Evolution of a Recording Curve

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A discussion of the reasons for the existence of "recording curves" and a presentation of the official specifications for the "New Orthophonic" curve currently used for RCA Victor records and well on the way to universal adoption by all record manufacturers.

The primary function of any home phonograph record is to provide entertainment for the consumer. That this entertainment may be provided in its best possible form has been one of the prime objectives of every record manufacturer since the start of the business at the turn of the century. The degree of success attained in this direction is judged largely by the sound of the finished record as reproduced on a typical or standard reproducer. The quality and balance of this sound is determined by the characteristics of the reproducer, the recording system, and to a very large extent, microphone placement, orchestra seating, and studio acoustics. Thus there are in effect three areas, any one or all of which may be made variable, to change the sound heard by the listener. It is the first two of these three areas, namely the over-all reproducing and recording characteristics, with which we are primarily interested.

During the period from approximately 1900 to 1925 when acoustical recording was used, both of these areas were relatively fixed; that is, balance, separation, etc., were being accomplished as well as possible by placement of the artists in relation to the horn of the recorder. With the advent of electrical recording equipment, great flexibility which had hitherto been impossible was provided for the recording director in making records. Flexibility in reproducing records was also provided with the introduction of the electric phonograph with tone and volume controls.

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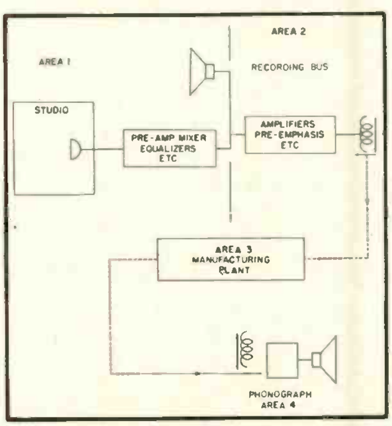

Fig. 1. The actual disc recording characteristic is defined as the characteristic of Area 2 alone. It includes the fixed high- and low-frequency pre-emphasis and crossover curve. All variable components are grouped in Area 1 and are used to obtain desired musical effects.

> **Hints for playing RCA VICTOR records**
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> Use of the "New Orthophonic" curve is recommended for all RCA Victor records and records released by RCA Victor since August, 1952. With a few exceptions in the early 6000, 7000, and 9000 series, this applies to all LM, WDM, and DM records or albums above 1701, and LCT and WCT above 1112. It also includes all LHMV, WHMV, LBC, WBC, and Extended Play 45's. Records issued prior to that date should be played with the same crossover and high-frequency characteristic, but without the roll-off at low frequencies. A 4- to 5-db increase in response at 50 cps, usually obtainable with a low-frequency tone control, is suggested for these records.

Although the improvements in general quality and frequency range obtained with the new equipment were outstanding, this added flexibility led to a period of confusion for the disc manufacturer, the phonograph manufacturer, and the consumer. The difficulty was that the record companies tried to make discs sound right on what they considered the best phonographs of the day, while the phonograph manufacturers were bringing out new models which, in their opinions, sounded best with all types of records. Whether or not this was a healthy condition is questionable. However, eventually a certain degree of standardization resulted largely because all companies had a common objective, namely, to bring the customer the best possible sound from the available reproducers.

The recent increasing interest of the audio engineer and owners of wide-range phonographs in the subject of disc recording and reproducing characteristics, and the many conflicting opinions now prevalent on the subject make it desirable that the past and present practices of one of the oldest record manufacturers be presented. Traditionally, the exact recording characteristic in use has been a closely guarded secret of each company; just as in the early days of disc recording a particular sound box was often the personal property and secret of success of a recording technician. While these ideas of the past have been changed materially through the efforts of RTMA, AES, and the record companies themselves, there still exists in the mind of the public considerable confusion on the subject.

Definitions

Much of the past confusion in the record and phonograph industry has risen from the lack of satisfactory and generally accepted definitions of expressions commonly used by the recording engineer; and still complicating the problem (both nationally and internationally) is the difficulty in making absolute measurements.

If a recording-reproducing system is divided into sections according to function, four general areas will result as shown in *Fig.* 1. Area 1 includes the studio, microphones, orchestra seating, mixers, variable equalizers, and amplifiers feeding the recording bus and monitor speaker. Area 2 contains tape or disc recorders and their associated amplifiers which produce certain magnetization *vs.* frequency characteristics on tape or velocity *vs.* frequency characteristics on disc with constant voltage input applied to the recording bus. Area 3, the manufacturing operation, may be disregarded in this discussion—its function, of course, is to provide finished records which duplicate the quality and frequency range recorded on the original lacquer master. Area 4 includes the finished record and the reproducer.

The fidelity of a recording is often judged in terms of the naturalness of the reproduced sound and the degree that it recreates the sound heard in the studio or the concert hall. The objective in modern phonograph recording is not always in that direction, however. Special acoustic effects, changes in normal balance among instruments and soloists, and in some cases—especially in "pop"

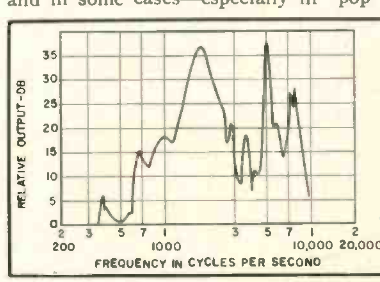


Fig. 2. Relative frequency response of an early Victor acoustic phonograph based on an ideal frequency record with 500 cps crossover.

recordings—unusual electronic sound effects are often used as devices to create a particular over-all effect desired by the conductor, artist, or musical director. In these cases, all of the variable items included in Area 1 are used as tools to obtain the desired result on the monitor speaker. The criterion, then, for judging recording fidelity is the degree that the reproduced sound matches the sound heard in the monitor speaker at the recording session rather than the sound that was heard in the studio itself.

From the foregoing discussion it can be seen that two definite advantages result from a grouping of recording components as shown in *Fig.* 1. First, all variable effects of studio, mixers, equalizers, etc. may be evaluated at the monitoring point and adjusted at will to obtain the desired sound. Secondly, the disc recorder and reproducer, although physically separated, may be considered as a unit whose sole function is to bring the same sound heard in the monitor speaker into the home of the listener through the medium of the record.

Unfortunately, the situation has not always been that simple and straightforward. In many early recording installations fixed and variable components were, of necessity, often intermixed throughout the system. An example of this in the early Victor electrical recording systems may serve to illustrate the point. Condenser microphones used at that time are known to have a sharply rising response characteristic at high frequencies. The point has never been completely resolved, but presumably due to speaker deficiencies, the high-frequency balance was satisfactory with these microphones. Later when ribbon-type velocity microphones replaced the condenser types, high-frequency pre-emphasis was added to in the preamplifier to preserve the former balance. Finally, when wide-range monitor speakers were installed, the pre-emphasis was removed from the preamplifiers and placed after the recording bus. Thus, at different times we have had the same fixed pre-emphasis in three different parts of the channel: in the microphone itself; after the microphone, but ahead of the monitor speaker; and finally after the monitor speaker. In each case it contributed the same effect to the over-all characteristic on the record. In other words, it was always part of the effective recording characteristic.

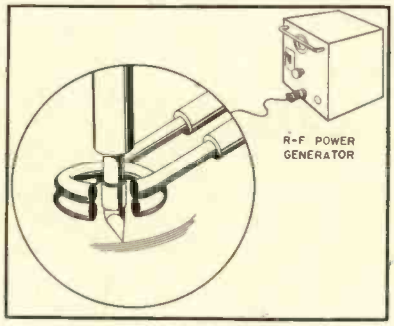


Fig. 5. R.f. induction heating applied to sapphire recording stylus. A small iron band slipped over the sapphire supplies the heat to the cutting tip by conduction.

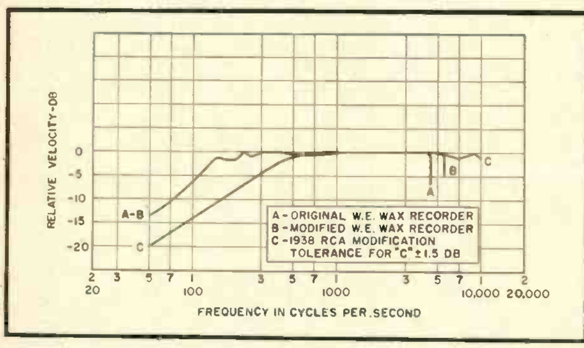
Recording Curve

In discussing a recording curve it is important to keep in mind the elements which are combined to form any conventional disc recording characteristic. First, we have the electromagnetic cutter response which ideally produces a constant-amplitude cut at low frequencies, changing gradually to a constant-velocity cut (decreasing amplitude) at high frequencies. The primary reason for maintaining constant-amplitude recording at low frequencies is to limit the modulation amplitudes (lateral groove excursions) to some practical value which can be successfully recorded and reproduced. The crossover (the transition point between constant-amplitude and constant-velocity recording) is defined as the intersection of the asymptotes to the two straight-line portions of this curve. Secondly, we have the high-frequency pre-emphasis and in some cases a moderate low-frequency pre-emphasis which are both added electrically in the recording amplifier. High-frequency pre-emphasis in recording is added in order to obtain a reduction of record noise by using a corresponding high-frequency attenuation in the reproducer. This pre-emphasis in recording is possible because the high frequencies in actual music and speech are attenuated with respect to the lower frequencies. Low-frequency pre-emphasis in recording, also possible because of actual attenuation of very low frequencies in music, permits the use of a corresponding low-frequency attenuation in the reproducer, thereby reducing hum and rumble.

When these two or three curves are added together the resulting curve gives what was generally considered to be the recording characteristic. This was true for all practical purposes when recording on wax discs, but is not necessarily true at high frequencies for lacquer discs due to recording losses which will be discussed later. It is largely due to the existence of these recording losses that the term "recording characteristic" is now defined as the actual velocity *vs.* frequency characteristic recorded on a disc with constant voltage input applied to the recording bus. Specifically, it is the over-all characteristic of Area 2 in *Fig.* 1 which involves the response-frequency characteristic of the recording amplifier after the bus, any fixed recording equalizers, the recorder itself, and the cutting properties of the stylus and disc material.

It is important to realize that for any given recording, the type of music, variations in microphone placement, studio acoustics, and recording equalizers will affect the actual velocity-frequency characteristic recorded on the final disc. However, if the consumer desires to reproduce the sound as originally heard from the monitor speaker, the recording characteristic and the reproducing characteristic must remain fixed and complementary.

One might conclude then that, provided they are matched, these characteristics in themselves are unimportant, serving only as a means to an end. This, in fact, would be true, were it not for the mechanical limitations of disc recording and reproducing and the question of record and system noise. These then become the real contributing factors in selecting a specific recording characteristic. Gradually as techniques and equipment have improved, the range of recorded and reproduced frequencies has been increased, making certain changes in the basic recording characteristic desirable for best over-all results.



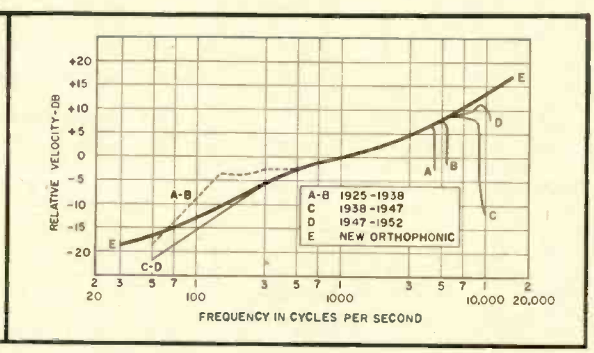


Fig. 3 (left). Relative frequency response of Western Electric "Wax Recorder" in original form and as modified by Western Electric and later by RCA Victor. Fig. 4 (right). Recording characteristics used on Victor records from 1925 to present. Dashed part of Curves A and B represent cutter characteristic. Filters were generally used to remove bass when using these cutters.

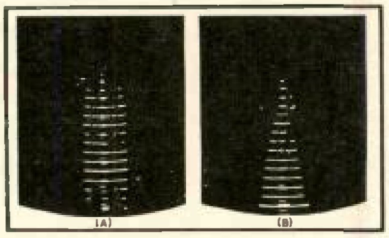


Fig. 6. The recording loss at 10,000 cps across a 12-in. LP record using a burnishing-type stylus is illustrated in (A). Use of a heated wax-type stylus eliminates this loss as shown by the light pattern in (B). The outer and inner bands are 1,000 cps tones recorded for reference purposes.

Early Victor Characteristics

As previously stated, with early mechanical recording techniques, playing the record on a phonograph offered the only satisfactory method of judging record quality, since monitoring at the recording session was impossible. Continuous experimentation with sound boxes, horns, recording and reproducing styli, etc. resulted in gradual improvements in clarity of tone and increased volume. In each case, however, the result of a change in equipment or in studio setup was evaluated in terms of playback results; the objective, of course, being to provide the consumer with the best possible sound.

Specific information concerning the characteristics of the various acoustical recorders used for the early Victor recordings is limited. Recent measurements of the frequency response of an early Victor acoustic phonograph shown in *Fig.* 2 give some idea of the over-all results obtained in those days. Actually the recorded range was somewhat greater than indicated by these reproducer curves. On December 29, 1924 the last Victor acoustic recordings were made, and on May 5, 1925 the first recording session with electrical recording equipment was held.

The electromagnetic recorder used was developed by Bell Telephone Laboratories. It is usually referred to as the "wax recorder" or "rubber-line recorder." It had a cross-over frequency of about 200 cps and a high-frequency cut-off of about 4,500 cps, as shown in *Fig.* 3, Curve A. Subsequent modifications by Bell Telephone Laboratories resulted in an extension of the high-frequency range to about 5,500 cps as shown in Curve B. During the early and middle '30's further development by RCA Victor engineers resulted in an extension of the high-frequency range to 10,000 cps or better and a smoothing out of the low-frequency range as shown in Curve C. The fact that intermodulation distortion at full 78-r.p.m. level is in the order of 2 to 3 per cent gives ample proof of the excellent design and performance of these recorders.

The over-all recording characteristic using the wax recorder and condenser microphone are shown in *Fig.* 4, Curves A and B. The actual effective low end of these curves is subject to some question, however, since it was common practice to use a rather elaborate "bass filter" to reduce the low-frequency response in order to obtain the best sound on average reproducers.

The change from condenser microphones to ribbon-type velocity microphones and new preamplifiers with high-frequency pre-emphasis built in was accomplished during 1932. The resulting over-all curve remained essentially unchanged.

In 1938 the improved RCA version of the wax recorder and completely new and improved recording channels were placed in operation. At that time the adjustable bass filter was discarded, pre-emphasis was removed from the preamplifier and added after the recording bus, and an 8,500-cps low-pass filter was added primarily to reduce noise and

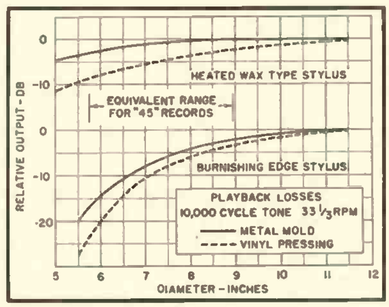


Fig. 7. At the lower recorded velocities, playback from the metal mold and light pattern measurements are in good agreement. At 5.5-cm/sec. level obtained with the heated stylus, playback output falls slightly below the indicated velocity due to curvature limitations toward the inside of the disc. Playback losses due to deformation of the record material exist in either case and are overcome by diameter equalization when recording music or speech.

distortion effects resulting from playback turntable flutter, pickup tracking, and manufacturing methods. The recording characteristic then became that of Curve C, *Fig.* 4. With the introduction of improved reproducers and manufacturing techniques after the war, the 8,500-cps filter was removed from the channel, resulting in Curve D. Finally, after the installation of feedback recorders with further improved high-frequency response, the "New Orthophonic" characteristic has been adopted. Examination of the curves of *Fig.* 4 will show that—except for the questionable low-frequency portion used in the early days of electrical recording—characteristic changes introduced throughout the years has been essentially extensions of range, the general curve throughout the middle range of frequencies being held constant. Furthermore, it may be assumed that the early electrical recordings (Curves A and B) also had approximately a 500-cps crossover point, since the change to the new equipment in 1938 was accomplished with no loss of bass on the finished records. Recent studio experience in rerecording many of these older records for the Collectors and Treasury series reissues has shown that a 500-cps crossover frequency represents about the best average characteristic for satisfactory reproduction of these records.

Hot-Stylus Recording

With the introduction of lacquer recordings for instantaneous playbacks and rerecording purposes, it became apparent that high-frequency recording losses existed which were not present when recording on wax. These losses are due largely to the elastic properties of lacquer recording materials and to the burnishing edges of lacquer recording styli which are required to obtain quiet cuts. Once again modifications were made to the wax recorder which largely overcame these recording losses on lacquer at 78 r.p.m. However, at the lower groove velocities encountered in 33-1/3 r.p.m. recordings it was found that the desired high-frequnecy equalization could be maintained on the disc

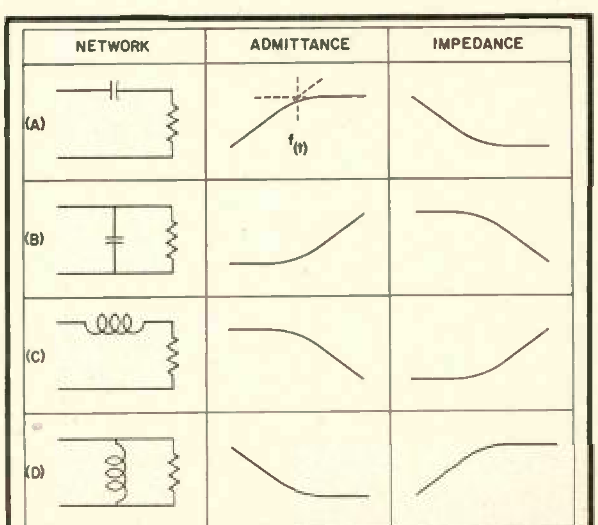


Fig. 8. Impedance or admittance either rise or fall at the rate of 6 db per octave. The asymptotes to the two straight-line portions of these curves intersect at a frequency $f_{(t)}$, often referred to as the turnover or crossover frequency. The exact frequency is determined by the time constant of the network.

only with additional electrical high-frequency pre-emphasis in the recording channel. The amount of additional pre-emphasis varied with styli and, of course, increased considerably with decreasing groove velocity. Since the recording amplifiers were capable of more than adequate power, no harmful distortion effects could be detected from the use of what appeared to be more than normal pre-emphasis at high frequencies. Due to the recording losses, this pre-emphasis did not appear on the disc.

During 1950 recording on lacquer with an electronically heated wax-type stylus was introduced. R.f. induction heating is used as shown in *Fig.* 5 where the work coil, sapphire stylus, and thin surrounding band are illustrated. One of the outstanding advantages of the heated wax-type stylus over the burnishing-type stylus is that high-frequency recording losses when cutting lacquer at low groove velocities are completely eliminated as can be seen from the light pattern photographs in *Fig.* 6. The upper part of this figure shows a heated stylus recording of a 10,000-cps tone recorded in bands across the entire playing surface of a typical twelve inch 33-1/3 r.p.m. LP record. The photograph in the lower part shows a similar recording made with a cold burnishing-type stylus. It can readily be seen that the width of the reflected light bands remains constant in the first case, while in the second photograph the width decreases toward the center of the record, indicating recording losses at the lower groove velocities.

Playback losses, of course, still exist and are compensated for by the addition of sufficient diameter equalization in recording to maintain constant high-frequency response across the playing surface of the record. These playback losses are a function of pickup construction, stylus size, and record material. The output voltages obtained from a modern high-quality pickup when playing the metal mold (sometimes called "mother") and vinyl pressing are shown in *Fig.* 7. The equivalent groove velocities and losses for 45 r.p.m. records are also indicated in this figure. It can readily be seen that the playback loss obtained from the rigid metal record is negligible, whereas the loss due to compound deformation amounts to some 5 or 6 db from the outside to the inside of the record.

Among the other advantages of heated stylus recording are:

1. Elimination of horns at the top edges of the grooves which are characteristic of recordings made with burnishing-edge styli. This improvement makes possible the use of slightly higher recording levels without damage to adjacent grooves and also results in finished pressings somewhat less susceptible to scuffing.
2. Reduced cutting noise, especially at the low groove velocities encountered toward the inside of fine-groove recordings. This reduction in cutting noise, of course, results in reduced surface noise on the final product.

TABLE I

Relative Velocity vs. Frequency "New Orthophonic" Curve

fcps	Vdb	fcps	Vdb
15000	+17.2	3000	+ 4.8
14000	+16.6	2000	+ 2.6
13000	+16.0	1000	± 0.0
12000	+15.3		
11000	+14.5	700	− 1.2
10000	+13.7	400	− 3.8
9000	+12.9	300	− 5.5
8000	+11.9	200	− 8.2
7000	+10.8	100	−13.1
6000	+ 9.6	70	−15.3
5000	+ 8.2	50	−17.0
4000	+ 6.6	30	−18.6

New Orthophonic Characteristic

It has been customary to refer to recording curves in terms of crossover frequency and amount of pre-emphasis at 10,000 cps relative to 1,000 cps. Unfortunately, these two factors alone do not adequately define a recording characteristic. When more information about a curve is required, a graph showing relative velocity *vs.* frequency is usually supplied. The obvious difficulty with a curve alone is that the true crossover frequency and pre-emphasis are usually obscured, making the design of suitable equalizers possible only by the cut and try method. To overcome these difficulties, recording curves now are often defined as conforming to the impedance or admittance of one or more electrical networks.

The impedance or admittance curves of simple two-element networks consisting of a resistor and capacitor or a resistor and inductor are all similar in shape when plotted with frequency on a logarithmic scale and impedance or admittance in decibels on a linear scale. These curves approach a 6-db-per-octave slope at one end and a limiting or fixed value at the other end, as shown in *Fig.* 8. The transition frequency or point of intersection of the two asymptotes to the curve is determined by the time constant of the circuit as follows:

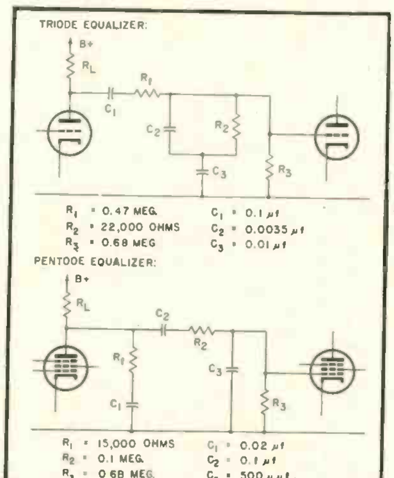


Fig. 9. When using magnetic pickups, simple RC equalizer circuits may be incorporated in a voltage amplifier stage to obtain the "New Orthophonic" characteristic. Additional adjustment of high- and low-frequency tone controls should be made to correct for pickup and tone arm characteristics.

$$f_{(T)} = \frac{1}{2\pi T};\ T = RC \text{ or } LR$$

Where f_T = Transition frequency in cps
T = Time constant in microseconds
R = Resistance in ohms
C = Capacitance in microfarads
L = Inductance in microhenries

At the frequency f_T the magnitude of the reactance of the capacitor or inductor is equal to the magnitude of the resistor. Also at this frequency the absolute value of the impedance or admittance is either 0.707 or 1.414 times its constant-impedance value, i.e. 3 db above or below the "flat" portion of the curve.

These curves have a general shape that fits the requirements of disc recording and reproducing characteristics. They are also curves that are easily obtained in amplifier designs either separately or in combination. It follows then that impedance or admittance curves provide an ideal method of expressing or defining a recording or reproducing characteristic.

To illustrate their use, three specific examples are cited here. These examples when combined form the "New Orthophonic" recording characteristic.

The expression "75-microsecond pre-emphasis" indicates that high frequencies are pre-emphasized according to a curve which conforms to the admittance of a parallel resistor and capacitor network, (B) of *Fig.* 8, with a time constant of 75 microseconds. The curve is +3 db at 2,120 cps and +13.7 db at 10,000 cps relative to low frequencies.

An ideal cutter characteristic as defined earlier may be represented by a curve which conforms to the admittance of a series RC network, (A) of *Fig.* 8, where the time constant defines the crossover frequency. For a 500-cps crossover point T = 318 microseconds. In a similar manner, low-frequency pre-emphasis may be expressed as a curve conforming to the admittance of a parallel resistor-inductor combination, as in (D) of *Fig.* 8. For 3-db rise at 50 cps, for example, the time constant of the network is 3,180 microseconds.

Any of the above curves may just as well be expressed as conforming to the impedance of suitable two-element networks, although use of the admittance curves is more generally accepted.

By algebraically adding the ordinates of these three curves, an over-all curve will be obtained which accurately defines the "New Orthophonic" recording characteristic. The relative velocity values for the over-all curve arbitrarily referenced to "0" db at 1,000 cycles are shown in Table I.

In making comparisons between the former RCA Victor curve and the "New Orthophonic" characteristic, sev-

(*Continued on page 53*)