AUDIO EQUALIZATION CURVES UP-TO-DATE

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Summary of curves now in use for FM broadcasting, disc recording, and tape recording—including the latest standard for the tape cassette.

IN a high-fidelity audio amplifier, flat frequency response in every stage is the design ideal, so that the equipment does not add anything to the frequency relationships of the original sound. This principle is also followed in the design of most microphones and loudspeakers, for the same reason.

But when sound is processed through FM broadcast, disc recording, and tape recording, flat frequency response is not used in each stage throughout the system. Each system introduces noise, distortion, or loss at some frequencies which is not introduced at others. To overcome these difficulties, nonlinear frequency response is deliberately introduced near the system input. A complementary nonlinear response is then produced somewhere before the system output.

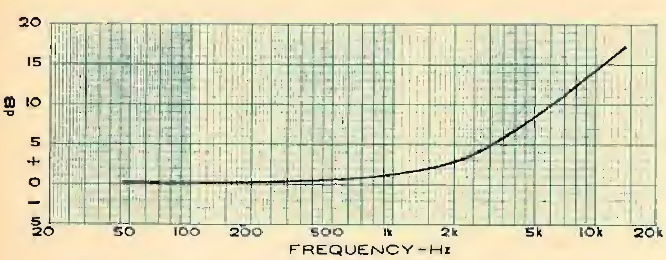
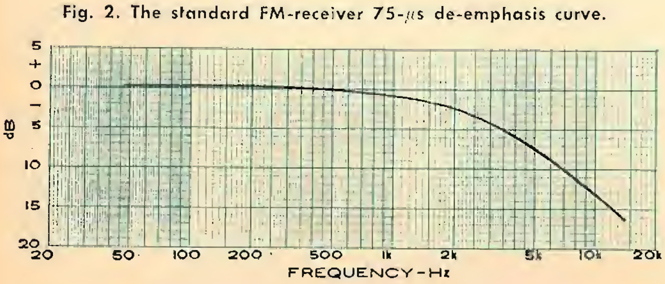


Fig. 1. Standard FM-transmitter 75-μs pre-emphasis curve.

Fig. 2. The standard FM-receiver 75-μs de-emphasis curve.



The over-all frequency response of FM, disc recording, and tape recording is made as flat as possible. Within the system, however, the frequency response is deliberately altered. This nonlinear response is known as *equalization*.

One thing common to all three systems: Most speech and music signals contain less energy at higher frequencies than lower. Thus the signal-to-noise ratio is inherently poorer at higher audio frequencies. For this reason, high-frequency boost—called *pre-emphasis*—is used near the system input in FM broadcasting, disc recording, and tape recording. As a complement, high-frequency attenuation—called *de-emphasis* —is then used near the system output.

FM-Broadcast Pre-emphasis

In the process of frequency modulation, the greater the amount of frequency deviation, the greater the amount of suppression of total system noise (provided only that signal amplitude is greater than noise). But the higher the modulating frequency, the less complete the suppression of noise. This is due to the lower modulation index produced by the higher audio modulating frequencies. Thus in an FM system not using pre-emphasis, both the modulation index and the signal-to-noise ratio are low at high audio frequencies. This noise consists—in the transmitter—of byproducts of the modulation method, and in the receiver of high-frequency impulse noise and possibly tube or transistor hiss.

In 1941 the FCC adopted a standard method of FM (and TV-sound) broadcast pre-emphasis. The system uses a 75-μs *RC* network which produces the frequency response curve shown in Fig. 1. This pre-emphasis provides a boost starting at about 300 Hz, increasing to about 17 dB at 15,000 Hz.

Thus noise suppression at higher audio frequencies is improved in the modulation system.

At the receiver, a complementary 75-μs de-emphasis network is used which produces the attenuation curve of Fig. 2. A loss of about 17 dB occurs at 15,000 Hz. Over-all system response is then essentially flat.

In most program material, higher audio-frequency energy is relatively small, and pre-emphasis does not adversely affect the over-all audio balance. But in some program material the jingle of keys or the overtones of a violin produce high-amplitude, high-frequency signals. If the over-all gain of the system is not reduced, the high-frequency material overmodulates and causes distortion in the receiver, due to excessive frequency deviation. If the system gain is reduced to accommodate the high-frequency material, mid-range program audio suffers, as it is proportionately reduced.

To overcome this problem, many FM and TV stations use a frequency-sensitive limiter (*e.g., CBS's* FM Volumax, *Fairchild's* Conax, *Gates'* Top Level). Such a device reduces high-frequency gain when high-frequency audio exceeds a certain level.

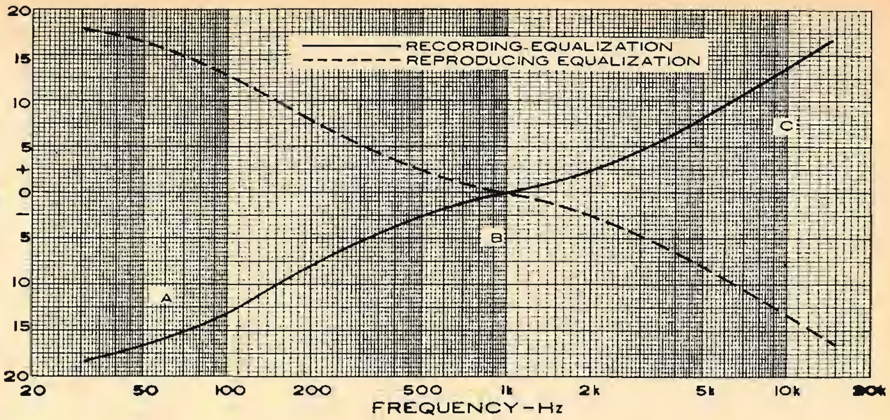


Fig. 3. Standard RIAA recording and playback equalization curves for discs.

Disc-Recording Equalization

The over-all frequency response of a disc recording and reproducing system is essentially flat, of course. But pre-equalization is used during recording, and complementary post-equalization during reproduction; each produces nonlinear frequency response. There are two reasons for disc-recording equalization—low-frequency groove limitations and high-frequency noise.

For mechanical reasons, the velocity of the recording stylus is constant for constant input power. Since stylus displacement becomes excessively large at low frequencies, the danger of overcutting the record groove exists. To prevent this excessive displacement, low-frequency attenuation is used. Low-frequency roll-off therefore permits higher over-all recording level without groove overcutting.

It has been found that a disc recording and reproducing system has greater noise content at the higher audio frequencies than at the middle or lower frequencies. This noise—called *surface noise*—is due chiefly to minute irregularities in the recording medium. Since the average amplitude of high-frequency program material is low, it is possible to provide high-frequency pre-emphasis, thereby improving high-frequency signal-to-noise ratio.

At one time several types of disc equalization were used. In the early 1950's, however, RIAA (Record Industry Association of America) adopted a standard method, which was also adopted by NAB (National Association of Broadcasters) in 1964. The standard RIAA/NAB disc-recording pre-emphasis curve is shown in Fig. 3 as a solid line. There are three sections to the curve.

A. The low-frequency section is attenuated; this is known as the *constant-amplitude* area, as the amplitude of stylus displacement is limited to avoid groove overcutting.

B. The mid-frequency section has a *constant-velocity* characteristic, and has an amplitude which rises with frequency.

C. The high-frequency section employs pre-emphasis which increases with frequency, to overcome high-frequency noise inherent in the disc medium.

The dashed line in Fig. 3 represents the frequency response of the RIAA/NAB playback equalization system. Since it is exactly complementary to the recording equalization curve, it restores the over-all system response to an essentially flat curve.

Tape Equalization

In magnetic tape recording, equalization is needed for two reasons—low-frequency loss during playback and high-frequency loss during recording.

Fig. 4 shows the record-playback response curve of a typical tape recorder without equalization. The signal-output amplitude of a tape playback head increases with frequency at the rate of 6 dB per octave. This is so because a tape playback head is a velocity-sensitive device, which responds to the rate of change (frequency) for a constant flux (signal recorded on the tape). This phenomenon causes low-frequency response to fall below that at mid-frequencies.

In the recording process, high-frequency response is attenuated due to self-demagnetization and bias-erasure losses.

Thus tape equalization must consist of both low- and high-frequency boost. This equalization may be applied during

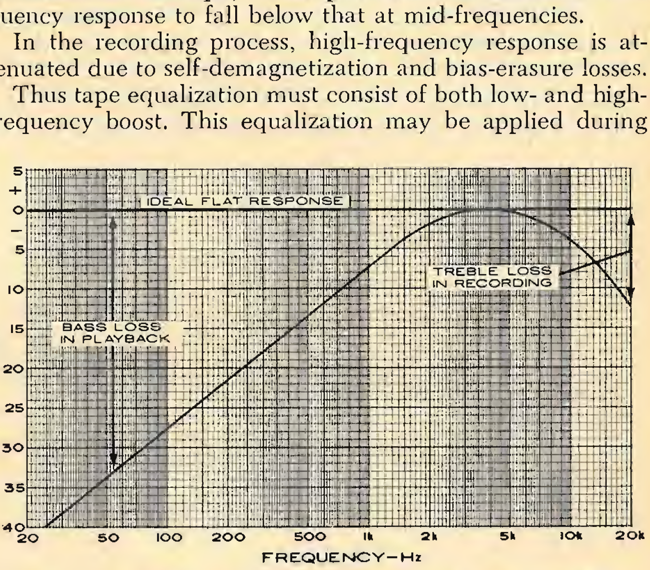


Fig. 4. Record-playback response of tape recorder without equalization shows wide departure from flat response.

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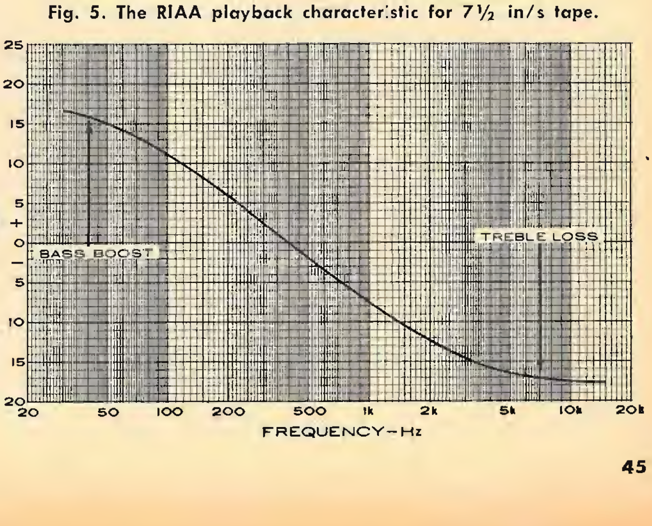
Fig. 5. The RIAA playback characteristic for 7½ in/s tape.



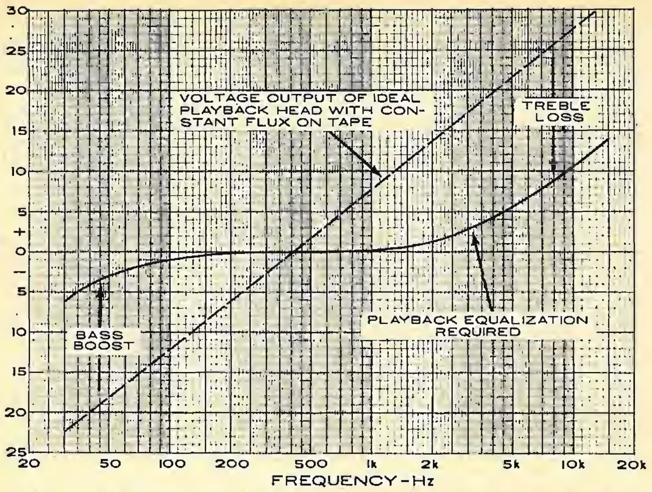


Fig. 6. New method of specifying tape equalization required.

either recording or playback, or both. The applicable criteria are flat response, minimum distortion, and maximum signal-to-noise ratio.

Current practice is to employ chiefly high-frequency (treble) boost during recording, and principally low-frequency (bass) boost during playback. Since typical audio program material contains low-level high-frequency signals, treble boost does not overload the tape, and provides maximum signal-to-noise ratio. Some bass boost is also employed during recording, but not enough bass boost to overload the tape.

During playback, bass boost is used to bring the over-all system response up to flat. No treble boost is necessary or desirable during playback, as this would emphasize tape noise.

The method of specifying and measuring tape equalization is not the same as that for FM broadcasting and disc recording. It is difficult to measure the recording characteristic of a tape system, since this means measuring the actual flux applied to the tape from the recording head. It is much easier to specify and measure the signal coming off the tape—that is, the playback characteristic.

Current standardization practice is to specify a playback characteristic which includes bass boost and treble loss. For example, Fig. 5 shows the RIAA playback characteristic for 7½ in/s tape. This curve specifies the response of the playback amplifier only, and does not include the head.

In practice, an audio generator is substituted for the playback head and the generator is used to feed a constant-amplitude signal at several frequencies throughout the audio range. The playback amplifier's frequency response is varied until the output conforms to Fig. 5.

Then the playback head is replaced in the circuit and the audio generator is connected to the input of the recording amplifier. The generator again is used to feed a constant-amplitude signal at several frequencies throughout the audio range. The audio-generator output is recorded on the tape, and the tape played back. The recording equalization is then varied until the playback amplifier output is flat. Thus only the playback characteristic need be specified, provided that over-all record-playback response is also specified as flat. The recording characteristic is therefore whatever additional equalization is necessary to produce flat over-all response.

New Method of Specifying

The preceding method is no longer used because of one disadvantage; it presumes that the playback head is ideal and has no irregularities. Fig. 6 shows the new method of specifying the playback characteristics. Constant flux *vs* frequency is maintained in the playback head, and the straight dashed line indicates what the ideal response should be—voltage output rising with frequency at the rate of 6 dB per octave. The curved line indicates the actual playback-amplifier output, which includes bass boost and treble loss.

In practice, the playback system is aligned by using an accurately calibrated test tape, until the playback output conforms to Fig. 6. Recording equalization is then accomplished in the manner just described.

Since the new method includes both record and playback heads in the alignment procedure, tape compatibility among various machines is assured.

In FM broadcasting and disc recording, it is possible to use a single equalization curve because operating conditions do not change. Such is not the case in tape recording where various operating modes are used. There are four speeds (15, 7½, 3¾, and 1⅞ in/s), two tape widths (250 and 150 mils), and three configurations (reel-to-reel, endless-loop cartridge, and coplanar cartridge, or cassette) in common consumer usage. (Other speeds, widths, and configurations are employed in broadcast, recording-studio, and industrial applications.)

As tape-to-head speed is reduced, high-frequency losses increase. Thus an equalization curve for one speed would not be optimum for a lower speed. Accordingly, several curves are needed for the various speeds.

Through the years different equalization methods and curves have been used by various manufacturers and organizations. To assure compatibility of tapes recorded on one machine and played back on another, it is desirable that there be standard methods of equalization which everyone uses. Such equalization curves were adopted by RIAA and NAB in 1965 governing reel-to-reel machines, and by RIAA in 1968 governing cartridge machines.

Fig. 7 shows the three standard tape playback characteristic curves. Curve A is specified by the NAB for 15 and 7½ in/s, and by RIAA for 7½ in/s only. Curve B is specified by NAB for 3¾ and 1⅞ in/s, and by RIAA for 3¾ in/s only. Curve C is not used by NAB, and is specified by RIAA for 1⅞ in/s only. (*This is also the curve specified by* Philips *for the 1⅞ in/s cassette—Editor*) Curves A and B are specified by NAB for reel-to-reel machines only; other curves are specified for NAB cartridge machines. RIAA specifies the curves for speeds only, making no distinction among reel-to-reel, endless-loop cartridges, and coplanar cartridges (cassettes).

At various points in high-fidelity FM, disc, and tape systems, inherent difficulties make it necessary to purposely distort flat frequency response. Standard methods and amounts of equalization have been adopted by the responsible organizations in this country and abroad. These equalization curves now serve as reference for all concerned with recording or playback. ▲

Fig. 7. The standard equalization curves for the various tape speeds.