

electrical degrees of the fundamental cycle of that component. Examination of a fundamental wave and its n th harmonic shows that (3) is equivalent to saying that the phase shift of the n th harmonic, measured in electrical degrees of its own cycle, must be either n times the phase shift of the fundamental or an integral multiple of 180 degrees. This can be true only if the phase shift for sinusoidal input is either proportional to the frequency, or zero or 180 degrees at all frequencies.¹ Failure to satisfy these three conditions results in three corresponding types of distortion: nonlinear distortion (amplitude distortion), frequency distortion (frequency discrimination), and phase distortion, any one of which alters the wave form of the output relative to that of the input.

Nonlinear distortion (amplitude distortion) is the generation in an amplifier or other four-terminal network of frequencies not present in the impressed signal. It is usually associated with a nonlinear relation between output and input amplitudes. In vacuum-tube amplifiers it is the result of curvature of the dynamic tube characteristics. The generation of harmonics and intermodulation frequencies was discussed in Chap. 4. A nonlinear relation between the output and input amplitudes when the dynamic transfer characteristic is curved is predicted by the fact that the third and higher odd-order terms of the series expansion for plate current [Eq. (3-56)] give rise to fundamental components of plate current, the amplitudes of which vary as the cube or higher odd power of the excitation voltage. For this reason, unless the coefficients of all odd-order terms of the series are negligibly small, the voltage, current, and power output are not proportional to the exciting voltage. Nonlinear distortion is objectionable in the amplification of speech and music mainly because intermodulation frequencies are in general inharmonically related to the impressed frequencies and, therefore, produce unpleasant discords.² Although it is the inharmonic intermodulation frequencies, rather than the harmonics, that are objectionable, nonlinear distortion is most readily measured and specified in terms of the distortion factor, defined in Sec. 4-18. Nonlinear distortion can be minimized by proper choice of tubes, load impedances, and operating voltages, and by avoiding too high excitation voltage.

Excessive nonlinear distortion may occur when the exciting voltage and grid bias are such that the normal range of operation on the dynamic transfer characteristic is exceeded. Figure 5-1 shows how improper choice of grid bias or the use of excessive excitation may result in the flattening of one or both peaks of the wave of alternating plate current. A similar flattening of the positive peak may result from the flow of grid

¹ FRY, T. C., *Physik. Z.*, **23**, 273 (1922).

² BARTLETT, A. C., *Wireless Eng.*, **12**, 70 (1935); BARROW, W. L., *Phys. Rev.*, **39**, 863 (1932); ESPLEY, D. C., *Proc. I.R.E.*, **22**, 78 (1934).

current. In the circuit of Fig. 3-18, the flow of grid current through the grid-circuit impedance z_c causes the instantaneous alternating grid voltage e_g to be less than the instantaneous grid excitation voltage v_g

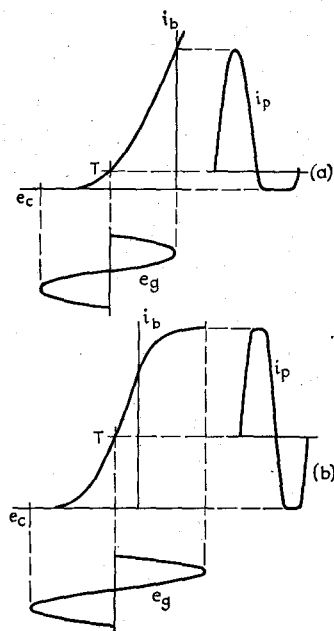


FIG. 5-1.—Distortion of waves of plate current as the result of overloading.

during the time in which the grid is positive. In the circuit of Fig. 5-2, the excitation voltage is produced by the flow of alternating current i_z through the grid-circuit impedance z_c . During the part of the cycle in which the grid is positive, a portion i_g of the current i flows into the grid of the tube and so reduces i_z below the value that it would have if grid current did not flow. The alternating grid voltage is therefore also reduced below the value it would have if the grid did not conduct. Flattening of the peaks of alternating plate current as the result of excessive grid excitation voltage is called *overloading*. Flattening of the plate current peaks is an indication of the generation of harmonics and intermodulation frequencies of large amplitude.

Frequency distortion in an amplifier or other four-terminal network is the variation of amplification or sensitivity with frequency of the impressed signal. In a vacuum-tube amplifier it results from dependence of circuit and interelectrode impedances upon frequency.¹ It can be minimized by proper design of input, output, and interstage coupling circuits, being least in amplifiers in which the circuits do not contain reactance. The difficulty of preventing frequency distortion increases with the width of the frequency band for which the amplifier is designed and with amplification per stage. Although frequency distortion may not produce disagreeable effects in the amplification of music, it impairs fidelity of tone and may prevent the reproduction of the sounds of some instruments. By eliminating the high frequencies essential to the reproduction of consonants, it may make reproduced speech difficult to understand.

¹ At ultrahigh-frequency electron transit time also causes frequency and phase distortion.

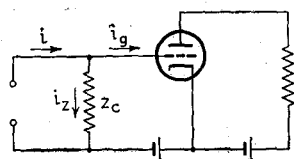


FIG. 5-2.—Diversion of current from the grid-circuit impedance as the result of flow of grid current when the grid is positive.