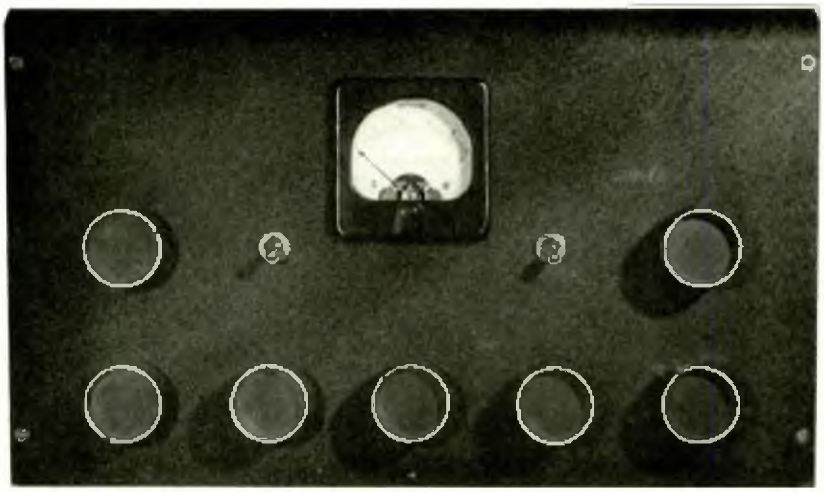

Multi-Purpose Audio Amplifier

MAURICE P. JOHNSON*

This high-quality audio amplifier combines high gain, unusually high fidelity, and an expander-compressor circuit. It can be easily built from readily obtainable components.

INNUMERABLE AUDIO AMPLIFIERS have been built to serve as "general purpose" systems, and have performed with varying degrees of excellence.

One common complaint against this type of unit, however, is that the very simplicity of the typical circuit limits its scope of application. On the other hand, some systems have been designed for special purposes, often with the result that the complexity of circuits results in a bulky, heavy unit, and again of restricted versatility.

The amplifier to be described incorporates more tubes and circuit features than are usually found in the general run of amplifiers in its power output class. It has been designed to serve equally satisfactorily as a recording and playback amplifier for a small studio, as a high-quality audio system for a-m and f-m tuners, and as a speech amplifier for a "ham" transmitter. The features included allow the unit to perform all the usual audio work of the home, ham-shack, or small studio. At the same time, it is compact enough to be portable without being unwieldly.

The circuit and construction shown are the result of careful study and trials of already available amplifiers. Several trial constructions and tests of possible circuit features and combinations were made, and the resulting final design incorporates the features which were considered necessary and equally useful in all the intended applications.

The unit has been tested for each of the above uses, and has been found entirely satisfactory in all cases. When used with a good speaker system, the quality leaves nothing to be desired. With an f-m, or a good a-m tuner, the fidelity of reception is extraordinary.

Design Considerations

In the selection of the output tubes, the requirements for each intended use were carefully considered.

For amateur applications, there are class B modulator tubes available to provide almost any modulation power needed, and those tubes generally used by hams can be driven by ten watts or less of audio. If the speech amplifier is designed to drive such tubes, it need not be altered as the transmitter grows in size and power, which results in a considerable saving in both time and expense as time goes along.

The best class B drivers would be constant-voltage tubes, and the nearest to constant voltage of the types available is the 6B4G series. With 350 volts on the plates, a pair of 6B4Gs in push-pull with self bias will give ten watts of audio power output with less than 5% total harmonic distortion. This will be sufficient for most modulators used by amateurs.

Recording heads and speakers present a variable impedance load, and for such use the 6B4Gs again give best results. Commonly used cutting heads require approximately one watt for average disc modulation, but several serious recordists have pointed out that a reserve power of ten times the average is necessary if instantaneous peaks are to be handled without distortion. This requirement is met readily by the ten-watt output.

High power is not generally needed for normal playback uses, but the dynamic range of this amplifier is increased by an expander circuit, described below. The extra power available allows high-level peaks without excess distortion.

Other requirements leading to the selection of a push-pull triode output were the desire for low hum levels, low distortion, and good frequency response without using degenerative circuits.

Since ten watts of audio meets all the demands to be made of this amplifier, operation of the 6B4Gs in push-pull with self-bias is entirely practical. This simplifies power-supply circuits, and also allows the use of a phase-inverter input instead of an input transformer. Resistance-capacitance coupling throughout the amplifier aids considerably in keeping the hum level low by avoiding inductive hum pickup, as well as inexpensively allowing good frequency-response characteristics.

A dual triode is desirable for phase-inverter use. A 6N7 will provide the high signal voltage necessary to produce full power output with the 6B4Gs. A self-balancing inverter circuit is used which automatically adjusts itself to slight differences in tube characteristics, and this particular circuit has proved the most satisfactory of several tested.

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Tone Control

In some applications, a flat frequency response is desired, but for maximum versatility some control over the response is necessary. In recording, a rising treble response is highly desirable. In a speech amplifier, however, suppression of the highs and lows allows maximum power at the speech frequencies, and an opposite response curve is needed. For these reasons, a popular type of dual tone control was selected for this unit, which makes use of a degenerative cathode circuit built around a 6C5 tube. Dual controls permit independent control of each end of the audio range. Either boost or attenuation of highs or lows is available with the two control potentiometers, so that practically any response curve can be obtained. The circut is so arranged that unity stage gain is obtained at mid-frequencies, regardless of the settings of the controls. More complete details on this tone control circuit can be obtained from the manufacturer of the special choke required for bass control.

It is accepted practice to limit the dynamic range of the material being recorded to prevent overcutting the disc at high volume levels, while keeping low volume levels at a suitable value above amplifier and disc surface noise. This calls for volume compression to be included in the amplifier. During playback, the volume range of the recording must be artificially increased to restore the reproduction to its original range and brilliance. This action is obtained from an expander.

In phone work on the ham bands, a high average modulation is needed for best operation. However, if the audio level is high, with the conventional speech amplifier, there is always the danger of overmodulation on voice peaks resulting in splatter. The compressor circuit is ideally suited for this application, since it will allow a high average modulation, while suppressing the peaks to prevent overmodulation. The compressor performs this helpful service by suppression rather than clipping of the audio peaks, and therefore gives less distortion.

——(Editor's Note: *The standard Thordarson tone control circuit employed here uses constants which cause the high-frequency boost curve to depart from flat at about 600 cps. Some users prefer to have the departure occur somewhat higher up in the frequency band, so that the response up to 2,000 cps is not affected by the boost control. To obtain this effect,* C_{11} *should be reduced in capacitance, with a suggested value being 0.005 μf.*)

Because of these advantages, it was decided that an expander-compressor circuit should be included in the design, and it is well worth the three tubes needed for its incorporation.

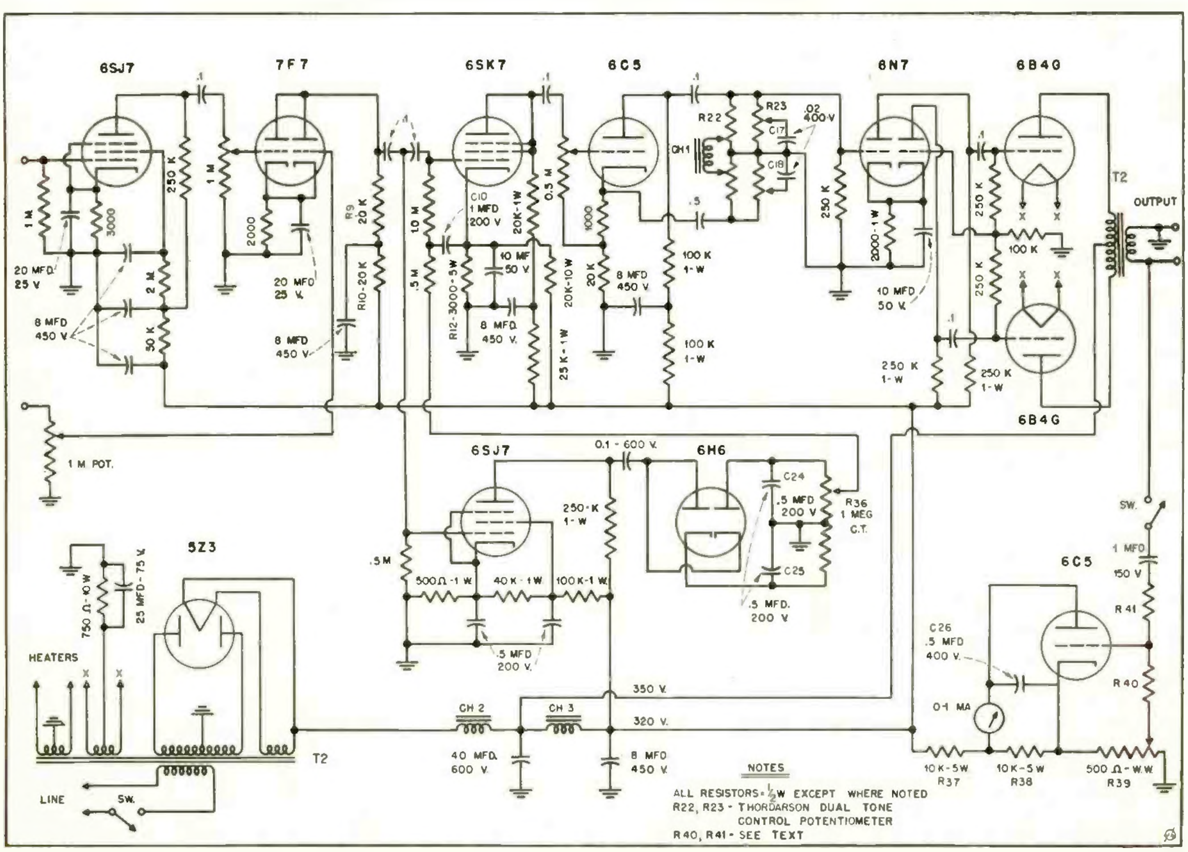
Expressor Circuit

The functions of expansion and compression are both available in the "expressor" circuit used, based upon a circuit originally appearing in *Electronics**. A 6SK7 tube is selected as the control tube because of its variable mu remote cut-off feature. The plate, screen, and suppressor are tied together to permit operation as a triode. The normal bias on the tube is obtained from the voltage divider formed by *R-13* and *R-16* in series.

Part of the input signal for the 6SK7 is fed to the 6SJ7, which works as a conventional pentode voltage amplifier. The amplified signal output of this tube is fed to the plate of one section and the cathode of the other section of a 6H6 duo-diode rectifier. The remaining plate and cathode are connected to the ends of a center tapped potentiometer, the center tap being grounded. The output of the 6H6 is a d-c voltage which

*"Volume Expansion with a Triode," by C. G. McProud, *Electronics*, August 1940.

Schematic diagram of the multi-purpose audio amplifier.



is applied to the signal grid of the 6SK7 tube, along with the regular signal input. This d-c voltage acts as the bias which causes expansion or compression, depending upon the voltage polarity. The RC values of this bias circuit are such that the bias follows the general audio level, rather than the audio itself. Since the time constants of the circuit are rather critical, for proper operation it is recommended that the values given for the parts be adhered to closely. Some control over the time delay may be had by varying the size of *C-10*, but the value listed was found to give a good average delay for ordinary use.

Potentiometer *R-36* allows control of the value of bias voltage. Maximum expansion is had at one end of the control, and maximum compression at the other extreme. Setting the control to the mid position grounds out the control-bias voltage, and thus removes the expressor action altogether. The 6SK7 then operates as a regular low-mu triode. Naturally, intermediate settings of the control potentiometer will give intermediate amounts of expression.

——(Editor's Note: *There are two time constants involved in any expressor circuit, and both should be considered. "Attack" time refers to the delay in operation of the circuit to increase or decrease the volume upon application of a signal, while the "release" time is the delay in return to normal gain. In this circuit, the attack time is the product of* R_{11} *and* C_{10}*, and the release time equals the product of* C_{35} *and half of* R_{36} plus *the attack time. Listening tests have indicated a recommended value of the order of 75 milliseconds for attack time and this delay would be obtained if* R_{11} *were 0.5 meg and* C_{10} *were 0.15 μf. The release time should be longer, usually between 200 and 300 milliseconds. With the suggested values for* R_{11} *and* C_{10}*, this would necessitate the use of 0.35-μf capacitors for* C_{34} *and* C_{35} *with the center-tapped 1-megohm potentiometer* R_{36}*.)*

The input circuit will depend upon the manner in which the amplifier is to be used. The amplifier shown in the photographs was intended for use with a remotely located multi-input preamplifier, which would be used whenever microphone pickups were necessary. Therefore, it was decided that two medium level input channels would be sufficient. One channel could be fed by the remote preamp, and the other channel serves for the turntable or tuner locations, through the use of a simple switching panel. The two amplifier inputs are of the high impedance type.

A dual triode is used as an electronic mixer, by feeding the grids individually while the plates are tied in parallel. Several types of tubes and variations of the mixing circuit were tried before the one shown was selected. A lock-in tube was chosen since it had the lowest noise level of types tested for this application.

In many cases, it is recommended that isolation resistors be added in the plate coupling arrangement, when dual triodes are used for this form of electronic mixer. However, the parallel connection of the plates to a single load resistor simplified the problem of shielding the leads and reduced the hum pickup at this sensitive point to a marked degree. A careful check of the mixing action proves that there is no interaction of the controls, and no noticeable distortion occurs in the stage. This is by far the most satisfactory of the many mixer elements commonly encountered.

Each mixer grid is fitted with a volume control potentiometer for controlling the input signal amplitude. A master gain control is added between the expressor and tone controls.

Although not used in the original construction, a 6SJ7 preamplifier stage is shown in the schematic. This was added for those persons who may wish to duplicate the amplifier and desire at least one microphone input without the necessity of using a separate preamplifier. It is recommended that not more than one microphone channel be added to the main amplifier chassis, because of the difficulty of adequately shielding and decoupling the high-gain stage when located with the power supply. If more than one mike channel is needed, a preamplifier is the best solution. It is then suggested that the layout shown in the photos be followed for the amplifier, and two medium level inputs be made by feeding the 7F7 grids directly, with the associated gain controls, in a manner similar to the one medium-level input to the 7F7 shown in the schematic.

Top view of the multi-purpose audio amplifier.

Monitoring Recordings

Another feature which has proved to be very useful is the output meter shown connected across the output transformer secondary. Special db or vu meters are available for use in keeping an accurate check on the output levels.

What was desired in this case, however, was not so much an extremely accurate indication of the exact output, but rather a simple indicator of reasonably good frequency characteristics for monitoring the recording level. A simple vacuum-tube voltmeter was constructed with an 0-1 ma meter as the indicator. The circuit is conventional. *C-26* is added to enable the movement to respond to peaks which might otherwise not show up on the meter. A 7F7 section was used for the triode meter tube in the pictured unit, but a 6C5 would be more suitable because of its metal shield. *R-39* is a wire wound potentiometer for adjustment of the bias. This allows the meter to be adjusted to function as a regular output indicator, by setting the bias so that the meter reads zero or nearly zero plate current with no signal. Any signal voltage will then cause the meter to read up scale, due to the rectifying action of the tube. It is also possible to increase the bias beyond the cutoff value, so that the meter will respond only to peaks. One note of caution: With no bias, the tube will draw more than the one milliampere maximum rated for the meter movement, therefore it is important to adjust the bias from a full-negative value toward a less-negative voltage. Cutoff will be readily determined, since the meter will begin to read a steady value of plate current if the bias is reduced below the cutoff value, with no applied signal.

There are many ways of coupling this output meter to the amplifier. Care must be taken to avoid shorting out the input to the meter. The coupling method shown has been satisfactory. The values of *R-40* and *R-41* must be selected by trial. They should be chosen so that the meter will read about half scale with normally used audio levels. It may be desirable to make a variable voltage divider if the amplifier is used repeatedly at varying levels. In the unit shown, *R-40* was made one megohm and *R-41* was made 5 megs to give good meter indications at normal speaker levels of approximately 5 watts.

The power supply is conventional. The components are oversize to give trouble-free operation and avoid excessive heating. Filter capacitors are large, and choke input is used. Separate windings are used for the output-tube filaments so that self bias can be used.

Considering the circuit as a whole, it will be noticed that every attention has been paid to securing freedom from hum without sacrificing good fidelity. Extensive decoupling is used in the plate voltage leads. By-pass and filter capacitors are large. Triodes are used wherever possible, with low values of plate loads. Coupling capacitors are large enough to give good response at the low frequencies. All resistors, and particularly those in the high-gain input stage should be of highest quality to reduce circuit noises as much as possible. The layout has been made with the idea of keeping the amplifier compact and without crowding of components. Care in construction and wiring has been amply rewarded in noise-free and trouble-free operation.

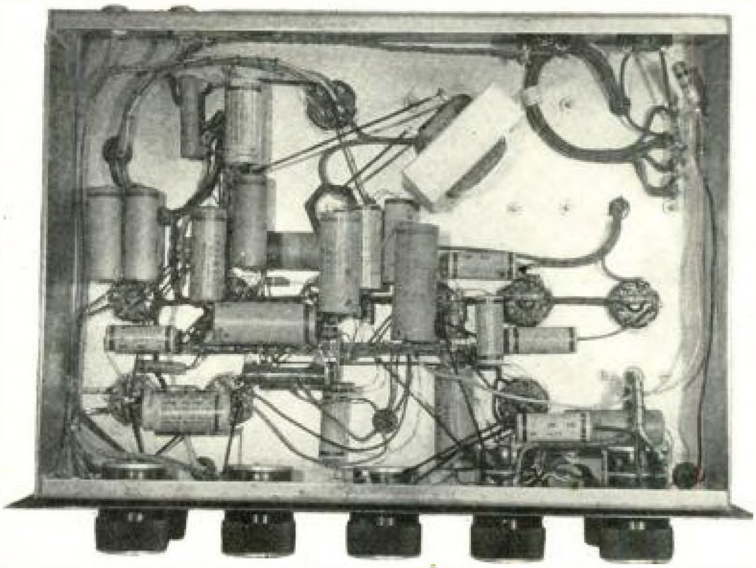
Construction

For those interested in duplicating this amplifier unit, the following information may be helpful.

The unit shown in the illustrations was constructed on a 10 x 14 x 3 inch chassis, and mounted in a desk style cabinet with a 9 x 15 inch front panel.

The controls, from left to right along the bottom of the panel are: bass control, treble control, master gain control, first input gain control, and second input gain control. Above the bass control on the left of the panel, is the output-meter bias adjustment. Beside this is the toggle switch in series with the meter lead. In the center of the panel is mounted the milliammeter. This is followed by the line switch, while the expressor control is mounted to the extreme right.

Looking at the top of the chassis, the power supply is arranged along the rear edge, the input choke and filter condenser mounted above the chassis. The output transformer is at the left rear. The row of tubes in the center, from left to right, consists of: push-pull 6B4Gs, 6N7, 6SK7, 6SJ7, and 6H6. Directly behind the panel, from left to right, are the tone control choke, followed by the 6C5 tone-control tube, and at the right of the meter, the output-meter tube and the 7F7 input mixer. If the 6SJ7 input stage is to be used, it



Bottom view of the multi-purpose audio amplifier.

should be located at the right, where the 7F7 is now shown, the 7F7 moved to the left where the meter tube is now located, and the meter tube mounted directly behind the meter movement. These locations have been selected in the interests of low hum and minimum interaction between stages. The components directly behind the panel should be set back sufficiently to avoid interfering with the controls and meter which are mounted on the panel.

The under-chassis view shows that the wiring is made as direct and point-to-point as possible. A row of tie-down lugs is run between the two lines of tube sockets, to mount resistor and condenser leads. The power supply wiring is cabled. The high-gain input leads are all made with shielded wire, which is bonded to the chassis every few inches. All ground points are tied together with bus-bar, even though the chassis is itself at ground potential. Care in wiring throughout will give an amplifier with inaudible hum even at high output levels.

Operation Notes

Some comments on the proper adjustments for best operation of this unit are in order.

With all controls full open, the gain in the amplifier becomes excessive. In fact, when an ordinary commercial shellac pressing is played with a high-quality pickup of the high-impedance type which gives approximately one volt output, the 6B4Gs will be overdriven if the controls are fully opened. The reason for incorporating this extra gain, however, will be apparent when the proper adjustment of the circuit is explained.

For correct action of the expressor, the signal applied to the 6SK7 grid is rather critical. With insufficient signal, the control bias developed will be low, and it will be impossible to obtain complete expansion or compression. On the other hand, if too great a signal voltage is applied to the grid, the expression bias will cause over-compression and over-expansion. Correct voltage will give smooth expansion with no tendency to distort, and will hold the output signal at a constant level when compressing, with no tendency to squelch or cut-off the 6SK7.

The input gain controls are used to set the signal to the proper level for proper expressor action, and usually this will call for about 0.25 to 0.5 volt signal on the input-mixer grid. Once the input gain controls are set to this level, there will be no need for readjusting them until a different pickup device is used. The master gain control, which is located after the expressor stage, is used as the conventional gain control, to set the output volume level to that desired for any particular application. Under these conditions of operation, a check of the waveform at each stage was made and no distortion was apparent on the c-r tube, even with the master gain control fully on.

Control over expansion or compression is had by varying the bias by means of potentiometer *R-36*. Do not use the input gain controls as a means of varying the expressor action, once the controls have been set to the proper positions.

Adjustment of the meter bias control was covered above. The remaining controls are conventional in action, and no

[*Continued on page 39*]

that below 700 cycles or above 7,000 cycles the intensity of the tones must be greater, and that it is particularly so with the bass notes to give a loudness of 60 db. The decibels of loudness levels are called Phons.

The required increase of intensity of the frequencies above 7,000 cycles does not vary greatly with the various degrees of loudness; but such increase does vary greatly in the frequencies below 700 cycles per second, and a higher fidelity is favored by great loudness. Therefore, any controlled reduction of amplified volume causes a greater loss in bass response and warrants a "boosted bass" in phonograph records and radio amplifiers, but it also makes automatic volume control likely to produce an unbalance between bass and treble tones.

Within certain limits all of our sense organs conform to the Weber-Fechner Law in psycho-physics: that equal increments of sensation are associated with equal increments of the logarithm of the number which represents the comparative ratios of the stimuli (therefore, the relationship between increase of stimulus and resulting increase of sensation).

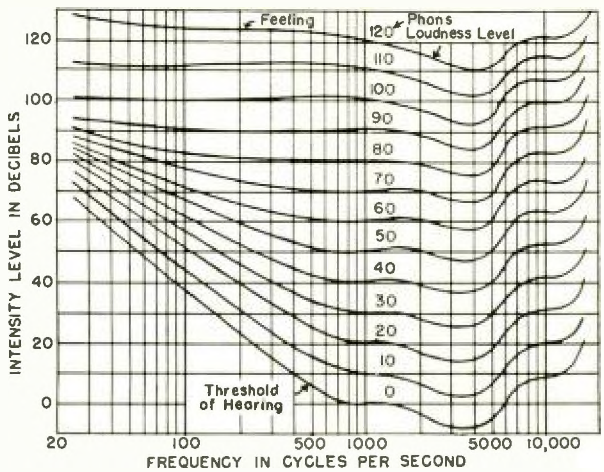
If one listens to music from a point 100 feet away and approaches to 10 feet, since the intensity of sound varies inversely as the square of the distance, it will be 100 times or 20 db greater. Also, all tones below 700 cycles frequency will sound disproportionately louder and a 100-cycle tone will have a loudness level a further 20 db above a higher-pitched tone. Thus the bass tones are lost as we get farther away or as the volume of a loudspeaker is reduced.

Overloading

When the ear is overloaded it acts as does an overloaded electron-tube amplifier by departing from a straight-line magnification of impressed frequencies and acting as a modulator which originates harmonic frequencies. This takes place when the intensity of the impressed tone exceeds 40 decibels above its threshold of hearing value; and higher harmonics result from increased overloading.

Another result of overloading is the impression in the brain of a shift in pitch, which is particularly noticeable for tones of 100 to 200 cycles per second. At 60 db, the tone seems two per cent lower in frequency, at 76 db three per cent lower, and at 93 db eleven per cent lower (as determined by S. S. Stevens at Harvard). Dr. Harvey Fletcher noted that a 222-cycle tone at 100 db sounded the same pitch as a 200-cycle tone at 40 db; and that a 421-cycle tone at 100 db was the octave above the 222-cycle tone and sounded the same in pitch as a 400-cycle tone at 40 db. Since the intensities produced by orchestras may be as high as 100 db it is evident that the crescendos produce dissonances.

Fig. 7. Intensity of sound waves at various frequencies (Fletcher).



Furthermore, if a pure tone receives a cyclical variation of its intensity its frequency is increased and decreased by the frequency of the intensity change; and the fundamental has only one-half intensity and each side-band one-quarter. A different modulation occurs where there is a cyclical variation of the frequency of a pure tone. This produces the musician's vibrato, which is best when varying six to seven times per second.

Visual Perception

An equivalent illusion occurs with visual perception where the speed of a rotating body appears to increase as the illumination is decreased, and vice versa. This indicates that there is a timing function associated with the mechanism of transmission of nerve impulses to the brain. About twenty years ago the writer proposed an electrostatic bio-chemical hypothesis to explain the transmission of nerve impulses as due to the charging and discharging of electrical condensers in the nerve system.

The time interval for charging would depend upon the intensity of the stimulus, and the frequency of charge-discharge cycle would also vary with such intensity. Therefore, an image would move a shorter distance (for a given velocity) upon the retina between successive periodic stimulations of the optic nerve endings when receiving a high illumination intensity than it would with dim illumination. Similarly with the stimuli of sound, the more rapid nerve transmission of high intensities gives a brain sense of a greater interval between each cycle, and therefore a lower pitch of tone.

In the construction of a nerve there is a central "axis cylinder" of about nine per cent of the nerve fibre, encased by a sheath of fatty myelin. The mineralized plasma of the central core makes of it an electrical conductor, while the fatty sheath is an insulator. Such is the manner of an electrical condenser.

Twenty years ago it was dicovered that no graduated impulses are carried by a nerve fibre, and that sensations were observed in steps or quanta and that a certain quantum represents the threshold of perception. If the transmission of nerve impulses were by direct electric current any stimulus would produce a proportionate effect by gradual change. This is not so.

We find that there is a threshold of hearing and that the loudness heard is directly related to the number of nerve fibres excited and the rate at which these excitations occur, since each fibre always carries its maximum impulse. When all nerve fibres have been excited at their maximum frequency no further loudness is possible as sound.

After a nervous impulse has passed through a nerve there is a refractory phase during which time the ionized nerve plasma and tissue is reconstructed and the nerve is unable to respond or conduct. Then there follows a relative-refractory phase during which the excitability, the conductivity, and the speed of propagation gradually return to normal, and upon doing so an inertia effect is exhibited by passing the normal to a supernormal state when the nerve is more sensitive, more highly conductive, and permits a greater speed of propagation, and so conducts quanta less than the threshold values. Then the supernormal state returns to normalcy.

The time interval of the refractory state is one millisecond, and for the relative-refractory state is three milliseconds. Therefore, the maximum number of nervous impulses that a single nerve fibre can send to the brain is 1,000 per second; and those periodic excitations greater than 300 per second will not be transmitted as normal impulses since trouble should be encountered in operation. if the above instructions are followed.

Coupling

The uses to which the amplifier is put will determine the output networks and input arrangements to be used. For recording. a crystal cutter should be coupled directly to the output plates, and a magnetic cutter should connect to the output transformer. Some load should be kept on the transformer at all times. A speaker with a pad for volume adjustment can be used for monitoring, or a pair of high impedance headphones can be shunted across the line without upsetting the impedance matches.

One application of interest to recording fans who are also hams, is the use of the amplifier as a speech amplifier when transmitting, and as a recording unit when receiving. A simple switching circuit will allow convenient changeover.

Undoubtedly many other uses will suggest themselves to builders of the unit. It has been found that the amplifier serves admirably in performing all the jobs in audio usually found in the home, ham-shack, or small studio.

Ratings

The ratings listed are given when the amplifier is properly adjusted. Considerable variation in gain is possible, but the values listed are conservative, and will be correct for most calculations. Bear in mind, also, that the gain is affected to by the tone and expression controls, and the frequency response is subject to almost any variation by means of the dual tone controls.

Power output—	+38 vu or 6 watts with low distortion +40 vu or 10 watts with 5% distortion
Gain —	75 db with expander-compressor off 86 db with expander fully on. (based on 100,000-ohm grid impedance) (values for unit not including 6SJ7 preamp)
Hum level—	at least 68 db below rated output, with bass control in full boost position. With bass control in normal setting. no hum is audible even with the ear next to the speaker cone.
Response —	±1 db from 60 to 10,000 cycles ±2.5 db from 30 to 15,000 cycles (The frequency response will be determined primarily by the output transformer, since all other stages are resistance coupled. These values are based on the medium-priced transformer used in the amplifier illustrated.)
Tone control—	Bass control varies response from +9 db to —25 db at 60 cycles. Treble control varies response from +12 to —30 db at 7000 cycles. By means of the two fully variable controls, practically any response curve desired can be obtained.