RC equalization curves

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An accurate graphic method for the audio technician of charting any equalization curve, such as those used for tone control and for disc and tape recording.

THOSE seriously involved in the field of audio must be on familiar terms with *RC* equalization curves, which play a vital role in audio equipment.

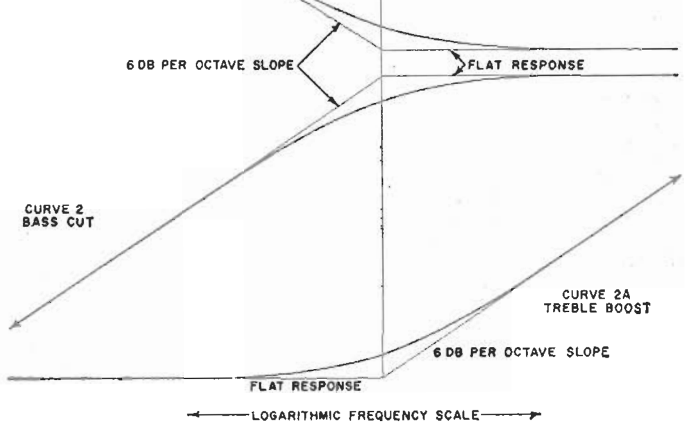
The reference is to curves produced by simple resistor-capacitor circuits which cause frequency response to shift from a flat characteristic until it attains a rate of rise or fall proportional to change in frequency. The part of an *RC* equalization curve that changes in proportion to frequency does so at the rate of 6 db per octave or 20 db per decade.

The equalization curves to be discussed here are the well-known standard characteristics employed for FM de-emphasis, for playback of phono discs, and for playback of tape. They are also the complementary equalization characteristics employed in FM broadcasting and in disc recording.

It frequently becomes necessary to plot one of these standard, or even non-standard, *RC* curves in order to ascertain with exactness how signal amplitude varies as frequency changes. In the case of standard curves, copies of them are not always at hand and even when they are it is not always possible to read them with the desired precision. It may be that the grid lines are, for example, at 5-db intervals, whereas closer spacing is required for reasonably accurate reading. Or, given an accurate copy of a standard curve, it may turn out that it is on the wrong size audio log paper for tracing in order to compare it with the performance of a piece of equipment; instead, it must be copied point by point.

For these and other reasons, the job of plotting an equalization curve point by point often arises. This is a tedious business at best. Therefore, it is the purpose of this article to describe a quick, graphic method of charting an equalization curve, standard or not. In most circumstances the method is accurate within ¼ db or less; at the outside the error is about ½ db.

Chart 1. The basic resistance-capacitance response characteristics.



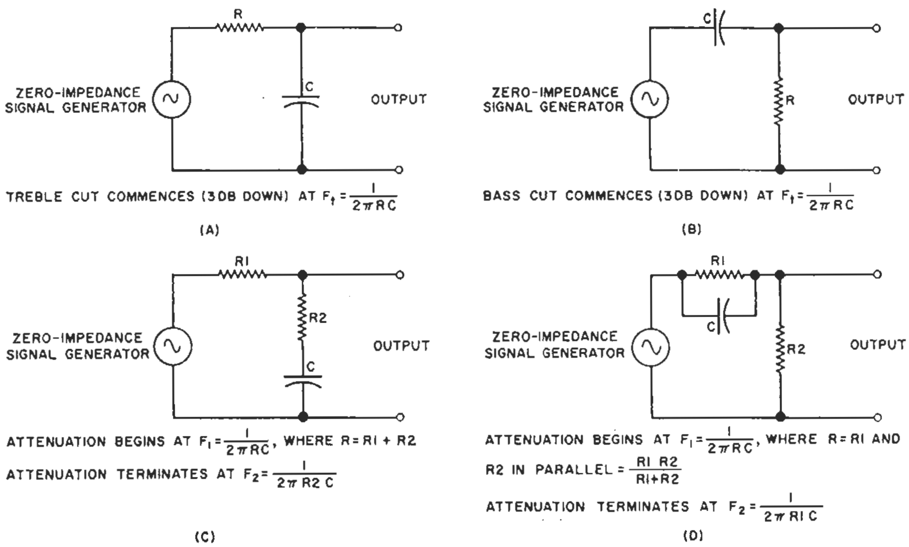
The graphic technique relies on two basic graphs, which are traced to delineate the desired equalization characteristic. It is only necessary to know the time constants—or turnover frequencies—of the curve in order to trace swiftly and with sufficient accuracy for most practical applications.

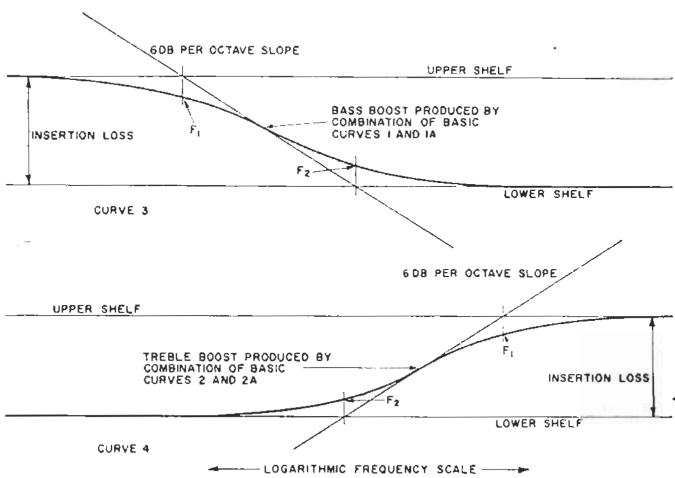
Before describing the technique of drawing *RC* equalization curves, or computing the values of points to be plotted, it is important to first discuss the nature of these curves.

Basic RC Curves

Chart 1 shows the four basic types of *RC* curves. Starting at a level, or shelf, where response is flat, each curve proceeds to rise or fall until it attains a maximum rate of 6 db per octave. The frequency at which the curve has risen 3 db above the shelf or fallen 3 db below the shelf is termed the *turnover frequency,* 3-db point, or sometimes the inflection point. The turnover frequency, F_t, is determined by the *RC*—resistance and capacitance—values employed in the equalization circuit: $F_t = 1/(2\pi RC)$.

In *RC* circuits where the rise or the fall in response





▲ **Fig. 1. (A) A circuit producing treble cut according to Curve 1 in Chart 1. (B) Circuit producing bass cut according to Curve 2 shown in Chart 1. (C) Circuit producing bass boost according to Curve 3 shown in Chart 2. (D) Circuit producing treble boost according to Curve 4 shown in Chart 2.**

◀ **Chart 2. Bass and treble boost produced by combining basic curves.**

is terminated before it can reach 6 db per octave, somewhat less than a 3-db change is achieved at the turnover frequency. Nonetheless, the turnover frequency, which depends on the *RC* time constant of the circuit, remains the same. Therefore it is best to avoid the expression "3-db point" and instead use the term "turnover frequency," although the two are quite often the same.

The rise or fall of an equalization curve is said to begin at the turnover frequency. If the curve is employed to terminate a previous rise or fall in bass or treble response, it may be said that the rise or fall terminates at the turnover frequency. Curve 1 in Chart 1 is treble cut, produced by the circuit of Fig. 1A. Curve 1A is bass boost. It cannot be produced purely as shown, because bass boost is actually achieved by reducing the treble frequencies. We will come to the practical circuit shortly. Note that rotating Curve 1 180 degrees produces Curve 1A. We shall take advantage of this later.

Curve 2 is bass cut, produced by the circuit of Fig. 1B. Curve 2A is treble boost, which cannot be produced purely as represented, because treble boost is actually achieved by reducing the bass frequencies. We shall discuss a practical circuit along these lines presently. Note that rotating Curve 2 180 degrees produces Curve 2A.

These four basic curves are combined to produce practical bass boost and treble boost curves, as shown in Chart 2.

Curve 3 represents a practical bass boost curve, produced by the circuit of Fig. 1C. Curve 3 is a combination of Curves 1 and 1A. It may also be viewed as limited treble cut (as distinguished from the infinite treble cut of Curve 1). Whether it is bass boost or treble cut depends on the choice of turnover frequencies. If turnover frequency F_1 is well up in the audio range, the curve becomes treble cut. If F_2 occurs toward the middle or low end of the audio range, the curve becomes bass boost. Note that if F_1 is moved below the audio range, the portion of the curve remaining *within* the range is the same as Curve 1A. If F_2 is moved above the audio range, the portion of the curve remaining *within* the range is the same as Curve 1.

Curve 4 represents a practical treble boost curve, produced by the circuit of Fig. 1D. Curve 4 is a combination of Curves 2 and 2A. Curve 4 may also be viewed as limited bass cut (as distinguished from the infinite bass cut of Curve 2). Whether it is treble boost or bass cut depends on the choice of turnover frequencies, in a manner similar to Curve 3.

Standard Equalization Curves

Figs. 2, 3, and 4 show the well-known FM de-emphasis, RIAA disc playback, and NAB tape playback curves respectively. Fig. 5 is the 3.75-ips tape playback curve which is coming into vogue. Following are the characteristics of each curve.

FM De-emphasis: This consists of infinite treble cut employed in FM reception (and in the sound portion of TV). Attenuation begins at 2122 cycles. FM de-emphasis is produced by Basic Curve 1.

RIAA Disc Playback: This consists of bass boost and treble cut, assuming that a velocity pickup is used. Bass boost begins at 500 cycles and terminates at 50 cycles. Total bass boost is 20 db. This portion of the RIAA characteristic consists of Basic Curves 1 and 1A. Treble cut commences at 2122 cycles, just as in the case of FM de-emphasis; it is produced by Basic Curve 1.

NAB Tape Playback (15 and 7.5 ips): This consists entirely of bass boost, beginning at the relatively high frequency of 3180 cycles and terminating at 50 cycles. Total boost is 36 db. It is produced by Basic Curves 1 and 1A. The NAB characteristic is frequently drawn so that the 0 db point occurs at 1000 cycles, which makes it appear that there is 26-db bass boost below 1000 cycles and 10-db treble cut above 1000 cycles. Actually, there is no treble cut as such.

3.75-ips Tape Playback: This is essentially the same as the NAB curve except that the bass boost starts at 1326 cycles instead of 3180 cycles. Total boost is 28.3 db.

The foregoing data is summarized in Table 1, which also presents the time constants corresponding to the turnover frequencies.

None of the standard curves just discussed employs Basic Curves 2 and 2A. However, if one is concerned with the equalization used in FM broadcasting and in disc recording, then Curves 2 and 2A come into play to achieve bass cut or treble boost. The FM pre-emphasis curve used by broadcasters is the complement of the one shown in Fig. 2. It corresponds to Basic Curve 2A (the practical circuit causes the treble boost to terminate beyond the end of the audio range). RIAA equalization used in recording is the complement of the curve of Fig. 3. It consists of Basic Curves 2 and 2A.

Drawing a Curve

To draw any standard or non-standard *RC* curve with accuracy, based on knowledge of the turnover frequency or frequencies, you will need only Graphs 1 and 2. Graph 1 presents Basic Curve 1 on audio log paper; by turning it upside down (180-degree rotation), you also have Basic Curve 1A. In the same fashion, Graph 2 presents Basic Curves 2 and 2A on audio log paper. Note that on each graph the turnover frequency is marked. This is the particular frequency value at which the

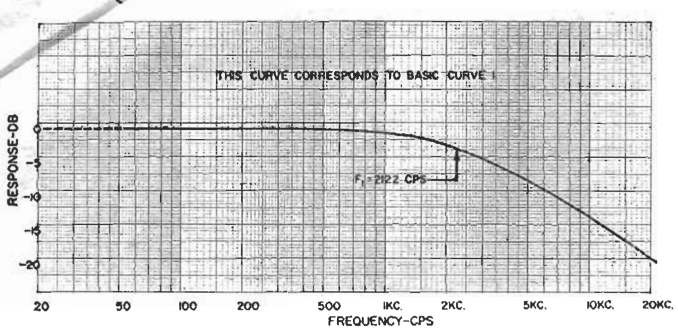


Fig. 2. The standard FM receiver de-emphasis curve.

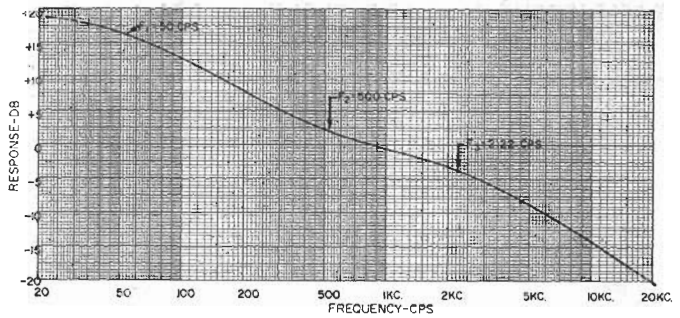


Fig. 3. The standard RIAA phono disc playback curve.

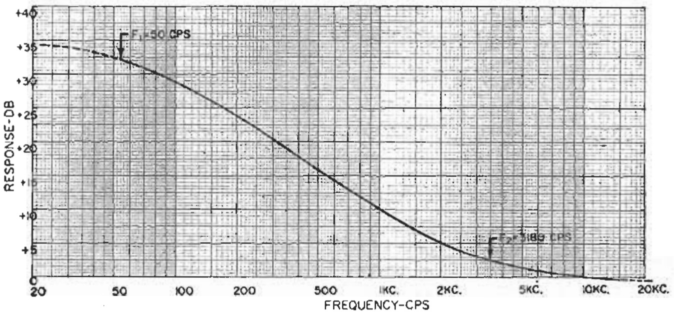


Fig. 4. The standard NAB tape recording playback curve.

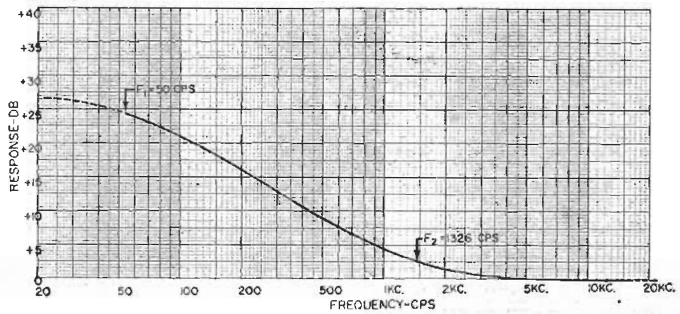
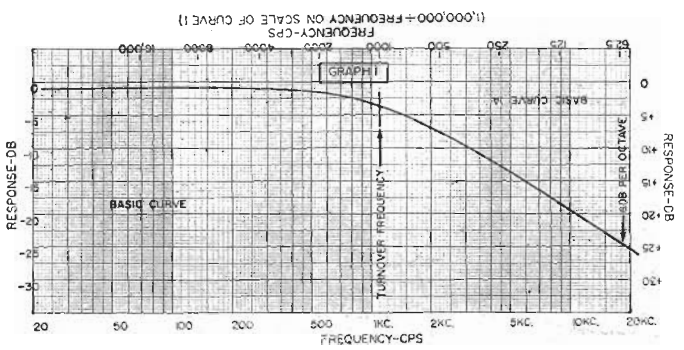
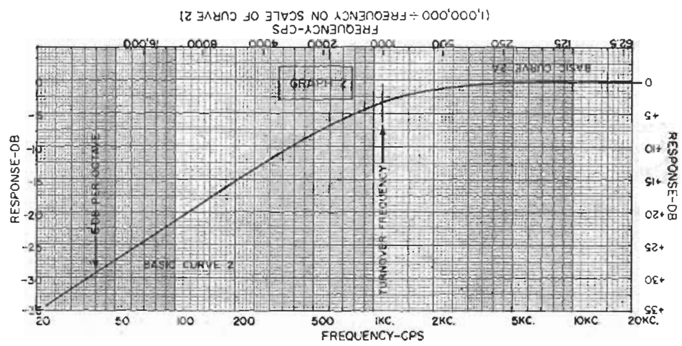


Fig. 5. The widely used 3¾-ips tape playback curve.



Graph 1. Basic Curves 1, 1A for treble roll-off, bass boost.



Graph 2. Basic Curves 2, 2A for bass roll-off, treble boost.

circuit response is reduced by 3 db.

In order to permit accurate copies of Graphs 1 and 2, Table 2 lists the required values, in decibels, for plotting Curves 1 and 2. These curves should be plotted on the same kind of audio log paper that you plan to use for drawing various *RC* curves. After plotting the values of Table 2, connect them with a French curve or other suitable smoothing device. Even careful freehand smoothing will be satisfactory for most purposes. The final curve should be dark to facilitate tracing.

The FM De-emphasis Curve

The FM de-emphasis curve consists of treble attenuation beginning at 2122 cycles. If the turnover is stated as a time constant, 75 μsec. in the present case, the turnover frequency is obtained by dividing the time constant (in microseconds) into 159,155 (which is 1,000,000 divided by 2π). Thus 159,155 divided by 75 is 2122.

The procedure for constructing the FM de-emphasis curve is as follows:

1. Place a transparent sheet of audio log paper over the sheet on which you have drawn Basic Curve 1. Of course both sheets must be to the same scale. Locate the upper sheet so that the turnover frequency marked on Basic Curve 1 corresponds to 2122 cycles and so that the flat portion of Basic Curve 1 is at the level designated "0 db" on the upper sheet. Trace Basic Curve 1.

2. You will find that the tracing does not fully cover the lower part of the audio range, because the turnover frequency of Basic Curve 1 is 1000 cycles, whereas the turnover for the FM de-emphasis curve is 2122 cycles. However, Basic Curve 1 has reached its flat portion by the time it has "run out" for tracing purposes. Therefore, extend response into the bass region simply by using a straightedge to draw a horizontal continuation of the curve you are constructing. Conversely, if you were constructing an attenuation curve which begins below 1000 cycles, the drawing would be incomplete at the upper end of the audio range. Again there is no problem. By the time Curve 1 has "run out" in the treble area it has reached a 6-db-per-octave slope. Therefore extend response into the treble region simply by using a straightedge to draw a continuation line that slopes 6 db per octave.

NAB Tape Playback Curve

The NAB curve consists of bass boost beginning at 3180 cycles and terminat-

Table 1. Turnover frequencies, time constants of four standard equalization curves.

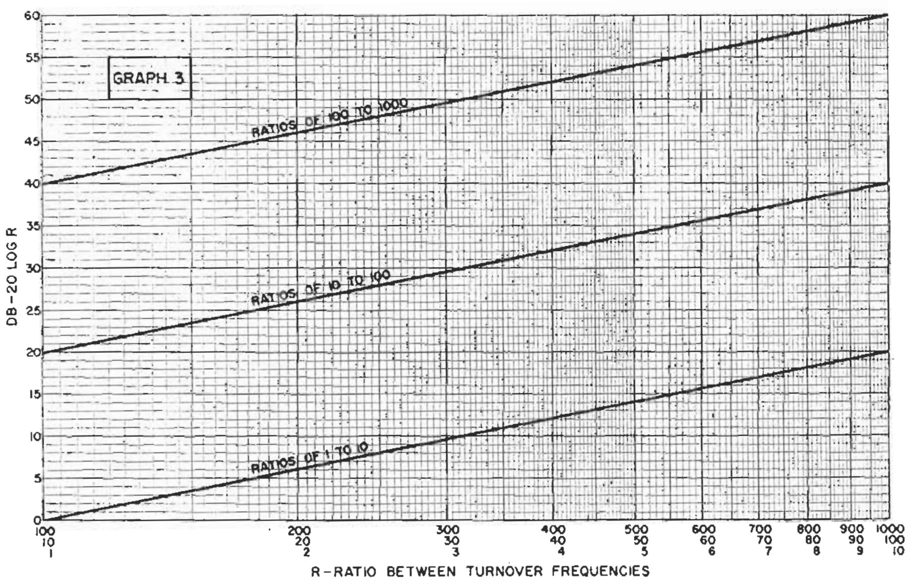
	FM De-Emphasis	NAB Tape Playback	3.75-ips Tape Playback	RIAA Disc Playback
Turnover Frequencies (cps)				
F_1—Attenuation begins	A 2122	B { 50	C { 50	D { 50
F_2—Attenuation terminates	——	3180	1326	500
F_3—Attenuation begins again	——	——	——	2122
Corresponding Time Constants (μsec.)				
T_1 for F_1	75	3180	3180	3180
T_2 for F_2	——	50	125	318
T_3 for F_3	——	——	——	75

A. Treble cut; B. Bass boost, with 36 db insertion loss; C. Bass boost, with 28.3 db insertion loss; D. Bass boost, with 20 db insertion loss.

BASIC CURVE 1 Freq. (cps)	Atten. (db)	BASIC CURVE 1 Freq. (cps)	Atten. (db)	BASIC CURVE 2 Freq. (cps)	Atten. (db)	BASIC CURVE 2 Freq. (cps)	Atten. (db)
20	0.00	1,300	4.30	20,000	0.01	900	3.49
*31.25	0.00	1,400	4.71	*16,000	0.02	800	4.09
50	0.01	1,500	5.12	10,000	0.04	700	4.83
*62.5	0.02	1,600	5.52	*8,000	0.07	600	5.77
100	0.04	1,800	6.27	7,000	0.09	500	6.99
*125	0.07	*2,000	6.99	6,000	0.12	450	7.74
150	0.10	2,400	8.30	5,000	0.17	400	8.60
200	0.17	2,800	9.46	*4,000	0.26	350	9.62
*250	0.26	3,200	10.51	3,600	0.32	300	10.83
300	0.37	3,600	11.45	3,200	0.41	*250	12.30
350	0.50	*4,000	12.30	2,800	0.52	200	14.15
400	0.64	4,500	13.27	2,400	0.70	150	16.57
450	0.80	5,000	14.15	*2,000	0.97	*125	18.13
*500	0.97	6,000	15.68	1,800	1.17	100	20.04
600	1.34	7,000	16.99	1,600	1.43	75	22.53
700	1.73	*8,000	18.13	1,400	1.79	*62.5	24.10
800	2.15	9,000	19.14	1,300	2.02	50	26.03
900	2.58	10,000	20.04	1,200	2.29	*31.25	30.11
*1,000	3.01	12,000	21.61	1,100	2.62	25	32.04
1,100	3.44	*16,000	24.10	*1,000	3.01	20	33.98
1,200	3.87	20,000	26.03				

*Octave frequencies relative to 1000 cps.

Table 2. The exact values to be employed in plotting the basic Curves 1 and 2.



Graph 3. Ratios between turnover frequencies, expressed as decibels gain or loss.

ing at 50 cycles. The construction procedure is as follows:

1. Determine the insertion loss, namely the total bass boost in decibels. This is computed as 20 times the log of the ratio between the turnover frequencies; divide the higher turnover frequency by the lower one. In the present example, the ratio between turnover frequencies is 63.6; the log of 63.6 is 18; and 20 times 18 is 36 (db). If you don't have a table of logarithms, use Graph 3 instead. To illustrate its use in the present example: Follow the horizontal axis out to the point corresponding to a ratio of 63.6. Move vertically to the middle line, which applies to ratios between 10 and 100. From this intersection move horizontally to the left scale, which reads 36 db.

2. On a sheet of audio log paper, draw two horizontal lines 36 db apart, corresponding to the insertion loss. These are designated the "upper shelf" and the "lower shelf," with the latter being on the 0 db level.

3. Determine the mean frequency, F_m, between the two turnover frequencies. F_m may be calculated as $\sqrt{F_1 \times F_2}$, where F_1 and F_2 are the two turnover frequencies. But much the easier way, when using audio log paper, is to measure half-way between 50 and 3180 cycles. Mark F_m, which is 399 cycles, at half the distance between the upper and lower shelves, namely at the 18 db level.

4. Turn Graph 1 upside down so that it becomes Basic Curve 1A. Place a sheet of audio log paper over Basic Curve 1A so that the turnover frequency corresponds to 3180 cycles; and so that the flat portion of the Basic Curve is at the 0 db level, coinciding with the lower shelf. Trace Basic Curve 1A until you come to point F_m on the upper sheet.

5. Return to Basic Curve 1 (by turning Graph 1 upside down again). Locate the turnover frequency so that it corresponds to 50 cycles on the upper sheet; and so that the flat portion of the curve coincides with the upper shelf. Trace Basic Curve 1A until you come to point F_m. At F_m you should run into the other half of your drawing unless: (a) You have done something wrong. (b) The two turnover frequencies are less than four octaves apart; in other words, form a ratio of less than 16:1. In the case of the NAB curve, the ratio is 63.6, and the two tracings will meet.

RIAA Disc Playback Curve

The RIAA curve consists of bass boost with turnover frequencies of 50 and 500 cycles; and of infinite treble cut with a turnover frequency of 2122 cycles.

Starting from the turnover frequency, an *RC* curve requires two octaves in either direction to become essentially a straight line—either flat or sloping 6 db per octave.

If an *RC* curve has two turnover frequencies, there is interaction between them: The upper portion of the curve is governed not only by the upper turnover frequency but also, to a lesser extent, by the lower frequency; therefore the upper portion changes shape somewhat. In the same way, the lower portion of the curve is governed by the upper turnover frequency as well as by the lower frequency. When the two turnover frequencies are at least four octaves apart—a ratio of 16:1 or greater—the amount of interaction is insignificant because each portion of the curve has become linear. Therefore, the upper half of the curve can be drawn independently of the lower half, as in the case of the NAB curve.

But if the turnover frequencies are less than four octaves apart, there is interaction and the upper and lower halves of the curve are not exactly the same as Basic Curves 1, 1A, 2, and 2A. This is the situation encountered in dealing with the bass boost portion of the RIAA curve, where the ratio between turnover frequencies is 10:1.

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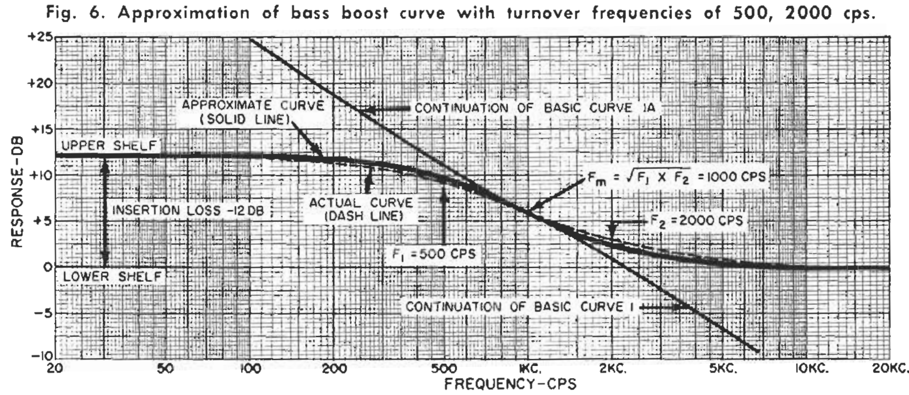
Fig. 6. Approximation of bass boost curve with turnover frequencies of 500, 2000 cps.



RC Equalization Curves

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On the other hand, it is possible to represent each half of the bass boost characteristic by means of the Basic Curves if we are willing to settle for an approximation which is accurate within ½ db or better.

Fig. 6 illustrates the approximation technique for a bass boost curve with the very low ratio of 4:1 between turnover frequencies; 500 and 2000 cycles are used in this example. The procedure is as follows:

1. As explained in the preceding example, determine the insertion loss (12 db) and draw the corresponding upper and lower shelves on a sheet of audio log paper. Determine F_m (1000 cycles) and mark it as a point at half the insertion loss (6 db level).

2. Place the audio log paper over Basic Curve 1A so that the turnover frequency corresponds to 2000 cycles; and so that the flat portion of the Basic Curve coincides with the lower shelf. Now slide the upper sheet to the right until Basic Curve 1A goes through point F_m, as marked on the upper sheet. Trace Basic Curve 1A as far as F_m.

3. Place the audio log paper over Basic Curve 1 so that the turnover frequency corresponds to 500 cycles; and so that the flat portion of the Basic Curve coincides with the upper shelf. Slide the upper sheet to the left until Basic Curve 1 goes through point F_m. Trace Basic Curve 1 as far as F_m.

Fig. 6 shows not only the approximate equalization curve for turnover frequencies of 500 and 2000 cycles, but also the exact curve. It may be seen that even though the turnover ratio is only 4:1, the error of the approximate curve is ½ db at worst. When the turnover ratio becomes as great as 10:1, which is the case for the bass boost portion of the RIAA curve, the error becomes much less than ½ db.

Fig. 7 illustrates the construction of the RIAA curve by the graphic method. The bass boost portion is drawn in the same manner as has been described for the bass boost curve of Fig. 6. However, the RIAA curve also contains treble cut. Moreover, there is less than a 16:1 ratio between the turnover ratios representing the beginning of bass boost (500 cycles) and the beginning of treble cut (2122 cycles). Therefore an approximation technique is required to merge the treble cut portion with the bass boost portion of the RIAA curve. The entire procedure is as follows:

1. In the same manner as for Fig. 6, draw the RIAA bass boost curve, based on an insertion loss of 20 db, with the upper and lower halves of the curve going to point F_{m1}, which is 158 cycles. The curve drawn thus far is represented by curve A-B in Fig. 7. The next step is to add treble cut.

2. Place the drawing over Basic Curve 1 so that the turnover frequency corresponds to 500 cycles; and so that the flat portion coincides with the lower shelf. Trace Basic Curve 1; this results in curve C-C in Fig. 7. It remains to join curves A-B and C-C.

3. Determine F_{m2}, the mean frequency between 500 cycles and 2122 cycles; as stated before, this is most easily done on audio log paper by measuring halfway between these frequencies. F_{m2} is 1030 cycles. Mark F_{m2} as a point on the lower shelf. Place a straightedge at point F_{m2} and turn the straightedge so that you have a line passing through this point and, at the same time, tangent to both curves A-B and C-C. Use this line, D-D, to connect the bass-boost and treble-cut curves.

The final curve, A-C, drawn as a heavy line in Fig. 7, is an extremely close approximation of the RIAA playback equalization curve. If you compare the construction of Fig. 7 with the actual RIAA curve in Fig. 3, you will find that the difference is barely discernible. While it has taken a fair amount of space to describe the construction technique, once it is learned the procedure goes very fast. Only a few minutes are required to draw curves even more complex than the RIAA characteristic.

The foregoing examples have not dealt with curves that rise with frequency, namely bass cut or treble boost. However, the procedures are exactly the same, except that Basic Curves 2 and 2A are used in the process. ▲

Fig. 7. Construction of the RIAA disc playback curve by means of the graphic method.