PRE-EMPHASIS AND DE-EMPHASIS

Why Measured in Microseconds?

By "CATHODE RAY"

THE difference between what is called "high-fidelity" reproduction and the ordinary sort is the upper-frequency limit. If the latter stops at 3000–4000c/s, "high - fidelity" goes up to perhaps 6000 or 8000c/s. Never mind the exact figures; that is the general idea. For various reasons, however, the effort put into achieving "high-fidelity" is not always rewarded with the expected number of phons of acclamation. One of those reasons often is that opening the frequency gate wider to let in the harmonic fairies, that tell us the difference between a violin and a flute, also lets in the noise demons that mess up the whole thing. Since the desired high-frequency sounds seldom represent deep transmitter modulation or full recording, it is generally quite safe to puff them up systematically at the sending or recording end, it being understood that they will be reduced back to normal proportions at the hearing end, in which process the noise (which hadn't the benefit of the extra rations) will be reduced below normal proportions. Pre-emphasis and de-emphasis.

That ought to be clear and understandable enough, but what may be a shade obscure to some readers is the practice of reckoning pre-emphasis and de-emphasis in microseconds (abbreviated μsecs). Obviously it is important that all who make receivers for pre-emphasized programmes should know how much they have been pre-emphasized, so as to apply an equal and opposite amount of de-emphasis. The simplest way of enlarging or reducing high frequencies in proportion to low is to use an amplifier coupling whose impedance is constant at the low frequencies and rises or falls at the high. Take inductance in series with resistance (Fig. 1*a*). At very low frequencies, the inductance does practically nothing. We have, in effect, a simple resistance coupling, with a level amplitude/frequency characteristic (left-hand end of Fig. 1*b*). At very high frequencies, the inductance does so much that now it is the resistance that can be neglected. We have an inductance coupling, with a rising characteristic (right-hand end of Fig. 1*b*). At middle frequencies, where neither resistance nor inductance predominates, there is a gradual transition from level to rising characteristic (middle of Fig. 1*b*).

The magnitudes of these effects are very much simpler to work out if one can assume that the amount of signal current flowing through the coupling is unaffected by the varying impedance of L, at any rate within the range of frequency concerned. For this to be so, the total impedance of L and R must be small compared with that of the valve; a condition that is easiest to fulfil by using a pentode or other type with an r_a of the megohm order. If then the coupling is never more than about 100,000 ohms the signal current can be assumed to be unaffected by it, and therefore equal, as near as makes no matter, to the grid signal voltage (call it E_g) multiplied by the mutual conductance of the valve, g_m. The signal voltage across the coupling is, of course, equal to the impedance, Z, of the coupling, multiplied by the signal current through it. So we have

Input voltage = E_g

Output voltage = $E_g g_m Z$

And therefore amplification = $\frac{E_g g_m Z}{E_g} = g_m Z$ (Z assumed $<< r_a$)

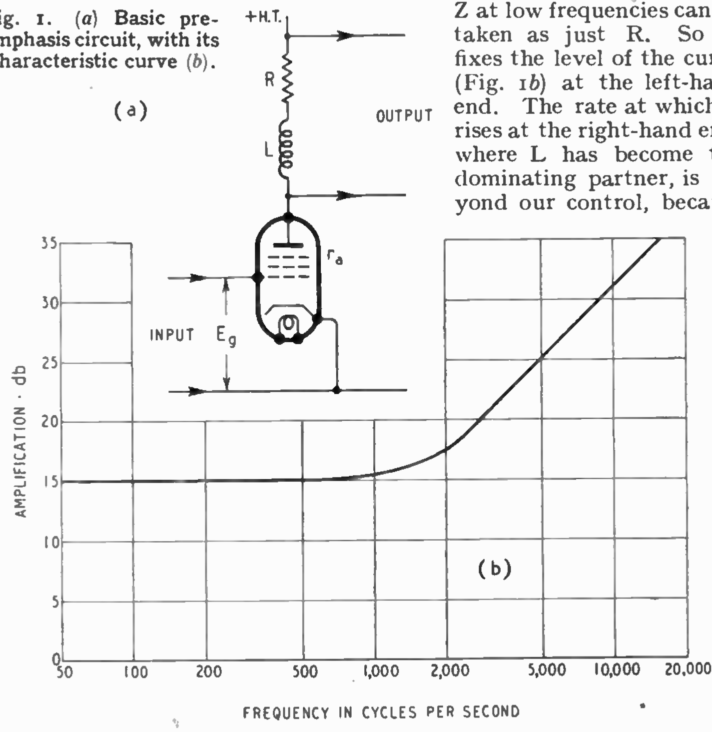

Fig. 1. (*a*) Basic pre-emphasis circuit, with its characteristic curve (*b*).

As we have already agreed, Z at low frequencies can be taken as just R. So R fixes the level of the curve (Fig. 1*b*) at the left-hand end. The rate at which it rises at the right-hand end, where L has become the dominating partner, is beyond our control, because if R is neglected, $Z = X_L$ (the inductive reactance), which is fixed by Nature in the relationship $X_L = 2\pi fL$. In other words, the amplification is proportional to the frequency. So the curve rises twofold for every doubling of frequency; that is, 6 decibels per octave. To get a quicker rate it

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would be necessary to use more than one stage of pre-emphatic amplification. But 6db per octave is a standard practice.

Obviously the sloping part of the curve can be moved bodily up or down by increasing or reducing L, which is the only other variable factor. But if R is simultaneously increased or reduced, the shape of the whole characteristic is not altered in the slightest; it is just higher or lower, which indicates higher or lower amplification of the stage, but is quite beside the point so far as pre-emphasis is concerned. Pre-emphasis is amplification of high frequencies *relative to the low*, so can be calculated as

$$\text{Pre-emphasis} = \frac{\text{Amplification at any high frequency, } f_h}{\text{Amplification at low frequencies}}$$

$$\approx \frac{g_m \times 2\pi f_h L}{g_m \times R} \approx 2\pi f_h \frac{L}{R}$$

The crucial pre-emphasis factor, then, is not L or R separately, but $\frac{L}{R}$.

$\frac{L}{R}$! That rings a bell somewhere.

Back in basic electrical theory—effect of switching a D.C. supply to a circuit consisting of L and R in series. The time the current would take to reach its final value, if it could continue to rise at its initial rate, equals $\frac{L}{R}$ seconds, which is called the time constant.

At the present moment we are not particularly interested in what happens when the D.C. supply is connected in Fig. 1*a*, but we are interested in any convenient figure that will tell us how much it pre-emphasizes, and at what frequencies. It is clear (I hope) that this already-familiar quantity, the time constant, tells us just that.

For example, in the published results of the B.B.C. frequency-modulation tests, it was mentioned[1] that a pre-emphasis of 50µsecs was found most satisfactory. That, which may to some have appeared a rather cryptic statement, is now seen to mean that $\frac{L}{R}$ in the pre-emphasis circuit was 0.00005, which in turn tells us the amount of pre-emphasis at any frequency. For example, f_h = 8000 c/s; then the amplification at that freqency, relative to the low frequencies, $\approx 2\pi \times 8000 \times 0.00005 = 2.5 = 8$db.

The approximate sign ($\approx$) in the formula just used above is a reminder that in calculating the amplification at high frequencies we were neglecting R altogether. That is only allowable well to the right in Fig. 1*b*, and fails over the important middle stretch. So here, as a matter of interest, is the more accurate and generally applicable formula, subject only to error due to the coupling impedance Z being assumed negligible compared with r_a:

Pre-emphasis at frequency f_h

$$= \sqrt{1 + \left(2\pi f_h \frac{L}{R}\right)^2}$$

Fig. 2 shows a characteristic curve for $\frac{L}{R} = 50\mu$secs, by both approximate and correct methods.

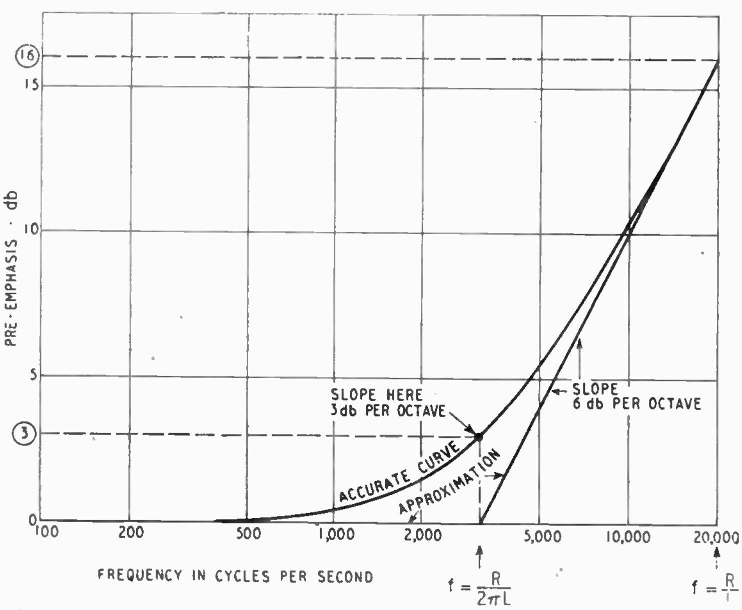

Fig. 2. Characteristic curve for a 50-µsec pre-emphasis circuit. It can be quickly sketched by putting in the 16-db point at the frequency equal to 1/time-constant, drawing a slope of 6db per octave through it, and smoothing it off into the horizontal through the 3-db point, at the frequency roughly equal to 1/(6 × time-constant).

The idea of *time*-constant, although it originally had to do with D.C., is not completely irrelevant to pre-emphasis. It very quickly enables one to sketch the characteristic curve without any formula at all. If the time in "time-constant" is looked on as the time of one cycle of signal, then it gives a frequency, the frequency at which the pre-emphasis is 6.36, or 16db. Try it with 50µsec. If each cycle lasts for 50µsecs, or 0.00005 sec., the frequency must be 20,000c/s. So one point on the 50µsec. curve is 20,000 c/s, 16db. An additional point is given by dividing this frequency by 6 (accurately, 2π). That gives the frequency of the middle of the bend, where the pre-emphasis is 2, or 3db. Knowing also that the straight of the slope is 6db per octave, a complete characteristic curve can be sketched in a few moments (Fig. 2).

Remember, however, not to extend the slope so far up that the coupling impedance becomes comparable with the valve impedance, as when that happens the curve starts to flatten out again. This tendency can be postponed by not attempting to amplify much (i.e., by making R quite small) and by using current negative feedback to increase the apparent r_a of the valve.

Although few readers will have

[1] *Wireless World*, Oct. 1946, p. 320.

a practical interest in pre-emphasis as such, I have gone through it in some detail, because the same principles apply to de-emphasis, which concerns or is soon likely to concern many, and to tone

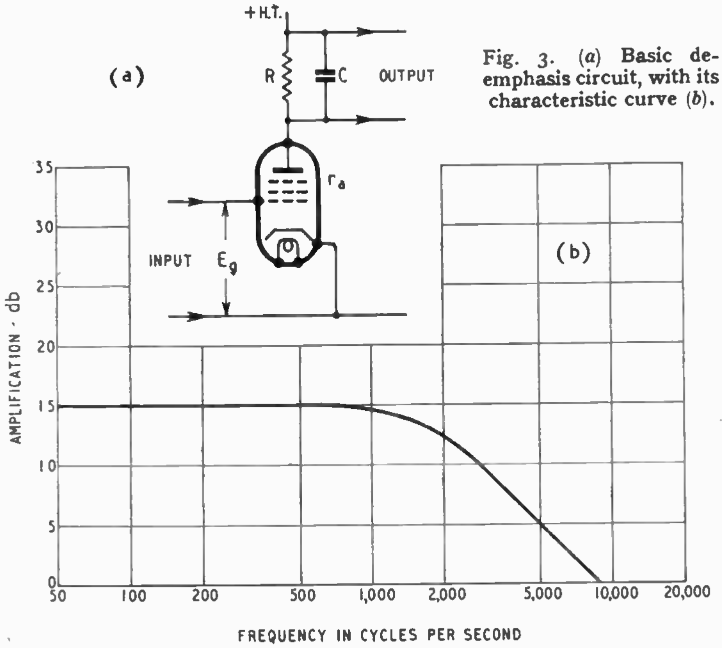

Fig. 3. (*a*) Basic de-emphasis circuit, with its characteristic curve (*b*).

control, which concerns almost everybody at some time or other. Also to unintentional distortion due to stray capacitance across the coupling resistor. And even to standard resistors intended for laboratory measurements over a wide range of frequency.

Substituting C for L in Fig. 1*a*, the reactance rises at the low-frequency end, giving bass lift. Putting L in parallel instead of in series gives bass loss. What we want for de-emphasis, however—high-note loss—is obtained by C in parallel with R (Fig. 3*a*), and the resulting characteristic (Fig. 3*b*) exactly straightens out Fig. 1*b*. At least, it does so if it begins to bend down at the same frequency as the other bends up. For that to happen, the time constant must be the same—another great advantage of the time-constant idea; it obviates calculations. That is just as well, because the fact that the de-emphasis circuit is a parallel one would make it a little more troublesome.

If the standard pre-emphasis is 50μsecs, all one has to do at the receiver is to see that the time-constant of the de-emphasis circuit is likewise.

The time-constant of a CR circuit is just CR. So after having chosen R to give a suitable stage gain, one simply divides 50×10^6 (or whatever the pre-emphasis time constant is) by R in ohms to get C in farads. Simpler still, divide microseconds by ohms to get microfarads. A convenient feature is that at the receiving end, where one might grudge a stage doing little but de-emphasizing, there is no reason why R should not be made large enough to give a useful gain; say 50,000 ohms; because that is the *maximum* coupling impedance. If RC is 50μsecs and R is 50,000 Ω, then C is of course 0.001μF. And the de-emphasis curve is just Fig. 2 upside down. To get the curve for any other time-constant, divide the frequency scale readings by the actual time constant relative to 50μsec. For example, for 75μsecs, divide all the frequencies by 1½.

Pre- and de-emphasis are usually associated with frequency modulation. One reason why it is not much applied to amplitude modulation may be the fear that if by any chance a programme does include strong sounds within the range of boosted frequencies, they would over-modulate the transmitter, and the last state would be worse than the first. Also A.M. is thoroughly established on a non-emphasized basis, whereas, F.M. being new, the receivers can be designed to fit pre-emphasized transmissions from the start. Over-modulation with F.M. is not quite so dire at the transmitting end as with A.M.; it means a greater-than-normal frequency deviation. But it is liable to cause distortion at the receiver. It is interesting to note that the B.B.C. recommends 50μsecs, instead of the American 75μsecs, on the ground that the advantage in signal-to-noise ratio with the latter was largely neutralized by a necessary reduction in depth of modulation.

A level wide-frequency-range characteristic for gramophone reproduction is unpopular because of the large amount of scratch that it brings in. So pre-emphasis might seem to be the answer. It certainly has been applied in many American records, but is not invariably a success. It is true that by its use scratch can be almost eliminated without making the record sound like the roll of muffled drums, but the heavy high-note recording is more than most pick-ups can stand without much buzzing and rattling. Moreover it makes acoustic gramophones sound shriller than ever.

The time-constant method is useful when considering how to *avoid* top-note loss. Suppose 3db loss is judged to be tolerable at 10,000c/s. The corresponding time-constant is the reciprocal of 2π times that, say $\frac{1}{63,000}$, which is 16μsecs. So if the unavoidable stray capacitance across the coupling resistor is, for instance, 32pF, the coupling resistance must not exceed $\frac{16}{32} = 0.5$ megohm.