Applications of the Audio Operational Amplifier to Studio Use*

RALPH GITTLEMAN

Melcor Electronics Corporation, Farmingdale, New York

The general-purpose dc operational amplifier is adapted to recording studio use. A simplified mixing console design is presented and the operational amplifier is applied to each active element of the console. Circuits are shown for use as microphone, tape, and phono preamplifier, equalizer, compressor-limiter, mixer module, booster and line amplifier, and power supply.

INTRODUCTION The general-purpose dc operational amplifier (Op-Amp) is a basic building block with which a great variety of circuit functions may be performed by the addition of external networks.

A general-purpose Op-Amp has two signal inputs and one signal output. The output level is dependent on the difference of the two input signals, or the value of either signal input with the other input zero. A signal at one input causes an in-phase amplified output signal; the same signal level applied to the other input causes the same output level, but with a phase shift of 180°. These inputs are referred to respectively as the non-inverting and the inverting input. In addition, the Op-Amp has a frequency response extending from dc to over 100 MHz.

This type of amplifier is designed to be used with extensive overall feedback in a multiplicity of widely varying applications. As a result, its open-loop or zero feedback parameters are of prime importance. The open-loop input impedance must be very high. Gain without feedback is extremely high so that the closed-loop performance, the performance with feedback, will be dependent only upon the external networks chosen to perform a specific function, rather than the characteristics of the basic building block itself.

Since these modules must be capable of amplifying dc signals, the equivalent input offset voltage and current are important parameters in determining the output voltage offset for a variety of gain configurations.

A knowledge of the high-frequency characteristics of the amplifier is also essential in applications involving pulse and variable frequency signals.

In applications involving low-level signals, the inherent noise of the amplifier must be known in order to determine its effect upon overall accuracy.

When high input impedance is required, the Op-Amp is used in the non-inverting mode i.e., signal is applied to the non-inverting input and feedback is applied to the inverting input. The result is an extremely high input impedance, typically many megohms. In this connection, approximately the same signal level is applied to both inputs; a common mode voltage is therefore present at the input, and a knowledge of this module parameter is necessary to prevent overloading the input on high signal levels as well as to determine the total error involved.

Electrical and mechanical parameters of an Op-Amp are shown in Fig. 1. The pin configuration is standardized. Pins 1 and 2 are the inputs; Pin 3 is available for trimming the dc offset voltage at the output terminal; Pin 4 is the output; Pin 5 is the negative supply voltage; Pin 6 is the audio and power supply common, and Pin 7 is the positive supply voltage. Parameters shown are those common to Op-Amp users and describe performance of a particular amplifier type under various conditions.

* Presented April 29, 1968 at the 34th Convention of the Audio Engineering Society, Hollywood, California.

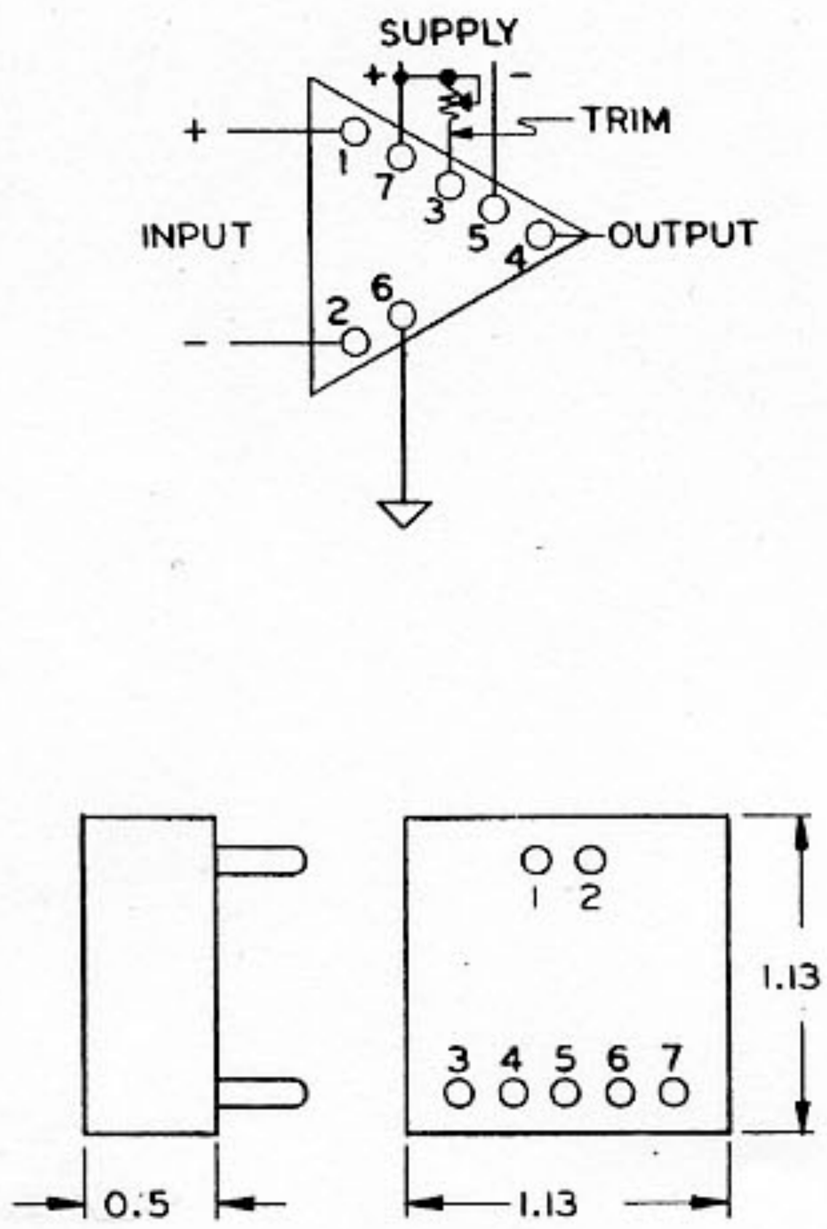


Fig. 1. An operational amplifier. **a.** Symbol and pin designation. **b.** Configuration. Open-loop parameters of Model 1731: gain = 100 dB; maximum input noise = 0.7 μV, 20 to 20,000 Hz; bandwidth = 40 MHz; small-signal gain bandwidth product, 50 kHz full output; input impedance = 200K Ω; maximum output impedance = 100Ω; maximum output power = +27 dBm, ±10 V ±100 MA; input voltage offset = 5 MV, 20 UV/°C; maximum common-mode input = ± 4 V; power required = ±15 V, 50 MA.

AN AUDIO OPERATIONAL AMPLIFIER

The audio operational amplifier to be discussed was designed specifically for the professional audio user. It retains all of the basic characteristics of the general-purpose operational amplifier, but specific parameters have been optimized for audio applications.

The input stage has been designed for minimum noise over the audio spectrum when operated at the conventional impedance levels of audio systems. Output stage circuitry was chosen to develop output power levels in excess of the maximum required in recording consoles. The frequency response has been internally shaped to guarantee stable operation in all standard circuit configurations.

The detailed design of this unit would require a separate paper. Only the application of the audio Op-Amp and the results obtained will be discussed.

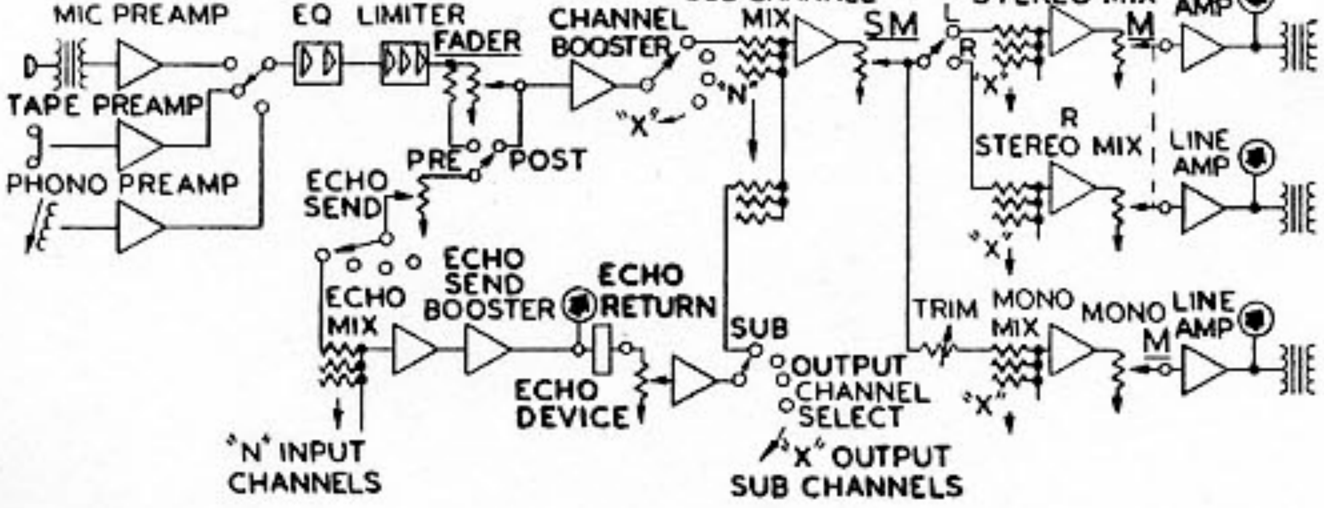


Fig. 2. Simplified functional diagram of a mixing console.

THE AUDIO OPERATIONAL AMPLIFIER IN USE

Figure 2 is a simplified diagram of a portion of a typical mixing console used by recording studios.

Low-level signals are supplied to the console from microphones, tape machines, and occasionally record turntables. Preamplification is performed and higher level signals are then applied to equalizers and compresser-limiters.

Signals from fader controls are mixed with signals from other channels and fed to monitor amplifiers and tape machines. Echo signals can also be picked off before or after the fader, applied to the echo device and mixed with the main signal at the mixer amplifier.

All of the active functions shown in Fig. 2 are performed by the audio operational amplifier.

Preamplifiers

Three different microphone preamplifier configurations are illustrated, along with tape and phono preamplifiers. The microphone preamplifier circuit configurations are shown in Fig. 3, each with 40 dB of gain and each with some merit of its own.

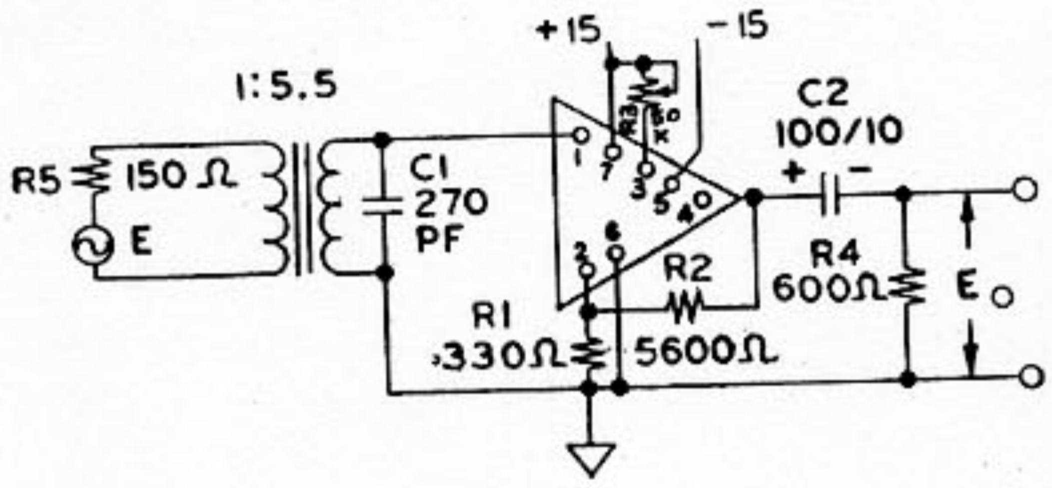
Figure 3a illustrates a conventional microphone preamplifier. An input transformer of proper turns ratio is chosen to provide the optimum ratio of voltage and current noise for minimum total noise level for the preamplifier. Noise, in this configuration, is −129 dBm unweighted 20 to 20,000 Hz. Gain changing is accomplished by varying the ratio of R_2 to R_1.

The second configuration in Fig. 3b has a transformerless unbalanced input. An equivalent noise of −124 dBm may be obtained with this simple circuit. Its features are low cost, very simple gain changing by varying the ratio of R_2 to R_1, light weight and freedom from the usual transformer problems. However, this configuration is very susceptible to hum pickup.

The third configuration, Fig. 3c, is most interesting and uses the amplifier in its differential input mode, resulting in a balanced transformerless preamplifier. The noise in this mode of operation is typically −123 dBm, with essentially complete cancellation of hum pickup. The significant features of this mode of operation are rejection of hum pickup, freedom from transformer problems, low cost, light weight, and isolation of grounding problems if the microphone input is floating and balanced. The resistors R_3 and R_4 are changed (simultaneously) to provide different gains. They should be 1% tolerance, as should R_1 and R_2, to assure common mode rejection of unwanted signals.

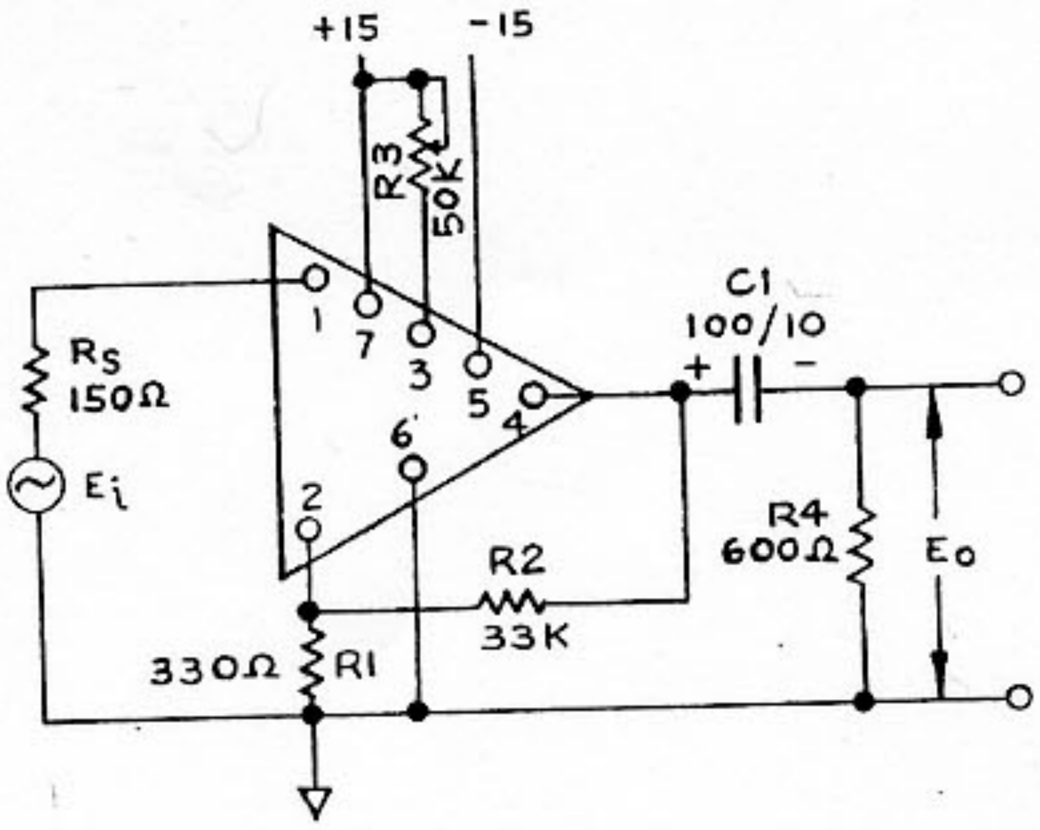
All of the preamplifiers could be used with an output transformer to match the amplifier to 600 ohm for maximum power output. As shown, the maximum output for all configurations without the output transformer is +20 dBm into 600 ohm. A matching transformer boosts this maximum output to +27 dBm.

The next application illustrated is the tape preamplifier. Excellent results have been obtained with the circuit of Fig. 4a. Trim equalization is obtained by varying R_6 for the high end. The small size, light weight and stability of this circuit make mounting at the head assembly feasible, with the attendant reduction in cable



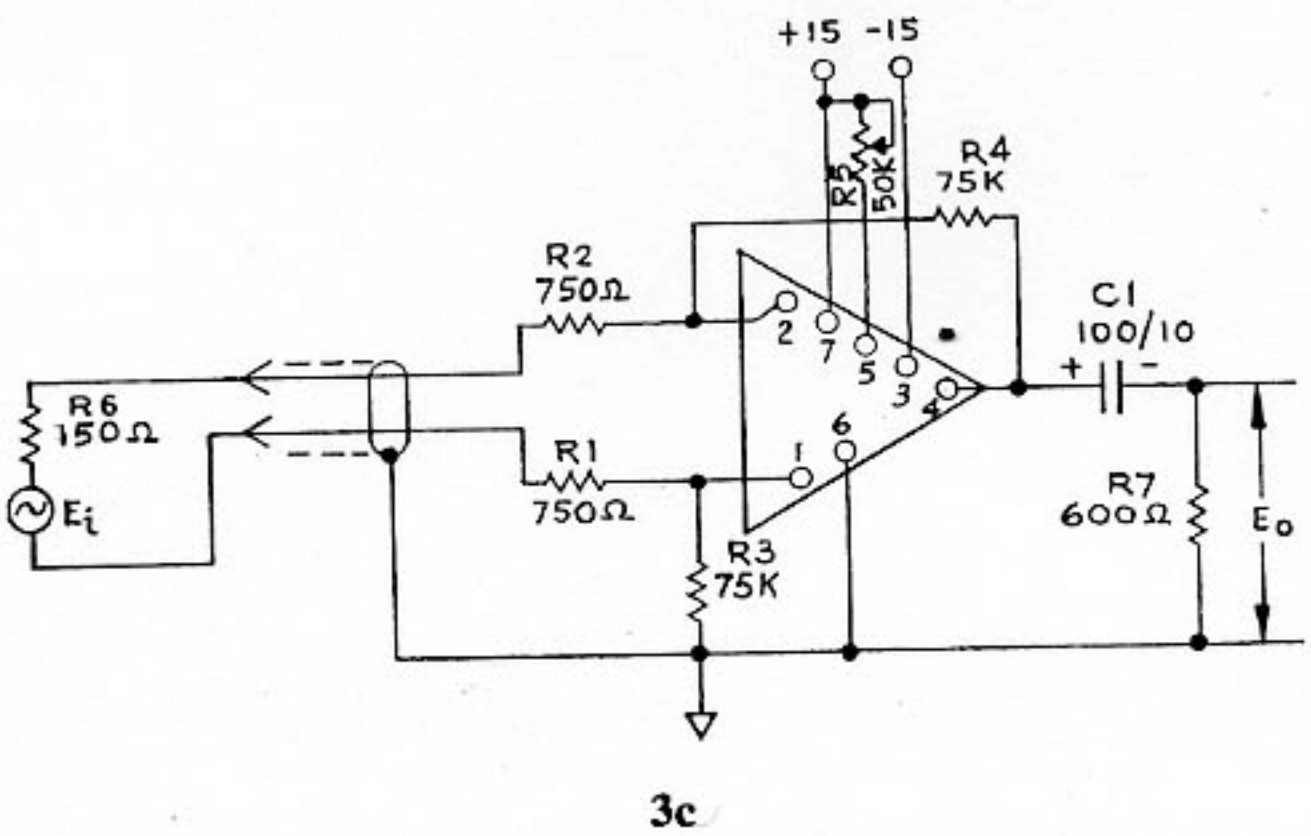
3a

	Parameters
Gain	40 db
Max. input noise	−129 dB, 20 to 20,000 Hz
Frequency response	±0.5 dB, 30 to 20,000 Hz
Input impedance	Greater than 1500 Ω
Max. output impedance	10 Ω
Max. output power	+20 dBm
Max. distortion	0.3%, 30 to 20,000 Hz, max. output
Power required	±25 mA full output



3b

	Parameters
Gain	40 dB
Typical input noise	−124 dBm, 20 to 20,000 Hz
Frequency response	±0.5 dB, 20 to 20,000 Hz
Input impedance	More than 1 megohm
Max. output impedance	10 Ω
Max. output power	+20 dBm
Max. distortion	0.25%, 20 to 20,000 Hz max. output
Power required	±25 mA full output



3c

	Parameters
Gain	40 dB
Typical input noise	−123, 20 to 20,000 Hz
Frequency response	±0.5 dB, 20 to 20,000 Hz
Input impedance	1500 Ω
Max. output impedance	5 Ω
Max. output	+20 dBm
Max. distortion	0.25%, 20 to 20,000 Hz max. output
Power required	±25 mA full output

Fig. 3. Microphone preamplifier configurations. **a.** Conventional preamplifier. **b.** Transformerless single-ended preamplifier. **c.** Balanced-input transformerless preamplier.

noise, etc. An interesting possibility is to provide quick-change replacement head assemblies with pre-equalized amplifiers in the assemblies themselves.

The last preamplifier to be shown is the module used as a very high-quality phono preamplifier. Trim equalization is obtained by varying R_7 for the high end. Again, extreme simplicity, very low distortion and noise along with small size and light weight make this a very useful application.

Equalizers

The next step in the chain is the equalizer. The operational amplifier technique of wave shaping with RC networks again provides reduction in size, weight and complexity. The bridged-T network shown in Fig. 5a is a very useful configuration and may be used in the feedback loop or ahead of the module input to provide boosts or dips at calculated frequencies. Other shaping networks can be used equally well. An actual working equalizer with the required flexibility becomes quite complex and no attempt is made to show the actual configuration.

As an example of some of the possibilities, Fig. 5b shows the Melcor Model AE-20 amplifier equalizer, using two Melcor Model 1731 modules in the equalizer portion and another as a variable-gain, transformer input, microphone preamplifier.

Compressors

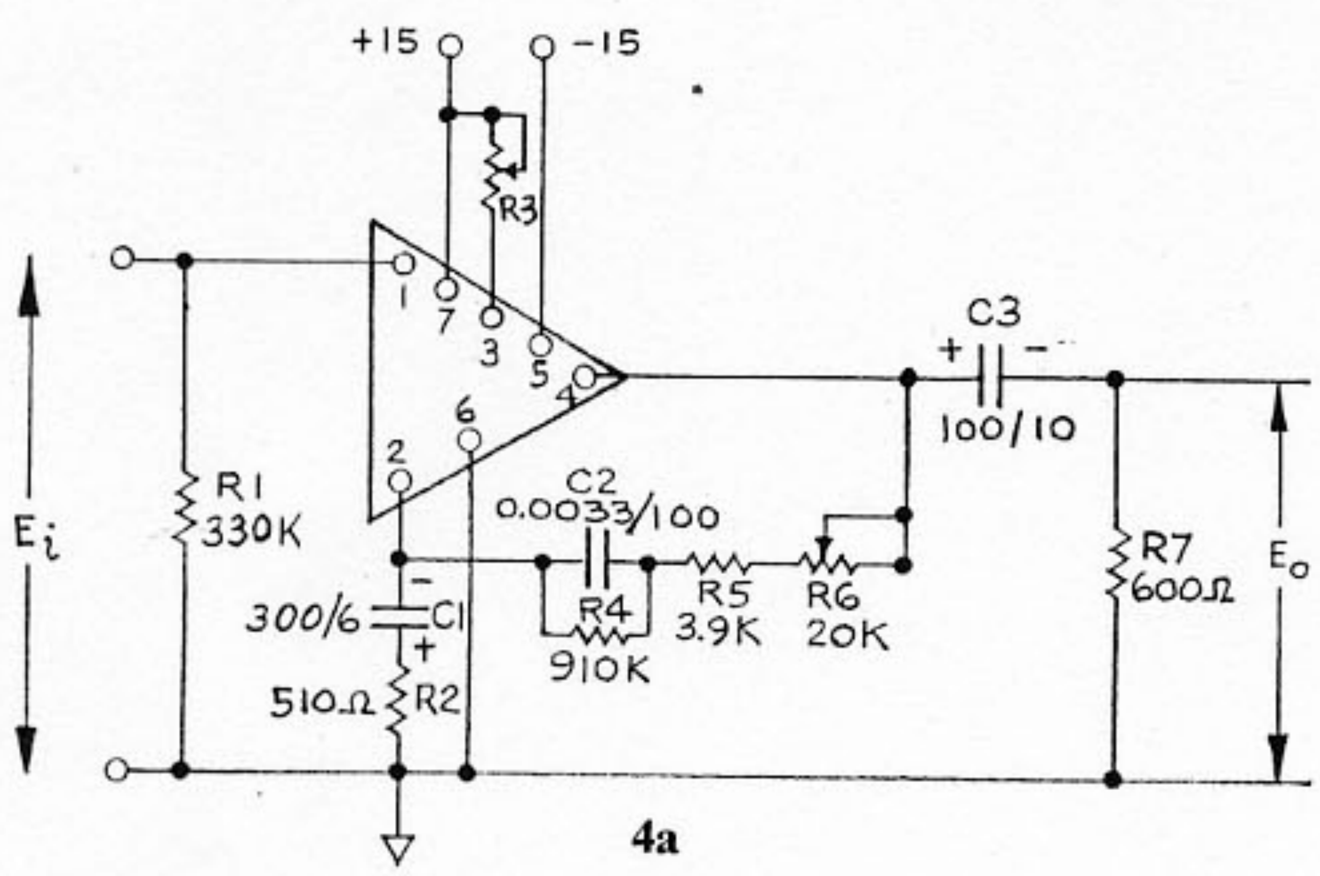
High-speed limiters or compressors in compact size to fit in strips for individual microphone channels or output channels can be designed using the operational amplifiers. The high input impedance, low output impedance, high gain, wide bandwidth and high power output of the audio Op-Amp module simplify some of the design problems. The block diagram shown in Fig. 6 indicates the basic elements required. Again, the details of the final circuit are beyond the scope of this paper.

Mixers

Lossless signal mixing is by this time quite commonplace and well proven in many applications. The simplicity of this operation is almost too good to be true. Figure 7 represents a ten-input lossless mixer. When each mixing resistor is driven from a different operational amplifier, isolation between channels is approximately 114 dB at 20 kHz and rises to approximately 134 dB at 1 kHz. Gain or loss from the mixing amplifier is achieved by raising or lowering the value of R_1, the feedback resistor, in relation to the input summing resistors.

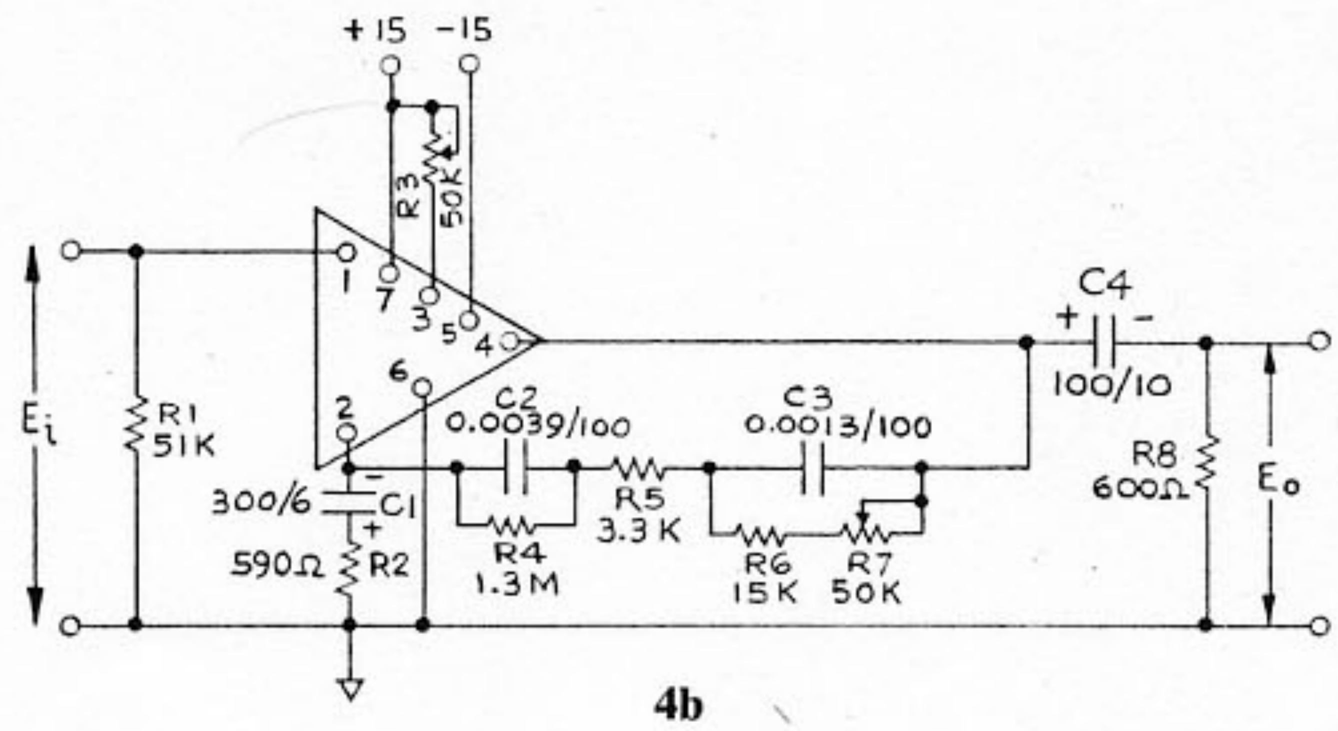
Boosters and Line Amplifiers

The only remaining amplifiers or active devices in the console are the line and booster amplifiers. These are the simplest of all. Figure 8 is a diagram of a 40 dB gain amplifier with the characteristics shown. The amplifier without an output transformer is capable of a +20 dBm output into 600 ohm or +27 dBm directly into 100 ohm. Again, feedback resistors may be changed to provide the desired gain.



4a

	Parameters
Gain	6 mV @ 700 Hz produces 0 dBm output
Max. input noise	−125 dBm, 20 to 20,000 Hz
Frequency response	±1 dB; NARTB curve at 15 ips
Input impedance	More than 300 KΩ
Max. output impedance	5 Ω
Max. output	+20 dBm
Max. distortion	0.5%, 20 to 20,000 Hz max. output
Power required	±25 mA full output



4b

	Parameters
Gain	3 mV at 1 KHz Produces 0 dBm output
Max. noise	−125 dBm, 20 to 20,000 Hz
Frequency response	±1 dB RIAA curve
Input impedance	Greater than 47 KΩ
Max. output impedance	5 Ω
Max. output power	+20 dBm
Max. distortion	0.5%, 20 to 20,000 Hz full output
Power required	±25 mA full output

Fig. 4. Preamplifier configurations. **a.** Tape preamplifier. **b.** Phonograph preamplifier.

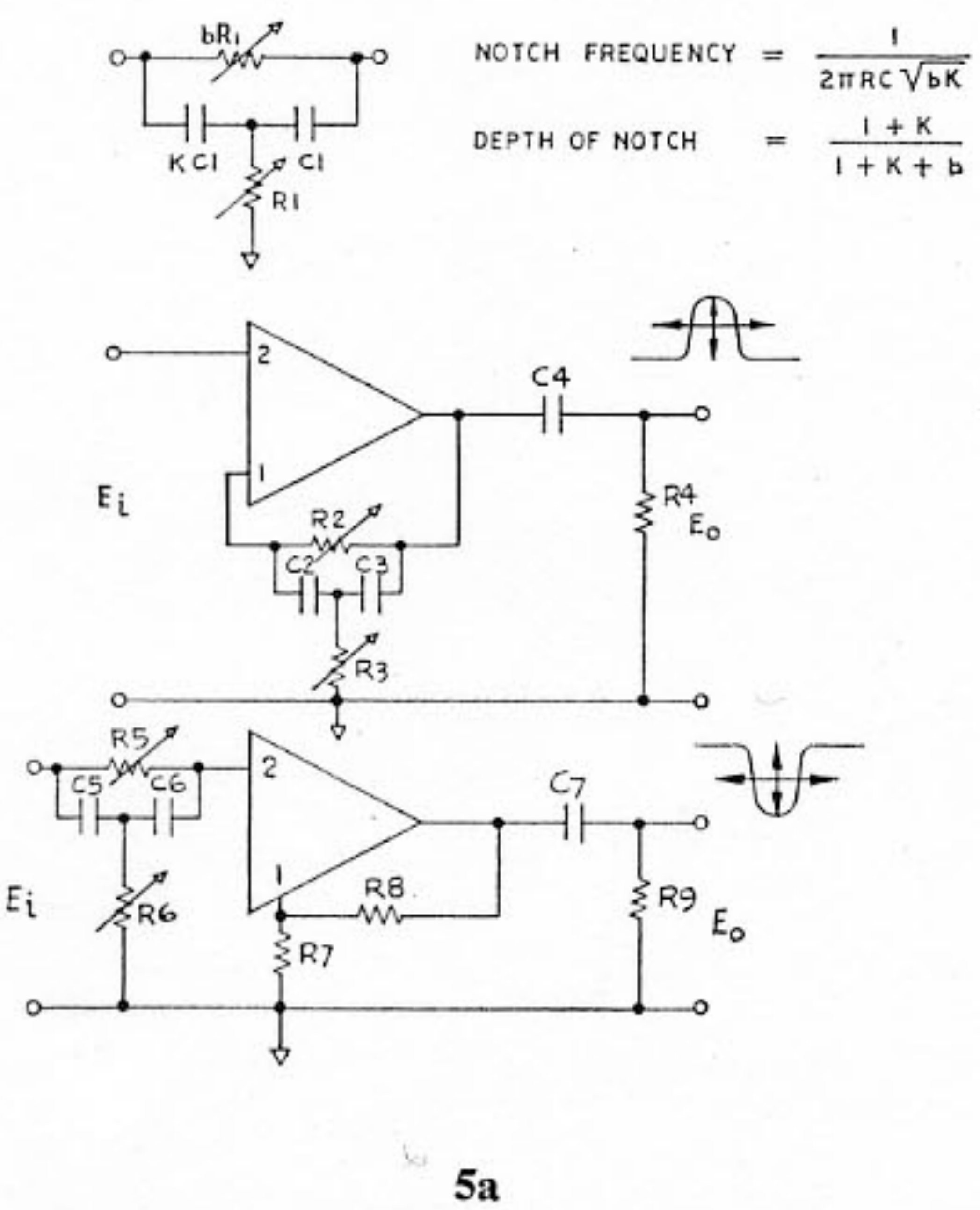
The audio operational amplifier that has been used in all of the previous configurations has been the Melcor Model 1731. If more power is required in any of the applications discussed, a higher output model can be substituted.

Other Applications

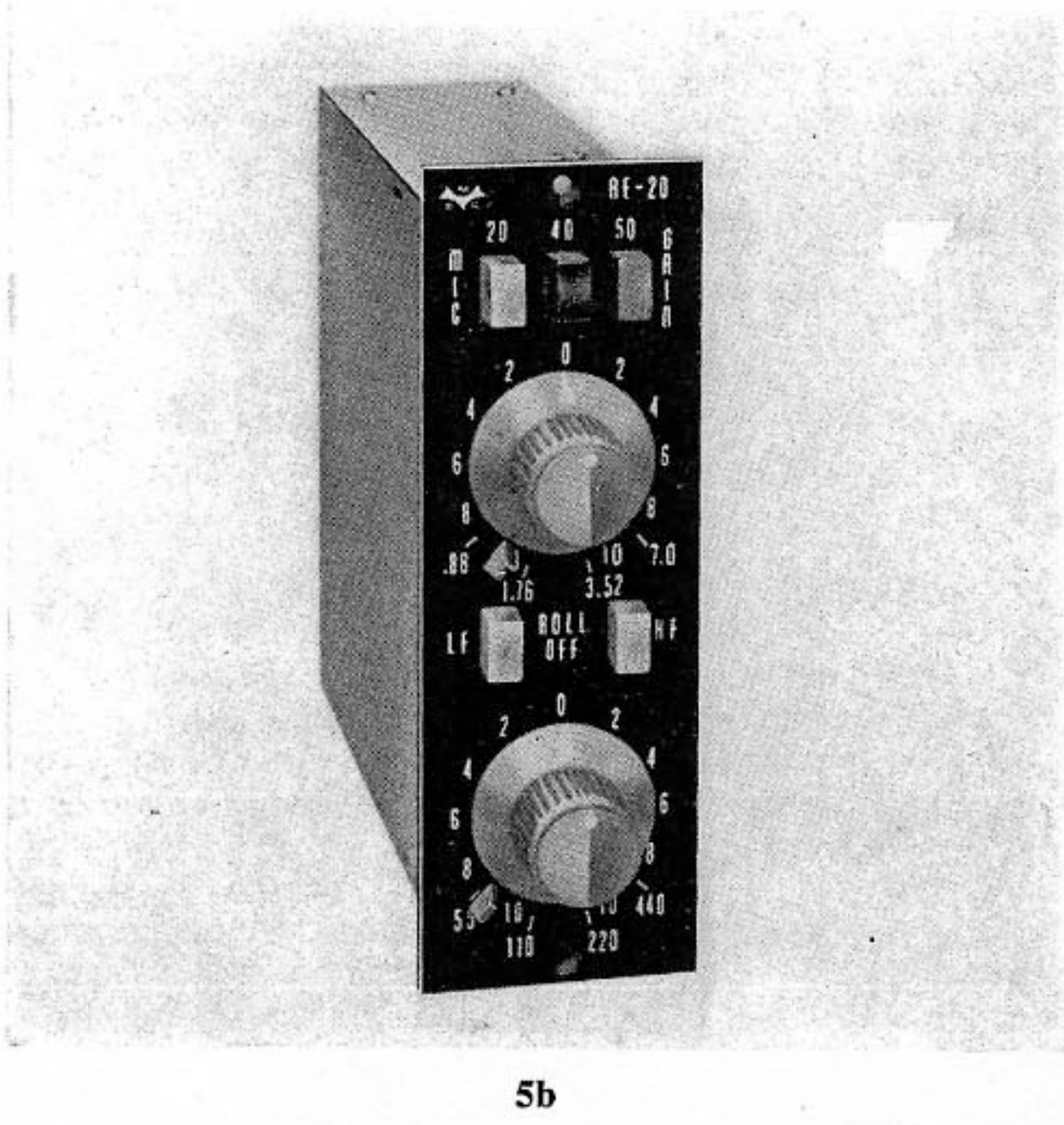
Once the signal has left the console, the job of the audio operational amplifier is by no means concluded. Units are available which are capable of driving monitor speakers. All of the electronics within the tape machine can be designed around the operational amplifier.

Figure 9 is a diagram for a 2 A 15 V regulator that provides current limiting and shortcircuit protection with the characteristics shown. Regulators for higher current and voltage are obtained by changing appropriate components.

Some imagination dilligently applied can simplify and improve a host of other tasks using the audio operational amplifier as the tool. Here are a few that come to mind: in-phase—out-of-phase matrixing for compatible stereo work; simple nonloading VU meter amplifiers; cueing amplifiers or headset drivers; high-speed tape du-



5a



5b

Fig. 5. **a.** Bridged-T notched filter for equalizer use. **b.** An amplifier equalizer based on Op-Amp modules.

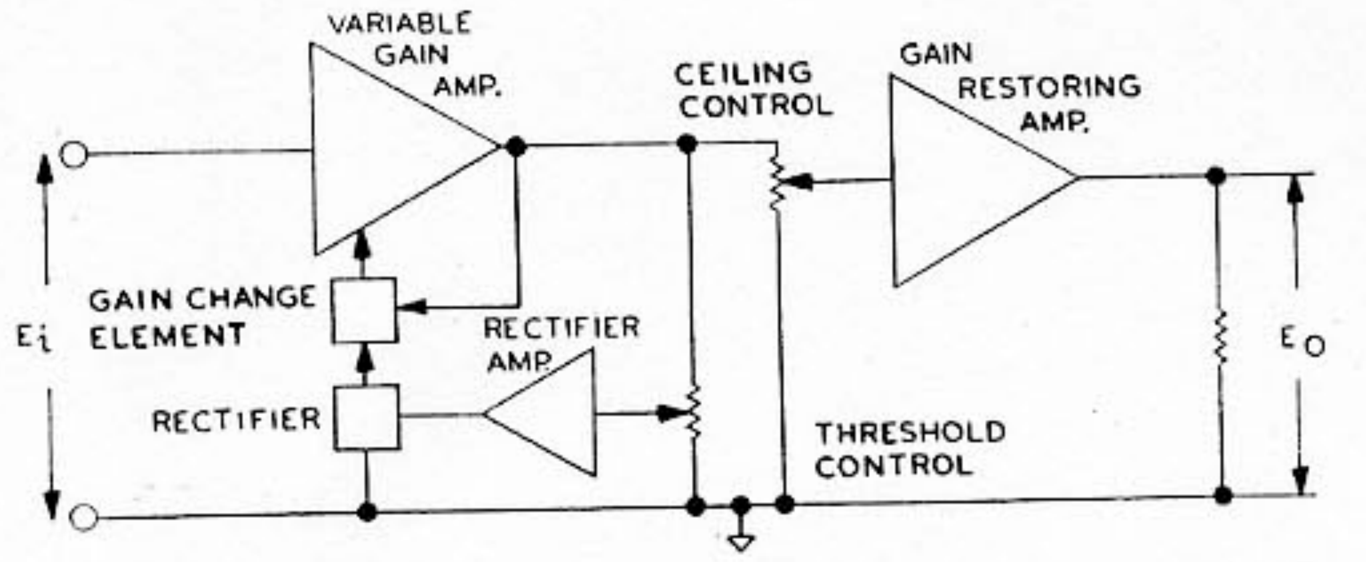
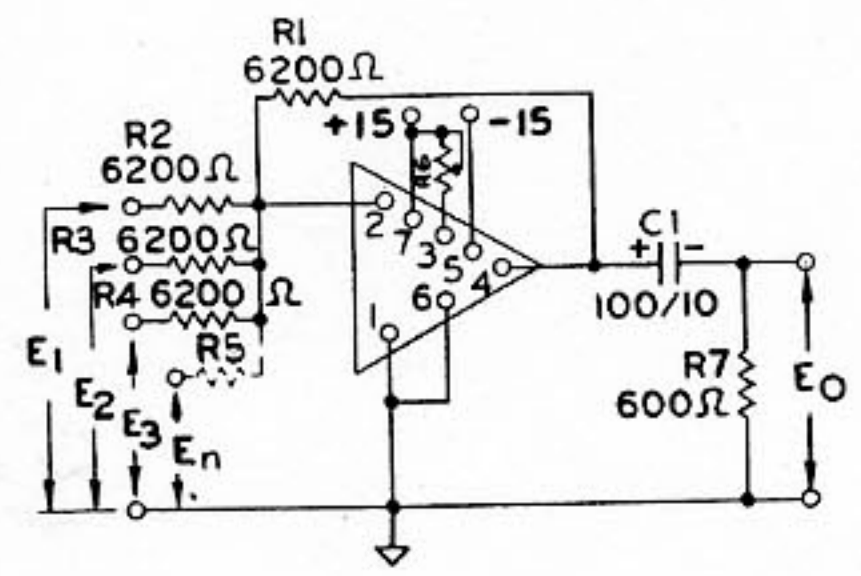


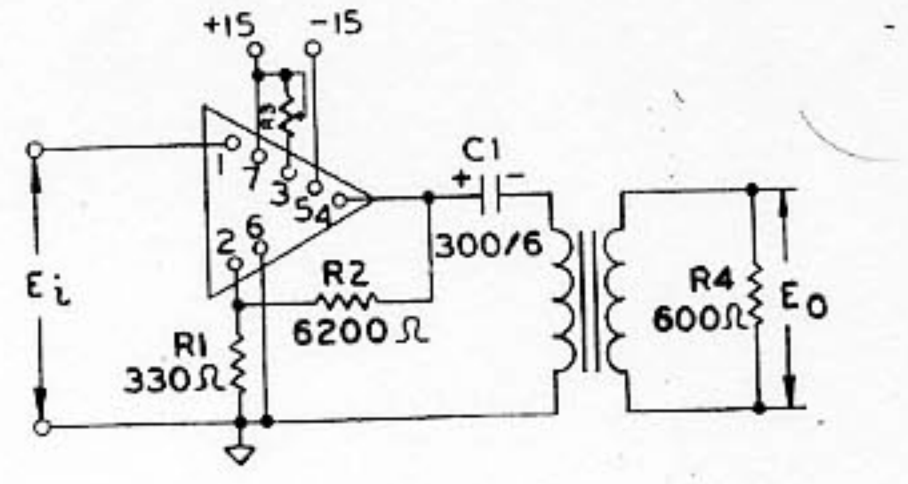
Fig. 6. Block diagram of a compressor-limiter using Op-Amps.



Parameters

Gain	0 dBm
Max. input noise	−105 dBm, 20 to 20,000 Hz
Frequency response	±0.25 dB, 20 to 20,000 Hz
Input impedance	6200 Ω
Max. output impedance	5 Ω
Max. output power	+20 dBm
Max. distortion	0.25%, 20 to 20,000 Hz full output
Power required	±25 mA full output

Fig. 7. Mixer module.



Parameters

Gain	40 dB
Max. noise	−125 dBm, 20 to 20,000 Hz
Frequency response	±0.5 dB, 20 to 20,000 Hz
Input impedance	More than 1 megohm
Max. output power	+27 dBm
Max. distortion	0.5%, 20 to 20,000 Hz full output
Power required	±50 mA full output

Fig. 8. Booster or line amplifier configuration.

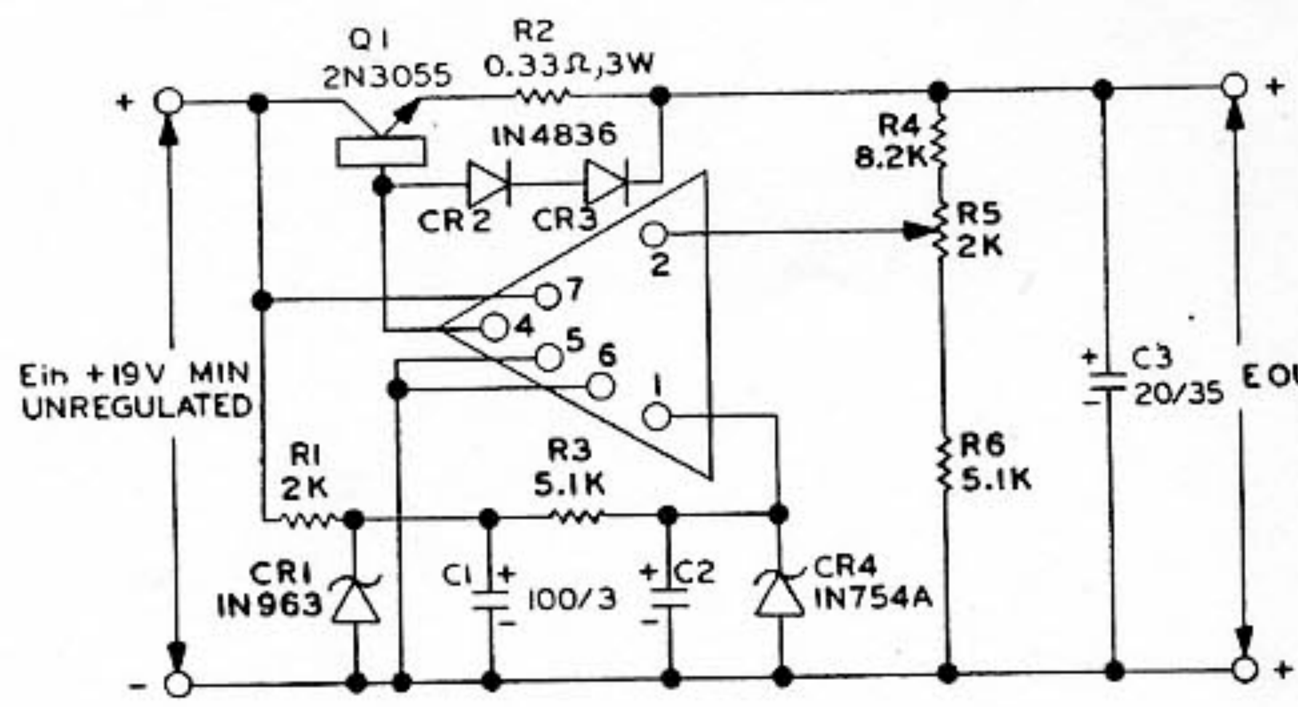


Fig. 9. Regulated power supply.

plicating systems; drivers for optical recording systems; gain modules for automated systems; test or bias oscillators; speaker systems.

CONCLUSION

The possibilities for using operational amplifiers in the recording studio are practically limitless. One can start with a module, make a component, make a strip, make a console, make a system. Flexibility is inherent: one can mix at levels from −30 dBm to +20 dBm with no loss or gain, design with or without transformers, load the amplifiers with rated load resistors or infinity or anything in between, use conventional T pads, L pads, H pads or simple potentiometers for fading. If more power is needed, it's easy to change the module and the power supply. One can put the limiter in front of the equalizer or after it or in the main channel, play back from tape or phono and record on tape. The versatility of these modules is indeed impressive.

THE AUTHOR

Ralph Gittleman received the B.S. in electrical engineering from Massachusetts Institute of Technology in 1952 and his Masters degree in electrical engineering from the Polytechnic Institute of Brooklyn in 1957. He was a member of the instructional staff of P.I.B.

While employed by the Arma Division of American Bosch Arma Corporation, Mr. Gittleman was responsible for the design and development of transistor circuits for AC analogue computers. He later joined the W. L. Maxon Corporation and as computer section manager was engaged in the design of analog and digital computers and ultrasonic and audio components. In 1960, Mr. Gittleman with two partners founded the Melcor Electronics Corporation. He is now president of the company.

Mr. Gittleman is a member of the Audio Engineering Society, the Institute of Electrical and Electronic Engineers and is a past secretary of the Institute of Electrical and Electronic Engineers Automatic Control Professional Group.