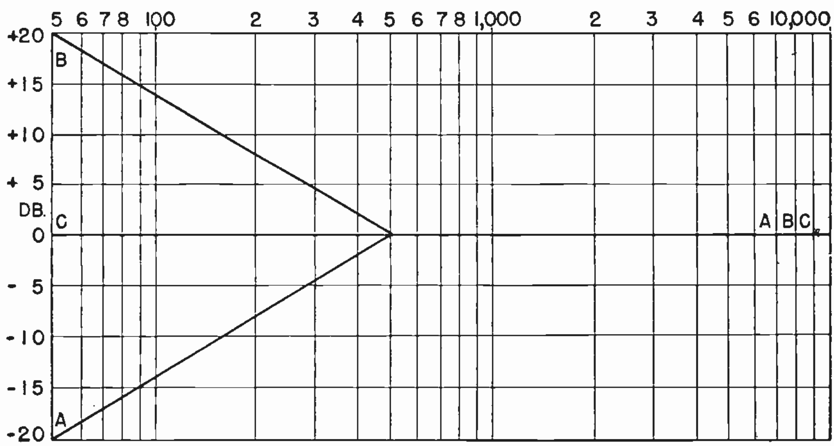


Fig. 1302—*Curve A, output of perfect magnetic pickup from perfect modified C-V disc. Curve B, required equalization. Curve C, output after insertion of proper low-boost equalizer.*

low the turnover frequency; the pickup would produce flat output only if groove width continued to increase with dropping frequency. Therefore, as shown in curve B, equalization equal to the drop will be required at the low-frequency end. With a low-boost equalizer inserted between pickup and amplifier, make new curves by replaying the disc. When the measured output is flat, as shown in curve C, the system is perfectly equalized.

In practical terms, almost no pickup is so perfect as to give a curve exactly like curve A in Fig. 1302, nor is any cutter so faultless as to produce a perfect modified-constant-velocity record. Neither is it possible to design an equalizer which would give precisely the correction shown. But, no matter what the output of the pickup from the test disc, a curve of it may be plotted. If a complementary curve is plotted showing the required equalization (like curve B in Fig. 1302), an equalizer can be chosen which, when properly adjusted, will give a reasonably flat output, regardless of the type pickup used or the curve of the cutting system. If the eventual pickup output is made flat within 2 or 3 decibels throughout the range, a very satisfactory re-recording system is obtained.

Dubbing of *commercial* phonograph records is a somewhat different matter. The curves used in making these records are not usually standard, although almost all U.S. makers use a 500-cycle turnover. Usually the high range is boosted, often not in a linear manner. If a frequency record could be obtained showing the curve used in these recordings, it would be a simple matter to adjust for flat output, just as was done above with our own test disc, but such records are not available. The best procedure is to use one of the available standard-frequency records, of the type recommended for use as a comparison in Chap. 11, and equalize the pickup for flat output from this. With these discs, incidentally, just about the same results as those shown in curve A of Fig. 1302 will be obtained, if the pickup is a very good magnetic. An adjustable high-frequency attenuator should be added in addition to whatever equalization is necessary for the original flat output. The phonograph records should then be adjusted by ear for the most natural sound, using a good loudspeaker system and a flat amplifier. *Do not try to eliminate surface noise.* Just adjust for the most *natural* sound of all the musical instruments. *Remember: while equalization of the pickup for phonograph records is a hit-or-miss proceeding, depending mostly on the ear, adjustment for playing one's own discs definitely is not.* Make the test record and the graphs. Just as with the recording amplifier and cutter, correction of the pickup is time-consuming and painstaking, but it is the only guarantee of good copies.

Choice of the pickup is very important. Only a few better grade magnetic units will have the ideal constant-velocity characteristic, and crystals will not have it at all. A good crystal will have a flat constant-amplitude characteristic. However, the type of characteristic is not nearly so important as the *frequency range* and the *linearity of response.* The dubbing pickup should have at least the same range as the cutting system, with very small peaks in the range. Most pickups — crystal and magnetic — have an upper and a lower resonance point, and additional ones are present, due to the arm. These peaks should be either outside the range to be reproduced or should be very small. The impracticality of equalizing out these peaks automatically precludes the use of cheap units.

There are a number of high-quality, reasonably priced (under $30) magnetic and crystal pickups or pickup cartridges available for nonprofessional use. Some of these are good enough for professional use. Most of them have permanent sapphire styli.

If a pickup without a permanent stylus is chosen, be sure to use only the best shadowgraphed steel needles, changing needles after each play. The surface of "acetate" discs is fairly soft and easily plowed up by improperly shaped or worn styli. Most separately sold "permanent" needles will not have the correct angle or the correct shape. Many of them will quickly ruin, not only instantaneous, but also shellac records. Any pickup used should also have low needle pressure on the disc. This can be determined with a postal scale. If it is realized that a pressure of 3 ounces on the minute area covered by the needle point is equal to *several tons per square inch,* its importance will be appreciated. Better pickups today exert pressure of only about 0.5 to 1 ounce, sometimes less. Do not counterweight a commercial pickup, however, to reduce pressure, since this will usually make it track improperly.

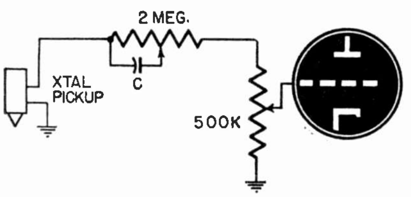


Fig. 1303—*Basic high-booster for crystal pickups.*

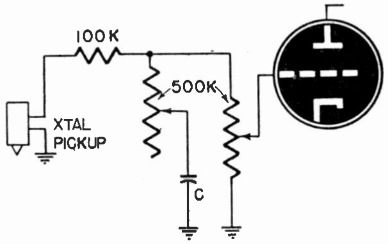


Fig. 1304—*Basic high-attenuator for crystal pickups.*

For reduction of angular tracking error (see Fig. 407, Chap. 4), a long pickup arm is best, but shorter ones with offset heads are acceptable. Short, straight arms often damage instantaneous discs to a slight extent and are likely to skid across the surface if the grooves are not deep enough.

Any equalizers must be placed between pickup and recording amplifier, *not* within the amplifier. Several equalizers for this purpose are shown here.

Since crystal pickups are constant-amplitude devices, they need high-frequency boost when playing standard discs. Fig. 1303 shows one standard method of boosting highs. The selection of value for C and the setting of the 2-megohm potentiometer determines the range and amount of boost. For sharper results, 2 such R-C combinations may be used in series.

For reduction of high-frequency response of crystal pickups, a condenser in series with a variable resistor may be shunted across the input tube grid, provided a series resistor is inserted between pickup and grid (see Fig. 1304). C is again a matter of choice through necessity. The series resistor is necessary to isolate pickup from equalizer and to keep the impedance across the pickup high, since low termination impedance will reduce output of lows. A crystal pickup is a capacitive device and a capacitor shunted directly across it would only reduce output without discriminating against any frequencies.

Fig. 1305 shows a low-frequency booster for magnetic pickups. R1 is the termination recommended by the manufacturer. R2, R3 and C are chosen by experiment. Output will be quite low with this circuit since it is actually a treble attenuator. Many circuits of this type are to be found in radio magazines and books, and experiment will be fruitful.

For the most reliable equalization, a small equalizing amplifier is recommended. One manufacturer recommends the one shown in Fig. 1306 for the variable-reluctance pickup cartridge, but it is valuable for any pickup. The tube is a 6SC7, and the required B-voltage of about 90 can be conveniently furnished by a 90-volt battery mounted within the playback turntable case, or by the main amplifier.

In this truly versatile unit, any standard R-C or L-C equalizers may be inserted in either the first plate circuit or the second grid circuit, without causing any undesirable reaction on input or output. If the gain of the preamplifier is not needed, a 0.5-megohm potentiometer may be connected from HI-output to ground and the desired output voltage tapped off. Or, if the main amplifier has a low-impedance input, the output may be taken off a tap the required resistance from ground. If the preamplifier gain is desired and the amplifier input is low-impedance, an ordinary plate-to-line transformer can be used. The input resistor R should equal whatever termination resistance the maker recommends for his pickup even if it is very low, though gain will be reduced in this case.

If desired, the amplifier may be constructed for use as a feedback equalizer such as that of Fig. 1113, Chap. 11. In this case, a 6SN7 may be used. It will have no gain except at the frequencies to be accentuated.

Dubbing Procedure

The actual procedure of dubbing is simple. Use a good turntable of correct speed — check with a stroboscope disc, *don't* estimate — and with no vibration. Start playback and recording tables, position the cutter over the beginning of the blank disc and lower it. Place the pickup needle in the first groove of the original, then open the gain control. The procedure from there on is the same as for any other recording.

The process described in the last paragraph is, according to purists, re-recording. The truer, original meaning of dubbing is the insertion within program material of matter recorded on another disc. For instance, during a dramatic performance which is being recorded through a microphone, phonograph records may be used, with the dubbing pickup, to furnish background and "bridge" music — an excellent reason for having mixing and monitoring facilities. Music can be faded in under the voices and then brought up to full volume to provide separation between scenes. Sound-effects libraries are available, which consist of records of almost every imaginable sound. During performances or dramatized talks, these sound-effect records can be played into the recording amplifier at the proper moment. They are often superior to effects created manually in the studio because of their very lifelike quality. Most of them were, in fact, recorded from life.

Often composite recordings can be made. One of the many uses to which dubbing can be put was demonstrated during a political campaign when an orator recorded a speech in which he referred often to the late President Roosevelt and several times quoted Roosevelt's words.

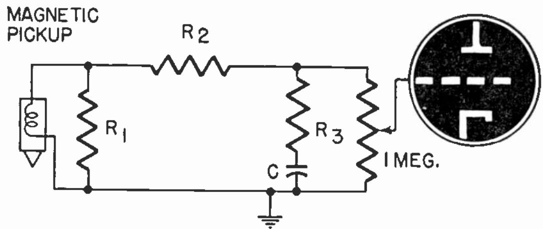


Fig. 1305—Bass booster for magnetic pickups.

But, instead of the orator repeating these words himself, he would say, "On July 14th, 1943, Franklin D. Roosevelt said . . ." and then a short excerpt from a record of Roosevelt's voice would be dubbed into the recording amplifier, after which the orator would continue.

Many interesting and — to the uninitiated — strange tricks can be done with dubbing. It is possible for a singer to sing all 4 parts of a barber-shop quartet. First make a record of the melody, and then a disc of the second tenor part, simultaneously dubbing in the record of the first part. Next, record the baritone part, dubbing in simultaneously the 2-voice disc just made; and finally record the bass while dubbing in the other 3 voices. Imagination and ingenuity will convert the dubbing pickup into a tool of many uses.

Pressing

If a substantial number of copies is to be made of a particular disc, the re-recording process is extremely tedious and time-consuming. In

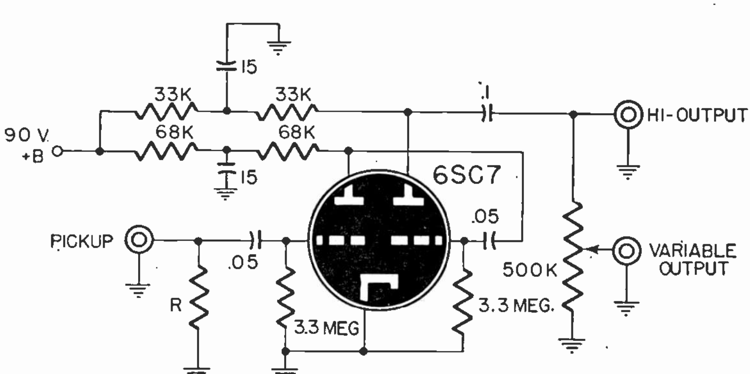


Fig. 1306—Typical unequalized preamplifier for low-level magnetic pickup.

addition, of course, the finished copies are not as permanent as a somewhat tougher material would be and they suffer from the inevitable loss of fidelity. Therefore, the pressing process is used. This is the method by which all commercial phonograph records are duplicated and turned out in mass production. The pressing is done in a factory, and the service is usually available to anyone. It is economical only when a large number of copies are to be made.

The original recording is made in the usual manner, although large producers of phonograph records frequently use wax blanks instead of instantaneous-type materials. The disc used, however, must be somewhat larger than usual, and the technical requirements for quality are strict. Table 13-1 gives the diameter of the blank discs used for finished pressings of given sizes. Maximum and minimum groove diameters are also shown.

Table 13-1 — Dimensions (in inches) of originals for processing.

Final disc size	Recording blank size	Groove diameters	
		Maximum	Minimum
10	11¼	9½	4½
12	13¼	11½	5
16	17¼	15½	6½

The cut must be the proper depth, shiny, and generally good, without any objectionable patterns (see next chapter). It is extremely important that no disc intended for processing be played back. Make sufficient test cuts to assure proper system adjustment, then depend on the monitor and the ear to tell whether the disc is satisfactory.

At the factory, the disc is clamped in a retainer ring (the reason for the extra diameter), and a microscopically thin, metal surface, is deposited over it. Next a heavy coating of copper is electroplated onto this surface. The whole is removed from the disc, and the part which contacted the original is a negative reproduction of the grooves. This copper negative is soldered to a heavy backing plate and becomes the initial master stamper. A thin coating of nickel is usually deposited on the grooved surface for additional strength.

The record material, which may be a shellac compound or vinyl acetate (known as *vinylite*), is prepared by heating, and the grooved face of the master is pressed into it. After cooling, the record is trimmed and labeled.

Selection of the record material is up to the recordist. Ordinary shellac is inexpensive, but rather coarse, containing an abrasive substance intended to grind steel needles to the shape of the groove, but in the process much surface noise is produced. Shellac is used for almost all phonograph records and is responsible for almost the entire scratch problem which has bothered the industry for years. It is quite hard, though brittle, and will take quite a beating.

Vinylite is much more expensive than shellac, but it is extremely smooth — almost as smooth as the original instantaneous disc coating. As a result, there is very little surface noise. Commercial record makers are just beginning to put out vinylite discs in limited quantities for public consumption. The rather surprising thing about the attendant advertising is that they are billed as unbreakable rather than scratchless. While it is perfectly true that breaking a vinylite record is a job for a tearer-in-half-of-telephone-books, the very much lowered surface noise would seem to be the important factor.

The comparative softness of vinylite discs is to some extent a disadvantage. A needle may be dropped on a shellac record without too much damage, if not dropped from too great a height; the same mishap with a vinylite will cause a deep furrow to be plowed up. Vinylites are also easily scratched in ordinary handling. For this reason, vinylite should not be chosen if the users will employ cheap heavy pickups and little care.

Some manufacturers make laminated pressings in which the actual playing surfaces are thin sheets of a high-grade material of better smoothness than ordinary shellac compounds. Between the playing surfaces is sandwiched a cheap paper filler. These discs can be reproduced excellently (with reasonable care) and often cost no more than standard shellac, because the expense of the good surfaces is offset by the cheapness of the filler material. Some British records are made with a very high grade of shellac with low surface noise.

Before making an original for pressing, it is advisable to consult with the company which will do the pressing and learn the detailed requirements. However, if a good re-recording system has been set up, any good record can be re-recorded onto a new oversize blank for pressing with only a small loss in fidelity.

The eccentric groove at the end of the pressings is placed in the master by the pressing firm and, if this is desired, no lock groove should be made in the original.

Chapter 14

Troubles in Recording

LIKE any other apparatus, recording systems develop difficulties and faults, and recordists run into snags. This chapter lists a number of common troubles of the system and suggested solutions.

The Stylus

SHARPNESS: If a stylus is sharp, the grooves will be shiny; if not, it will tear instead of engraving and polishing. If it is dull and if it is actually chipped, an audible hiss can usually be heard during cutting. Have styli resharpened frequently.

LENGTH: Styli which are too long or short for the system after it has been adjusted will cause variations in the angle which the cutting face makes with the disc surface. This angle should be just 90 degrees. Use only styli of the length used when adjustment was made.

SHANK: If the shank is too soft, as with steel styli, high frequencies will be attenuated due to stylus compliance. Stellite and sapphire styli are invariably mounted in sufficiently stiff shanks.

The Cutter

OVERLOADS: Distortion not present in the amplifier or sound source may be traced to cutter overload. Do not exceed the manufacturer-recommended applied voltage and/or power. Above this limit, cutter response is nonlinear, that is, an increase of level applied will not cause a corresponding increase of stylus movement. To make certain cutter is operating linearly, feed amplifier an oscillator tone which is varied in level in 2-db steps. Playback on a linear phonograph should show an output increasing in steps of the same amount. If increase becomes smaller as level reaches the maximum, cutter is being overloaded at the point where the increase begins to vary. Since surface noise is not an important factor with instantaneous discs, it is best to lean over backward in staying under the maximum allowable level to be fed the cutter.

If pre-emphasis of any frequencies is employed prior to the cutter, measure maximum level at the most pre-emphasized frequency.

CONNECTION: Feed magnetic cutters from a source of the same impedance at which the maker rates the cutter. Experiment with the connection of crystal cutters as suggested in Chap. 11. Mistakes in connection may cause distortion.

AVAILABLE DRIVING POWER: If distortion occurs on peaks, it may be caused by an amplifier with insufficient power to supply the peaks without excessive distortion. Use an amplifier capable of supplying 3 times the normally required power, at 2% or less harmonic distortion. If amplifier is too small, reduce output and cut at lower average level.

The Feed Mechanism

GROOVE SPACING: A pattern somewhat like Fig. 1401-a indicates that the lead screw is not spacing the grooves accurately. The screw may

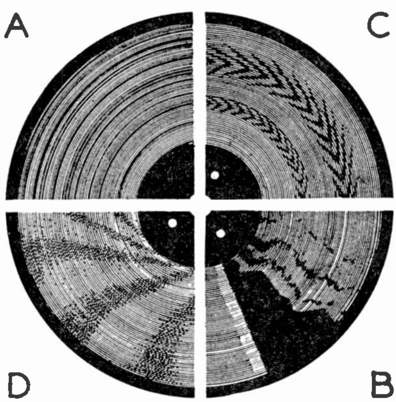


Fig. 1401—*Four common types of faulty disc pattern, each caused by some specific recording defect described in text: a—Improper groove spacing; b—Recording on a warped disc; c, d—Hum or turntable rumble.*

be worn so that some of the threads are chipped off or the threads may be fouled with chip or dust and dirt. They may be insufficiently lubricated. The guide trolley may be too dry to allow the cutter mount to travel freely; causing the mount to rise and take the half-nut out of the screw threads. The half-nut may not be solidly in the threads; there is often an adjustment for this.

The Disc

SURFACE BRIGHTNESS: A well-cut disc will appear shiny under a single light source. If it is not, probably the stylus is bad. Or it may be that the disc coating has dried out from age, or, with off-brand discs, the coating may be inferior to begin with. Dullness will mean surface noise in playback.

WARPING: Discs which are warped before cutting will cause the stylus to jump up, causing a pattern like that of Fig. 1401-b. It is usually impossible to flatten warped records, and they should be discarded. This is actually good economy, since a jumping stylus will come down too hard and will eventually, if not immediately, become a broken stylus. Good styli, as you will discover, are much more expensive than good discs!

CUTTING DEPTH: If cutter weight is too great, the stylus will cut too deep. If stylus hits base material, it will be chipped. Even if it is not, groove width may become so great that the stylus will cut into adjacent grooves on high-level passages. If depth of cut is too small, playback pickups will not track, but will jump out of the groove and skid. Chips should be about the texture of a very coarse human hair and should come out in one piece, not crumbled.

The Turntable

SPEED: Speed should always be measured while a cut is being made. On rimdrive tables, a small adjustment of idler pressure will often correct small speed discrepancies. If the speed is uneven, the motor may be too small or the idlers may be flatted. Chip may also tangle in either the drive mechanism or the motor and cause binding. If the overhead lathe does not exactly fit the table, it can cause speed variation. Bearings may also be fouled with chip. Lubrication of the entire mechanical system may be insufficient. Warped or unevenly coated discs can cause wows.

VIBRATION: Turntable rumble will record a hum on all discs cut with it present. This will cause an optical pattern which resembles Fig. 1401-c or d. (This pattern is also caused by amplifier hum.) Try isolating the motor from the case and mounting with shock mounts or putting the screws through live-rubber grommets. See that the case is solid, with no loose wooden parts. Often rumble can be minimized by fastening the motor and table very tightly to the case. This problem is prevalent with the less expensive motors; but even with the best ones, the shock mounts supplied may be dried out, in which case they should be replaced. Be sure that the assembly is gravitationally centered. Flatted idlers are a cause of rumble, as are uneven or worn drive shafts and bearings. The motor armature may not be properly centered. Idler pressure against turntable may be too great.

The Amplifier

HUM: See that filament leads are twisted and kept as far as possible from audio leads, especially in early stages. Mount power transformers as far from low-level, a.f. stages as possible, and orient for least hum before screwing to chassis. Orient interstage and input transformers also. See that filter condensers are of high quality and in good condition. The entire power supply filter must be very effective. If system is in 2 or more parts, see that all chassis, motor frames, cabinets, etc., are bonded together and grounded with very heavy wire or shield braiding. While an actual ground may not be necessary, bonding definitely is. However, grounding is good for draining static charges, especially on the disc. See that high-impedance input leads are shielded and the shield securely grounded to the system. Do not overdo the shielding within the amplifier, as this will reduce high-frequency response. Check for bad potentiometers whose arms do not make positive contact with the resistance strip.

RANDOM NOISE: This can be caused by excessive gain making audible the tube hiss caused by shot effect. Loose connections or cold solder jobs are a prime cause. Check all plugs and terminals. Bad interstage blocking condensers and plate load resistors are often guilty. If nothing else works, prod the wiring gently with the insulated handle of a screwdriver until the noise is localized. See that all components are rigidly mounted. Small resistors and condensers can be mounted by their leads if the leads are not too long, but never wire 2 of them in series and support them by 1 lead of each. Make generous use of small tie lugs, brackets, and mounting strips. If all else fails, remove all ground connections from the chassis and run a heavy bus bar through the amplifier, tying all grounds to it. Grounds for each stage should be very close to the same point. Check microphones, pickups, and tuners to see that they are noiseless.

MICROPHONICS: If sound is heard when a tube is lightly tapped, the tube must be shock-mounted. (Occasionally a particular tube may be microphonic because of a manufacturing defect. Replace it.) Fasten the socket to the chassis through 2 rubber grommets. Pentodes are more susceptible to microphonics than triodes, as well as being more subject to hum and shot effect. However, non-microphonic pentodes, such as the 6SJ7-Y, are often available. 6J7's are less noisy and cause less hum than 6SJ7's.

HIGH-FREQUENCY DROPOFF: High-impedance circuits are most susceptible, especially plate circuits of pentodes and all grid circuits. Keep wiring of these parts away from chassis and as far as possible from each other. Use no more shielded wire in the amplifier than the minimum which will eliminate hum. Use high-quality transformers correctly connected. Check to see that no shielded leads longer than about 15 feet are run to the amplifier from microphones, pickups, and tuners which have high-impedance output. If longer lines must be run, use low-impedance devices and line-to-grid input transformers. Do not try to correct by using equalizers except as a very last resort.

LOW-FREQUENCY DROPOFF: Use large interstage blocking condensers — 0.1 μf being about right for any stage. See that interstage and output transformers are not carrying any more d.c. than ratings allow. Where possible, it is desirable to use transformers rated at zero d.c., with shunt-fed plate circuits. See that cathode bypass condensers are large and in good shape. Where the cathode resistor is 2,500 ohms or more, 25 μf should be used; larger capacitance where the cathode resistance is smaller. To be exact, condenser's reactance (X_c) should always be 0.1 R or less at the lowest desired frequency.

Positive feedback: If the amplifier develops oscillations, it is probable that some stage is feeding back to another stage in phase. Be sure that inputs and outputs are well separated. Capacitance between input and output leads will decrease to below the danger point if this precaution is taken. Use decoupling filters on at least every other stage to prevent low-frequency motorboating oscillation.

Negative feedback: Negative or inverse feedback is used to increase range and reduce distortion. Be sure the feedback components do not introduce frequency discrimination. Unintentional inverse feedback may occur when the output of one stage is fed back to the input of an earlier stage through capacitance between closely spaced wires. Since the feedback is capacitive, it will increase with increasing frequency and the highs will feed back most, causing an over-all reduction of high response. Whether this unintentional capacitive coupling will cause high-frequency reduction or oscillation depends entirely on whether it is in or out of phase; in other words, on which stage feeds back to which stage. However, since unintentional coupling is undesirable in any case, eliminate it by isolating leads as far as possible. Don't try to cram a big amplifier into a small space. Recording systems are not ideal pocket-size gadgets!

General

Chip: The chip must not be allowed to entangle with the stylus. Use a hand brush and plenty of personal attention, or an automatic brush such as that shown in Fig. 409, Chap. 4. If it does tangle, extricate it with the utmost care. If the stylus jumps over the chip, the disc will be damaged.

Playback: Use only the lightweight pickups and the best shadowgraphed steel or built-in permanent needles to play records back. Frequency-response faults may be corrected by the methods presented in Chap. 13.

Storage: Store discs on edge in a press. Keeping them on a shelf beside or between a number of other discs, all fairly tightly packed is ideal for prevention of warping. Keep away from excessive heat. Store in record envelopes, as dust is the cause of much noise in playback. If discs become too dusty, wash in almost cold water (no soap) and dry either with a lintless silk cloth or leave exposed in a dustless room. If water is hard, it is better to dry the disc with a lintless cloth.

Glossary

acetate: Term erroneously used to designate instantaneous discs.
automatic equalizer: Device which automatically compensates for loss in high-frequency response due to diminishing groove diameter as cutter moves inward.
blank: The disc before it is cut.
center pin: Pin at center of turntable which passes through center hole of disc.
center post: The end support of lathe mechanisms which is placed over the center pin.
chip: The thread of disc coating material which is dug out by the stylus.
christmas tree pattern: See **light pattern.**
constant amplitude: Method of recording in which groove width is the same at all frequencies with constant cutter voltage.
constant velocity: Method of recording where groove width decreases with rising frequency with constant cutter voltage.
crossover frequency: See **turnover frequency.**
cut: (*Verb*) To make a recording. (*Noun*) A recording.
cutter: Device which converts electrical (audio) energy to movement of stylus; counterpart of the phono pickup used for playback.
cutting angle: Vertical angle *cutting face* of stylus makes with disc surface on forward side. Should normally be exactly 90 degrees, but may be very slightly less, never more.
cutting head: See **cutter.**
depth of cut: Distance of vertical penetration of stylus into disc coating material, governed by weight applied to cutter. This determines also the lateral dimension of the groove, and the amount of land between grooves.
dubbing: Duplication of all or part of material on one disc, by playing it through pickup and amplifier into cutter and recording on a new disc. See Fig. 1301. See also **re-recording.**
dummy load: A resistor which temporarily replaces a reactive load, such as a loudspeaker or cutter, and is of the same impedance. Used for measurement purposes to avoid changes in meter readings due to varying reactance of normal load.
equalization: Deliberate alteration of frequency response for some specific purpose.
feed mechanism: Mechanical assembly which carries cutter across disc during recording. Term means entire unit, including guide rods, feed screw, center and outside posts, etc.
feed screw: Threaded rod of feed mechanism which revolves in synchronism with turntable and pushes cutter across disc during recording.
fidelity: *Likeness* between original and reproduced sounds. Not to be confused with *quality*, which denotes pleasing tone of reproduced sound, but may or may not be an accurate likeness of the original.
governor: Device which regulates the speed of nonsynchronous motors.
groove: The spiral track cut into the disc coating material, path of which is varied in accordance with modulation.
groove width: The amount of lateral variation in the path of the groove caused by modulation.
idler: Rubber-rimmed wheel used in rim-driven turntables to transmit motor shaft movement to turntable.
instantaneous recording: Record which may be played back immediately after it is cut, without further processing.
land: Band of uncut record surface between adjacent grooves. See Fig. 703.
lateral recording: Recording method in which modulation causes variations in the *lateral* path of the groove. See **groove width.**

lathe: Overhead-type feed mechanism as distinguished from a swinging-arm type mechanism.

lead screw: See **feed screw.**

light pattern: See Fig. 1103, in Chapter 11 and accompanying text.

lock groove: Groove at end of cut designed to prevent pickup from flying off. The lock groove is a perfect circle rather than a spiral. See Fig. 1206.

modified constant velocity: Most used recording method. Constant amplitude is employed up to a selected turnover frequency and constant velocity above that frequency.

monitor amplifier: Amplifier and associated loudspeaker used to listen to material being recorded, as distinguished from recording amplifier which feeds cutter only.

pattern: Visible results, on finished discs, because of improper adjustments of the recording system or inferior components. See Figs. 1103 and 1401.

pinch effect: Narrowing of portions of grooves at small cutting diameters near center of disc, which reduces high-frequency response and increases distortion in playback. Important only in 33 1/3-r.p.m. recording. See Fig. 1109.

pitch: *(General)* Frequency of sound. *(Recording)* Number of grooves cut per inch.

pre-emphasis: Progressive boosting of frequencies at one end of range (usually high end) during recording. A form of equalization.

pressing: Method of duplicating records in large quantity; a manufacturing process. Term also used to refer to a record made by the pressing process.

re-recording: Duplication of an entire disc by playing it into recording amplifier and recording on a new disc. See **dubbing.**

rolloff: Progressive attenuation of frequencies at one end of range. The reverse of pre-emphasis.

rumble: Low-frequency noise heard in record playback, caused by motor vibration in cutting or playback turntable.

sapphire: Very hard and smooth precious (or synthetic) stone used as tip material in best (and most expensive) styli.

shellac: Gritty, brittle material of which most phonograph records are made.

spiral: *(Noun)* Path of grooves during recording. *(Verb)* Process of separating different selections on same disc by momentarily greatly decreasing the cutting pitch.

stellite: A metallic alloy used as tip material in medium-priced styli.

stroboscope disc: Disc printed with radial lines, used in checking turntable speed.

stylus: Cutting tool.

synchronous motor: One whose speed is governed by power-line frequency.

thread: See **chip.**

tone control: Equalizer device used in phonographs to allow listener to attenuate or boost low or high frequencies.

tracking error: Failure of the stylus cutting face surface to coincide with a disc radius drawn through the stylus. Error exists when face cuts radius at an angle. Occurs with swinging arm feed mechanisms.

transition frequency: See **turnover frequency.**

turnover frequency: Frequency at which constant amplitude changes to constant velocity response in modified constant velocity records. Usually between 250 and 1,000 cycles.

vertical recording: Recording method wherein modulation varies groove depths.

vinylite: Smooth, flexible material of which certain pressings are made.

volume indicator: Meter, neon light, or "magic eye" tube which visually indicates maximum allowable cutting level.

wow: Wavering of musical tones caused by variations in turntable speed in recording or playback.