A CLASS-D HI-FI AMPLIFIER

A practical circuit using pulse-width modulation
By I. Queen. Radio-Electronics, September 1967.

Switching amplifiers have been described several times in recent publications. A build-it-yourself amplifier of this kind was covered in a series of articles by Norman Crowhurst which began in Radio-Electronics for July 1965. The response of the amplifier was quite limited and I wondered what could be done to broaden it for hi-fi use. I found my answer during a trip to england. I came across the Sinclair X-20 switching-type hi-fi amplifier. This mode of operation is also called class D and pulse-width modulation. This is a description of that unit.

The X-20 uses 12 transistors, is mounted on a printed-board measuring 8 1/4 x 3 1/4 x 1 inches, and weighs less than 4 1/2 oz. It has less than 0.1% total harmonic distortion at 10 watts. Though it is capable of 40 watts peak music power, Sinclair specifies it at 20 watts of average music power.

The X-20 was available without power supply or volume and tone controls. We mounted the X-20 in an aluminum chassis (10 x 5 x 3 inches) and added the tone and volume controls and power supply. Fig. 1 shows the simple supple we used and Fig. 2 the controls.

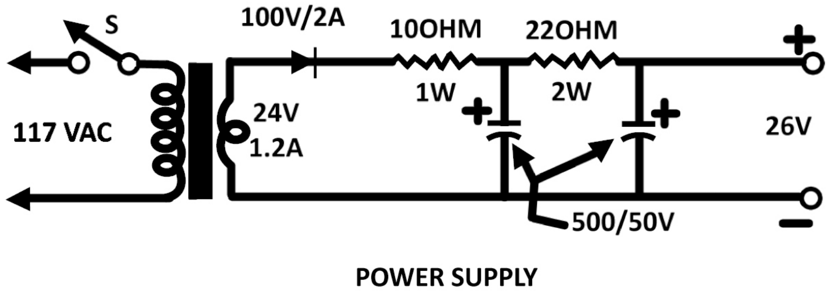

Fig. 1 - Power supply for the amplifier

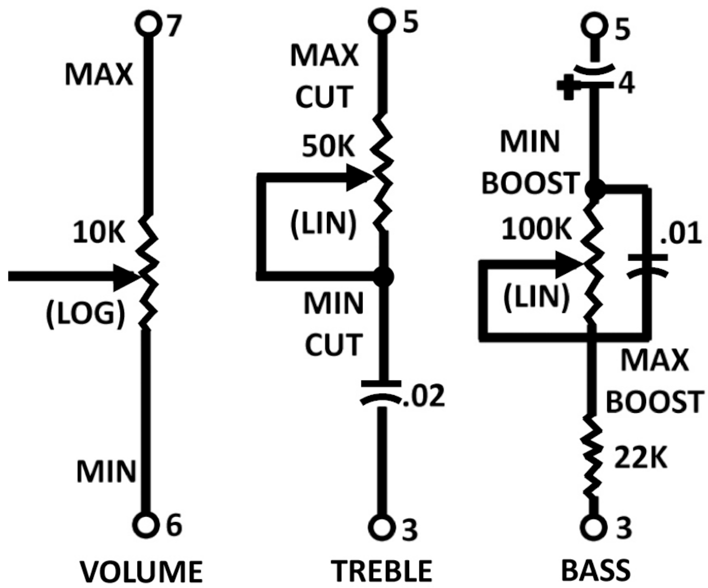

Fig. 2 - Amplifier controls. Either or both tone controls can be used

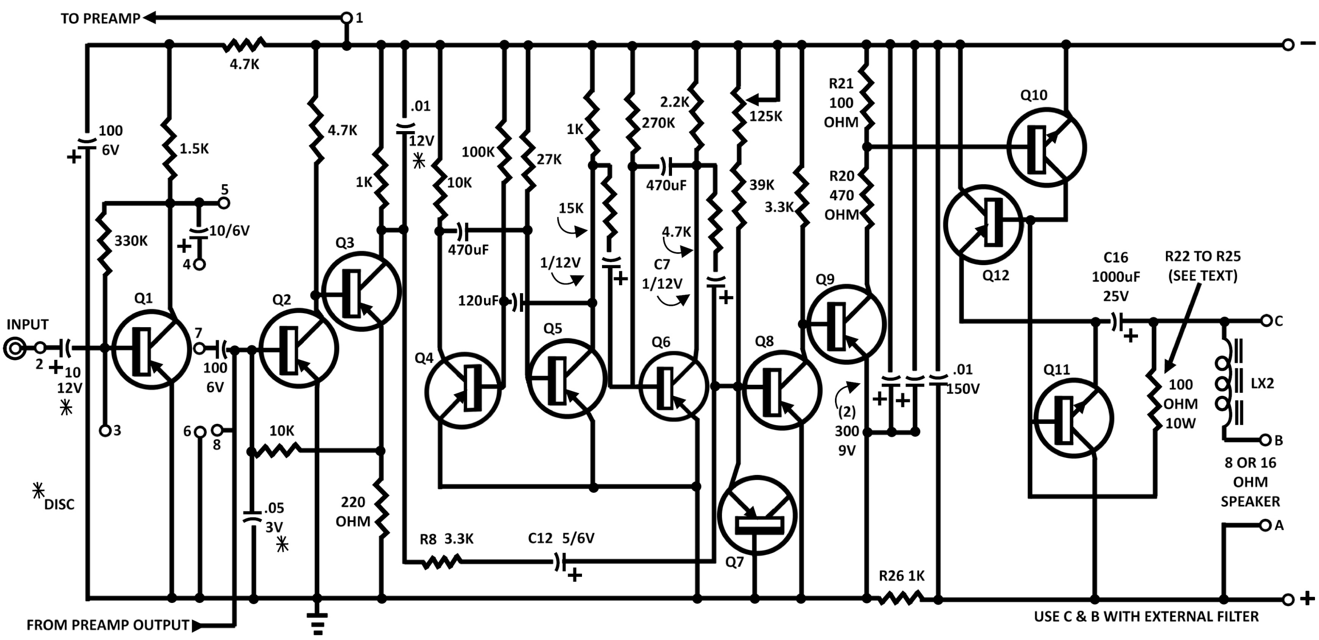

Fig. 3 - Schematic of the Sinclair X-20 pulse-width modulated amplifier.

The schematic of the X-20 is shown in Fig. 3. The operation is as follows:

Q1 is a preamplifier stage which can handle as little as 1 mV (into 5,000 ohms). The preamp stage is followed by high-gain stages Q2 and Q3, after the external volume control. Q4 and Q5 form a free-running multivibrator at about 75 kHz. The output of Q5 is a square wave. It is fed into Q6, a feedback integrator - note the capacitor between collector and base. After integration the waveform becomes triangular and is fed into Q8 and Q9. Q7 (a transistor with collector left open so it acts as a diode) conducts only when the applied signal exceed the negative bias at it's emitter - that is, its anode in this hookup.

C7 and Q8 differentiate the square waves, converting them to pulses. Negative peaks drive Q8 to conduction blocking Q9. Positive peaks will block Q8, this permitting Q9 to conduct. Due to the large amplification of Q8 and Q9, the transistors are overloaded by these pulses, and their tops are flattened. The output becomes a symmetrical square wave, assuming there is no audio signal being fed into the amplifier.

When audio is applied, signal from Q3 are fed through R8 and C12. Q7, acting as a diode, mixes them with the pulses from Q6. When the speech signal is positive-going, it adds to the positive pulse, increasing and widening it. At the same time, the positive going speech signal will reduce and narrow the negative pulse, when it is present. Of course, when the audio wave goes negative, the opposite will happen (see Fig. 4). During a complete audio cycle, the output waveform from Q9 will look like Fig. 4-a then like 4-b, back to 4-a then to 4-c, then finally back to 4-a. The pulses, varying in width according to the audio-rate signal being fed to the amplifier, are reduced in amplitude by R20 and R21, then fed to the base of Q10

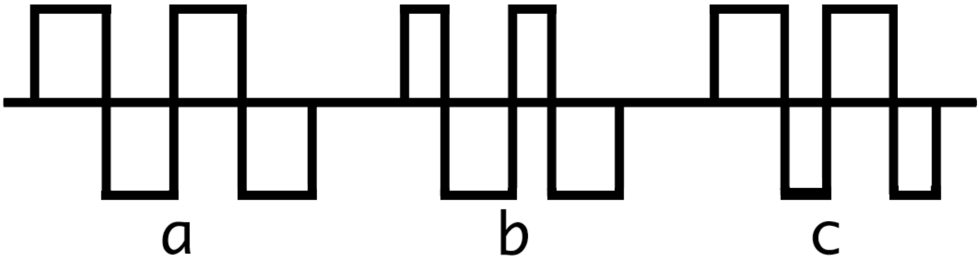

Fig. 4 - Amplitude output waveforms.
Pulse width - above and below baseline - varies with instantaneous polarity and frequency of the audio signal.
a - No audio Input, **b** - the negative audio half-cycle, **c** - the positive half-cycle.

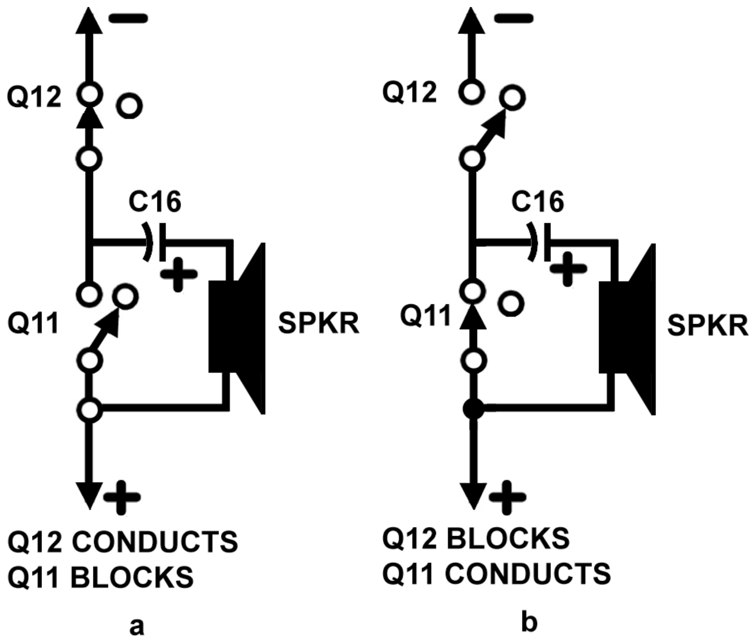

Fig. 5 - Basic output circuit with Q11 and Q12 represented by switches.

Transistor Q10 acts as a control device, whose resistance varies with its base bias. When the base goes more positive (than its emitter) Q10 conducts. The transistor blocks when the base goes more negative, of course.

The two-transistor output stage, Q11 and Q12, is in series across the power supply. When the control transistor conducts, the bases of both output transistors are in effect connected to negative. Therefore, Q12 conducts, whole Q11 blocks. On the other hand, when the control transistor is blocked, the bases of the output transistors return to positive, through resistors R22, R23, R24, R25 (shown as a 100-ohm, 10-watt unit) and the speaker. Q11 conducts, and Q12 is cut off.

What effect does this have on the speaker? Fig. 5 shows. For the moment, assume there is no audio to the amplifier, Q10 will have equal on-off intervals at the high switching frequency of 75 kHz. Q11 and Q12 are represented by switches. In fig. 5-a, C16 will charge through the speaker. In 5-b, it discharges and current goes through the speaker in the opposite direction.

When audio is applied to the input of the amplifier, conditions change. The negative and positive pulse widths are no longer equal. One output transistor will conduct for a longer period than the other. During the next half-cycle, the second transistor will conduct longer. And so on. This pulse width varies at the audio rate of the input signal, which becomes audible in the speaker.