Bass Without Big Baffles

Subjective Synthesis from Artificial Harmonics

By K. A. EXLEY

MODERN amplifiers, attractive as they may be in their aesthetic achievements, still suffer, in the opinion of the writer, from certain practical disadvantages.

First, in consideration of the question of initial cost and complexity of equipment, many constructors cannot afford the time, money or even perhaps patience, required to produce a high-fidelity amplifier containing ten or twelve valves in its main and pre-amplifier stages, apart from the power-supply units.

Secondly, few enthusiasts can erect a large enough baffle system in their small living rooms to radiate the low frequencies so faithfully presented to the loudspeaker by such an elaborate amplifier. Due usually to complaints from their less scientifically minded cohabitants, enthusiasts resort to using small baffle systems in which (in the case of cabinets) to house their loudspeakers. The result is loss and wastage of the bass tones which can never reach the ear in sufficient volume for musical requirements. In addition, damage to their loudspeakers is probably due to insufficient air loading at low frequencies.

The idea underlying this article may not find ready acceptance with high-fidelity purists, but it is one which has proved of value in other branches of music-making.

It is worthy of note, that a 50-c/s note suffers a loss of 8 db when the loudspeaker is mounted on a baffle board as large as 6 feet square.

Regarding the reproduction of middle and high audio frequencies, few will disagree with the statement that it is easy, with a modern moving-coil speaker and negative feedback, to obtain a high standard of fidelity. The main difficulty in achieving realistic reproduction in the home seems to be in making the lower bass frequencies audible with reasonably *small* baffle systems.

There are two possible modes of approach to the problem. The first lies in the adoption of either a vented or an infinite baffle type cabinet. Such cabinets require special construction and if the range of frequencies radiated is to extend down to 30 or 40 c/s, a cabinet of considerable dimensions is required. The second approach to the problem is utilized in the amplifier to be described, and has the advantage of economy and simplicity. The method consists essentially of increasing the harmonic content of the lower bass frequencies by introducing harmonics from a second channel in which amplitude distortion has been allowed to occur.

The Human Ear

Before proceeding further we must consider one or two basic points. First, it is wished to stress that the human ear, with its physiological imperfections, and the pleasurable or unpleasurable impressions that it is capable of receiving from a sound, should be the ultimate and final judge of the performance of any amplifier intended for the reproduction of music. Second, the term "realism of reproduction," involves the use of a subjective sense which is not interested, necessarily, in either linearity or freedom from distortion. It is not a term, therefore, to be assessed on cathode-ray oscilloscope appearances.

The human ear is far from being distortionless in itself, and, due to its properties of adding subjective tones, finds it almost impossible to distinguish between a pure fundamental tone, and suitably mixed harmonics with the original fundamental removed. For similar reasons, the aural senses are particularly tolerant to the addition of harmonics to a fundamental tone whose frequency lies below 100 c/s, and tend to interpret the phenomenon as an increase in volume of the fundamental. Above 100 c/s, however, the addition of random harmonics to a fundamental tone becomes increasingly unpleasant to the ear.

These facts are made use of by organ builders, who, in order to economize in space, replace lengthy bass pipes by several shorter ones in harmonic relation which are sounded in unison instead of a fundamental pipe. We are quite justified in deceiving the ear if the results are pleasurable from a musical standpoint.

Similarly, in the case of an amplifier, harmonics can be added to a low fundamental frequency by the introduction of non-linearity, and the ear notices little alteration in the sound from the loudspeaker. But, due to their shorter wavelength, harmonics can be radiated from a small speaker and baffle with greater efficiency than their fundamental. Using this principle it is possible to obtain an apparently full and realistic bass response from quite small baffles or cabinets.

Amplifier Details

Referring to the accompanying diagram, it will be seen that the circuit is designed with a view to economy of components, and comprises three stages of amplification, the final of which is a single output pentode V_4, with negative feedback.

The additional valve V_3, in the second stage is for the purpose of generating the required harmonics. Gain will be found adequate for many of the popular gramophone pickups.

The first stage of the amplifier comprises a high-gain triode V_1, preceded by a volume control at the input end of the circuit.

In the second stage, the low-gain triode V_2, is preceded by a simple but versatile tone compensation circuit. Three controls alter separately the levels of bass, middle and high audio frequencies over a relative range of up to 26db. It is not claimed, however, that *accurate* correction of recording characteristics can be obtained with this simple tone control circuit. It may be thought strange that the middle frequency level is made variable, but this enables the full power output of the amplifier to be used if required, without the addition of a further stage of amplification.

The output stage consists of a 4.5-watt pentode, loaded through a high-inductance output transformer. Negative feedback, which is linear, is taken from the secondary of the transformer to the cathode of V_2, but not to the distorting valve V_3. Resistive values quoted for the feedback circuit pertain to the use of a speech coil of impedance 15 ohms.

The distorting valve V_3, receives its input from the anode of V_1, through a low-pass filter R_5C_4, and is, for all practical purposes, functional only below about 100 c/s, with the usual settings of the tone controls. A high-gain triode is used in which grid distortion is produced by providing a high anode load R_{12}, of 0.5 megohm, and zero cathode bias. The distorted output from V_3, (which is equivalent to the fundamental plus multiple harmonics), is coupled to the grid of the output valve by means of a condenser C_8, and a switch. The latter allows the "harmonic bass" component to be switched in or out of the main amplifier as desired.

It will be noted that V_3, is not included in the feedback loop for obvious reasons, but further distortion of the harmonic component in the output stage is

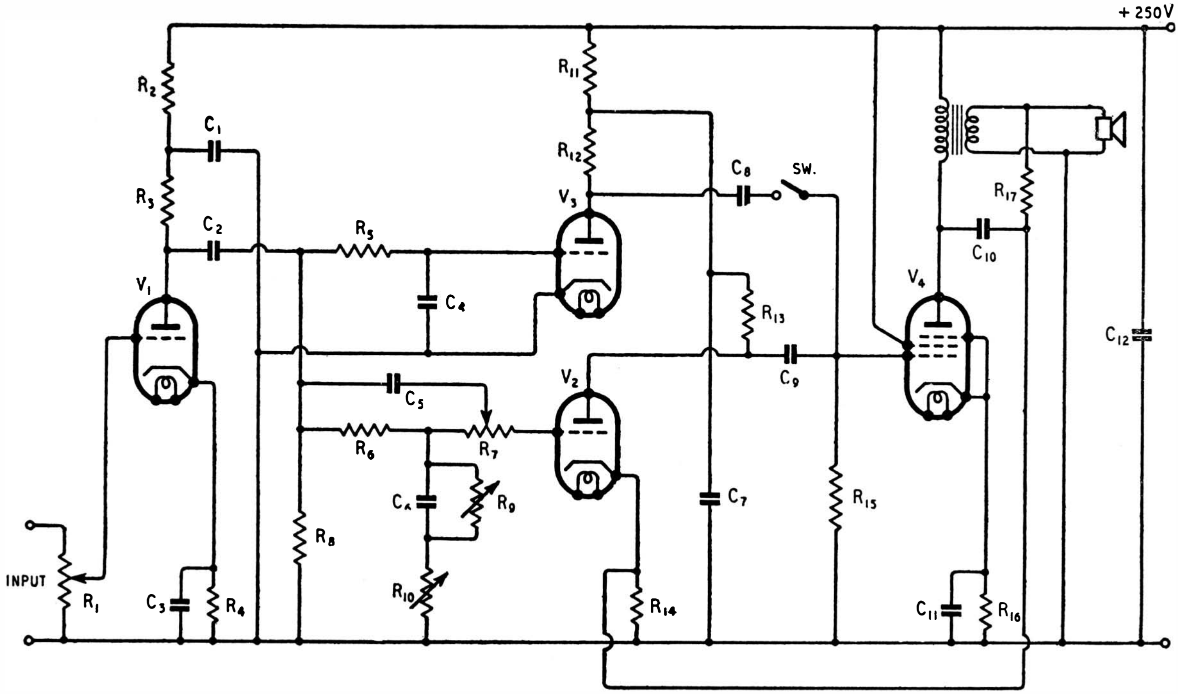

Fig. 1. Circuit diagram of amplifier with non-linear stage, V3, for producing artificial harmonics at low frequencies.

List of Component Values for Circuit of Fig. 1

R_1 50 kΩ, variable (or other value suitable to source impedance.)
R_2 22 kΩ, (1 watt)
R_3 0.1 MΩ
R_4 2 kΩ
R_5 0.1 MΩ
R_6 0.1 MΩ
R_7 0.25 MΩ, variable (treble control)
R_8 0.5 MΩ
R_9 0.25 MΩ, variable (bass control)
R_{10} 100 kΩ, variable (middle-frequency control)
R_{11} 10 kΩ, (1 watt)
R_{12} 0.5 MΩ
R_{13} 47 kΩ, (1 watt)
R_{14} 1 kΩ
R_{15} 0.25 MΩ
R_{16} 180Ω, (3 watt)
R_{17} 2 kΩ, (for 15-ohm speech coil)
All resistors are $\frac{1}{4}$-watt rating unless otherwise stated.
C_1 8μF, electrolytic, 350 V working
C_2 0.1 μF, paper
C_3 50 μF, electrolytic, 25V working
C_4 0.1 μF, paper
C_5 500 pF, silvered mica
C_6 0.05 μF, paper
C_7 16 μF, electrolytic, 350 V working
C_8 0.1 μF, paper.
C_9 0.1 μF, paper
C_{10} 100 pF, silvered mica
C_{11} 50 μF, electrolytic, 50V working
C_{12} 32 μF, electrolytic, 350 V working
V_1 and V_3, 6SF5 (or equivalent high-gain triode)
V_2 6J5
V_4 EL33 (Mullard) Sw, switch, panel type.

minimized by reflex negative feedback through V_2.

The final bass product reaching the loudspeaker is a mixture of the "pure" bass component from V_2, and the "harmonic" bass component from V_3, with a slight, though unimportant, phase difference between the two. The middle and high audio frequencies do not pass through the non-linear channel and are therefore not themselves distorted or modulated.

The small feedback condenser C_{10}, is merely to avoid troubles with the leakage inductance of the output transformer at high frequencies.

It is advisable to use with the amplifier a loudspeaker whose diaphragm has a soft suspension, with a bass resonance below 60 c/s. Some commercial manufacturers produce a type of artificial bass by forcing the low frequencies into a speaker with a high bass resonant frequency e.g., 150 c/s. Although this may make a bass note "audible" using a small baffle, the results are unnatural and displeasing to the ear on music and even more so when reproducing speech, owing to boom and accentuation of the upper bass region.