

## Audio Circuits Using the NE5532/4



ON Semiconductor®

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### APPLICATION NOTE

#### Audio Circuits Using the NE5532/34

The following will explain some of ON Semiconductors low noise op amps and show their use in some audio applications.

#### Description

The 5532 is a dual high-performance low noise operational amplifier. Compared to most of the standard operational amplifiers, such as the 1458, it shows better noise performance, improved output drive capability and considerably higher small-signal and power bandwidths.

This makes the device especially suitable for application in high quality and professional audio equipment, instrumentation and control circuits, and telephone channel amplifiers. The op amp is internally-compensated for gains equal to one. If very low noise is of prime importance, it is recommended that the 5532A version be used which has guaranteed noise voltage specifications.

#### APPLICATIONS

ON Semiconductors 5532 High-Performance Op Amp is an ideal amplifier for use in high quality and professional audio equipment which requires low noise and low distortion.

The circuit (Figure 1) included in this application note has been assembled on a PC board, and tested with actual audio input devices (Tuner and Turntable). It consists of a Recording Industry Association of America (RIAA)

preamp, input buffer, 5-band equalizer, and mixer. Although the circuit design is not new, its performance using the 5532 has been improved.

The RIAA preamp section is a standard compensation configuration with low frequency boost provided by the Magnetic cartridge and the RC network in the op amp feedback loop. Cartridge loading is accomplished via R1. 47 kΩ was chosen as a typical value, and may differ from cartridge to cartridge.

The Equalizer section consists of an input buffer, 5 active variable band pass/notch (depending on R9's setting) filters, and an output summing amplifier. The input buffer is a standard unity gain design providing impedance matching between the preamplifier and the equalizer section. Because the 5532 is internally-compensated, no external compensation is required. The 5-band active filter section is actually five individual active filters with the same feedback design for all five. The main difference in all five stages is the values of C5 and C6, which are responsible for setting the center frequency of each stage. Linear pots are recommended for R9. To simplify use of this circuit, a component value table is provided, which lists center frequencies and their associated capacitor values. Notice that C5 equals 10 × C6 and the value of R8 and R10 are related to R9 by a factor of 10 as well. The values listed in the table are common and easily found standard values.

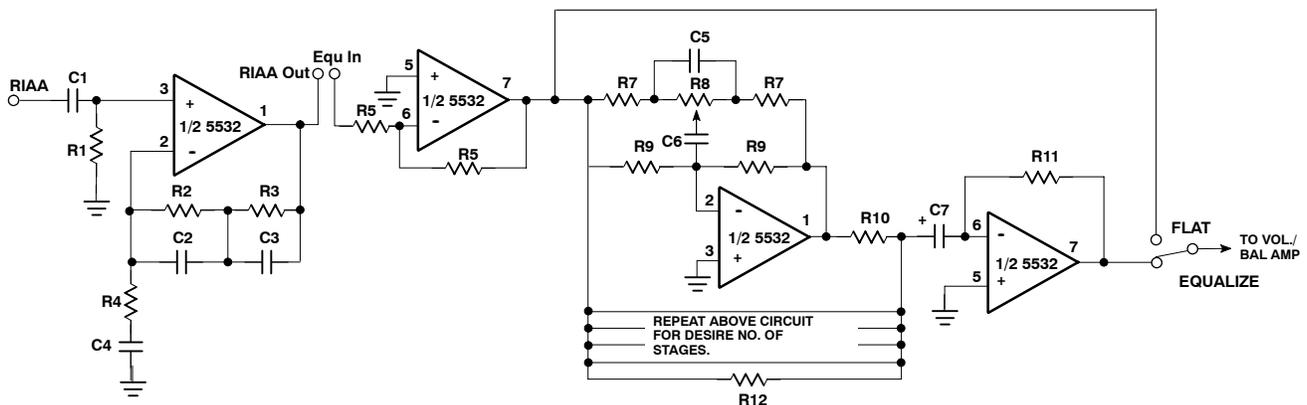


Figure 1. RIAA - Equalizer Schematic

**RIAA Equalization Audio Preamplifier Using NE5532A**

With the onset of new recording techniques with sophisticated playback equipment, a new breed of low noise operational amplifiers was developed to complement the state-of-the-art in audio reproduction. The first ultra-low noise op amp introduced by ON Semiconductors was called the NE5534A. This is a single operational amplifier with less than  $4 \text{ nV}/\sqrt{\text{Hz}}$  input noise voltage. The NE5534A is internally-compensated at a gain of three. This device has been used in many audio preamp and equalizer (active filter) applications since its introduction.

Many of the amplifiers that are being designed today are DC-coupled. This means that very low frequencies (2-15 Hz) are being amplified. These low frequencies are common to turntables because of rumble and tone arm resonances. Since the amplifiers can reproduce these

sub-audible tones, they become quite objectionable because the speakers try to reproduce these tones. This causes non-linearities when the actual recorded material is amplified and converted to sound waves.

The RIAA has proposed a change in its standard playback response curve in order to alleviate some of the problems that were previously discussed. The changes occur primarily at the low frequency range with a slight modification to the high frequency range (See Figure 2). Note that the response peak for the bass section of the playback curve now occurs at 31.5 Hz and begins to roll off below that frequency. The roll-off occurs by introducing a fourth RC network with a  $7950 \mu\text{s}$  time constant to the three existing networks that make up the equalization circuit. The high end of the equalization curve is extended to 20 kHz, because recordings at these frequencies are achievable on many current discs.

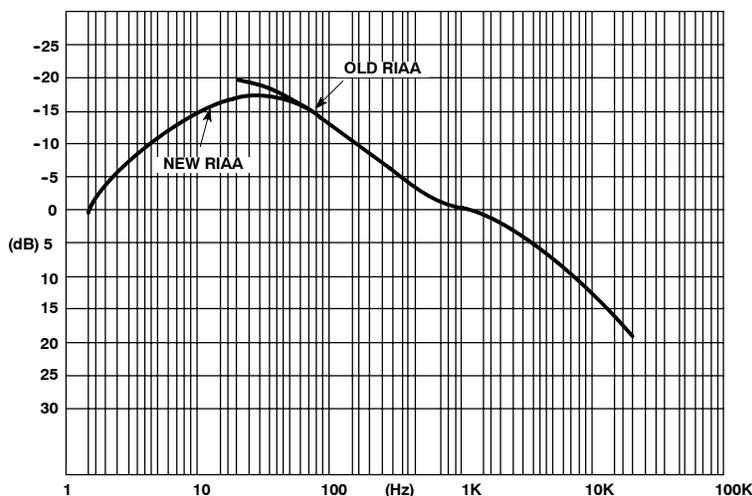
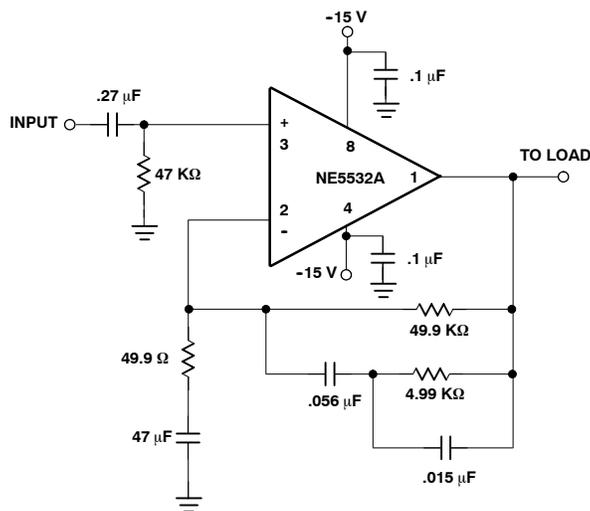


Figure 2. Proposed RIAA Playback Equalization



NOTE:  
All resistors are 1% metal film.

Figure 3. RIAA Phonograph Preamplifier Using the NE5532A

# AND8177/D

## COMPONENT VALUES FOR FIGURE 1

R8 = 25 kΩ R7 = 2.4 kΩ R9 = 240 kΩ			R8 = 50 kΩ R7 = 5.1 kΩ R9 = 510 kΩ			R8 = 100 kΩ R7 = 10 kΩ R9 = 1 megΩ		
f <sub>o</sub>	C5	C6	f <sub>o</sub>	C5	C6	f <sub>o</sub>	C5	C6
23 Hz	1 μF	0.1 μF	25 Hz	0.47 μF	0.047 μF	12 Hz	0.47 μF	0.047 μF
50 Hz	0.47 μF	0.047 μF	36 Hz	0.33 μF	0.033 μF	18 Hz	0.33 μF	0.033 μF
72 Hz	0.33 μF	0.033 μF	54 Hz	0.22 μF	0.022 μF	27 Hz	0.22 μF	0.022 μF
108 Hz	0.22 μF	0.022 μF	79 Hz	0.15 μF	0.015 μF	39 Hz	0.15 μF	0.015 μF
158 Hz	0.15 μF	0.015 μF	119 Hz	0.1 μF	0.01 μF	59 Hz	0.1 μF	0.01 μF
238 Hz	0.1 μF	0.01 μF	145 Hz	0.082 μF	0.0082 μF	72 Hz	0.082 μF	0.0082 μF
290 Hz	0.082 μF	0.0082 μF	175 Hz	0.068 μF	0.0068 μF	87 Hz	0.068 μF	0.0068 μF
350 Hz	0.068 μF	0.0068 μF	212 Hz	0.056 μF	0.0056 μF	106 Hz	0.056 μF	0.0056 μF
425 Hz	0.056 μF	0.0056 μF	253 Hz	0.047 μF	0.0047 μF	126 Hz	0.047 μF	0.0047 μF
506 Hz	0.047 μF	0.0047 μF	360 Hz	0.033 μF	0.0033 μF	180 Hz	0.033 μF	0.0033 μF
721 Hz	0.033 μF	0.0033 μF	541 Hz	0.022 μF	0.0022 μF	270 Hz	0.022 μF	0.0022 μF
1082 Hz	0.022 μF	0.0022 μF	794 Hz	0.015 μF	0.0015 μF	397 Hz	0.015 μF	0.0015 μF
1588 Hz	0.015 μF	0.0015 μF	1191 Hz	0.01 μF	0.001 μF	595 Hz	0.01 μF	0.001 μF
2382 Hz	0.01 μF	0.001 μF	1452 Hz	0.0082 μF	820 pF	726 Hz	0.0082 μF	820 pF
2904 Hz	0.0082 μF	820 pF	1751 Hz	0.0068 μF	680 pF	875 Hz	0.0068 μF	680 pF
3502 Hz	0.0068 μF	680 pF	2126 Hz	0.0056 μF	560 pF	1063 Hz	0.0056 μF	560 pF
4253 Hz	0.0056 μF	560 pF	2534 Hz	0.0047 μF	470 pF	1267 Hz	0.0047 μF	470 pF
5068 Hz	0.0047 μF	470 pF	3609 Hz	0.0033 μF	330 pF	1804 Hz	0.0033 μF	330 pF
7218 Hz	0.0033 μF	330 pF	5413 Hz	0.0022 μF	220 pF	2706 Hz	0.0022 μF	220 pF
10827 Hz	0.0022 μF	220 pF	7940 Hz	0.0015 μF	150 pF	3970 Hz	0.0015 μF	150 pF
15880 Hz	0.0015 μF	150 pF	11910 Hz	0.001 μF	100 pF	5955 Hz	0.001 μF	100 pF
23820 Hz	0.001 μF	100 pF	14524 Hz	820 pF	82 pF	7262 Hz	820 pF	82 pF
			17514 Hz	680 pF	68 pF	8757 Hz	680 pF	68 pF
			21267 Hz	560 pF	56 pF	10633 Hz	560 pF	56 pF
						12670 Hz	470 pF	47 pF
						18045 Hz	330 pF	33 pF

**NE5534 Description**

The 5534 is a single high-performance low noise operational amplifier. Compared to other operational amplifiers, such as TL083, they show better noise performance, improved output drive capability and considerably higher small-signal and power bandwidths.

This makes the devices especially suitable for application in high quality and professional audio equipment, instrumentation and control circuits, and telephone channel amplifiers.

The op amps are internally-compensated for gain equal to, or higher than, three. The frequency response can be optimized with an external compensation capacitor for various applications (unity gain amplifier, capacitive load, slew rate, low overshoot, etc.) If very low noise is of prime importance, it is recommended that the 5534A version be used which has guaranteed noise specifications.

**APPLICATIONS**

**Diode Protection of Input**

The input leads of the device are protected from differential transients above  $\pm 0.6$  V by internal back-to-back diodes (Figure 4). Their presence imposes certain limitations on the amplifier dynamic characteristics related to closed-loop gain and slew rate.

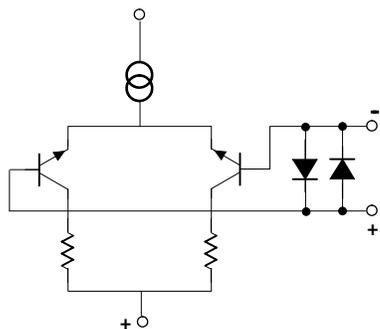


Figure 4.

Consider the unity gain follower as an example.

Assume a signal input square wave with  $dV/dt$  of  $250$  V/ $\mu$ s and  $2$  V peak amplitude as shown (Figures 5 and 6). If a  $22$  pF compensation capacitor is inserted and the

$R_1$   $C_1$  circuit deleted, the device slew rate falls to approximately  $7$  V/ $\mu$ s. The input waveform will reach  $2$  V/ $250$  V/ $\mu$ s or  $8$  ns, while the output will have changed ( $8 \times 10^{-3}$ ) only  $56$  mV. The differential input signal is then  $(V_{IN} - V_O) R_1/R_1 + R_F$  or approximately  $1$  V.

The diode limiter will definitely be active and output distortion will occur; therefore,  $V_{IN} < 1$  V as indicated.

Next, a sine wave input is used with a similar circuit.

The slew rate of the input waveform now depends on frequency and the exact expression is:

$$\frac{dv}{dt} = 2\omega \cos \omega t$$

The upper limit before slew rate distortion occurs for small-signal ( $V_{IN} < 100$  mV) conditions is found by setting the slew rate to  $7$  V/ $\mu$ s. That is:

$$7 \times 10^6 \text{ V}/\mu\text{s} = 2\omega \cos \omega t$$

at  $\omega t = 0$

$$\omega_{LIMIT} = \frac{7 \times 10^6}{2} = 3.5 \times 10^6 \text{ rad/s}$$

$$f_{LIMIT} = \frac{3.5 \times 10^6}{2\pi} \approx 560 \text{ kHz}$$

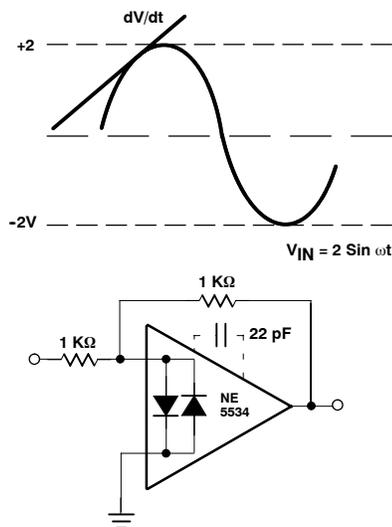


Figure 5.

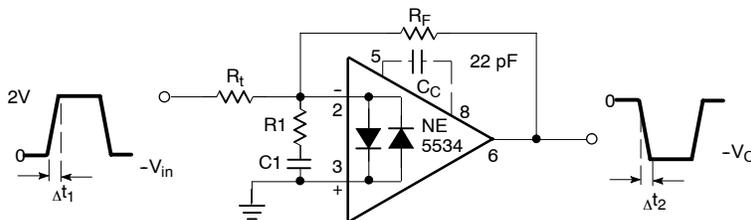


Figure 6.

**External Compensation Network Improves Bandwidth**

By using an external lead-lag network, the follower circuit slew rate and small-signal bandwidth can be increased. This may be useful in situations where a closed-loop gain less than 3 to 5 is indicated. A number of examples are shown in subsequent figures. The principle benefit of using the network approach is that the full slew rate and bandwidth of the device is retained, while impulse-related parameters such as damping and phase margin are controlled by choosing the appropriate circuit constants. For example, consider the following configuration (Figure 7):

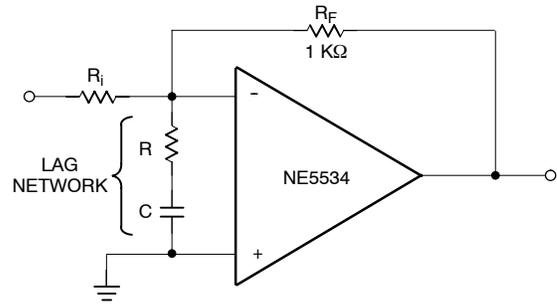


Figure 7.

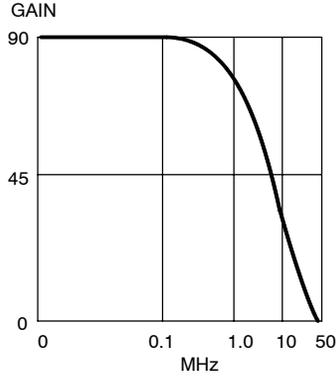


Figure 8.

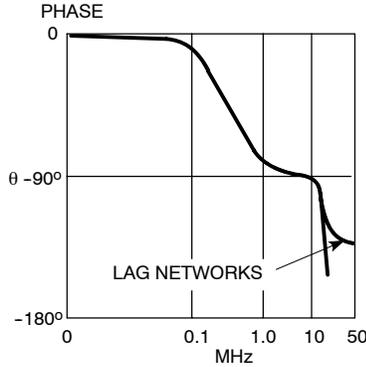


Figure 9.

The major problem to be overcome is poor phase margin leading to instability.

By choosing the lag network break frequency one decade below the unity gain crossover frequency (30-50 MHz), the phase and gain margin are improved (see Figures 8 and 9). An appropriate value for R is 270 Ω. Setting the lag network break frequency at 5 MHz, C may be calculated:

$$C = \frac{1}{2 \pi \cdot 270 \cdot 5 \times 10^6}$$

$$= 118 \text{ pF}$$

**Rules and Examples**

**Compensation Using Pins 5 and 8 (Limited Bandwidth and Slew Rate)**

A single-pole and zero inserted in the transfer function will give an added 45° of phase margin, depending on the network values.

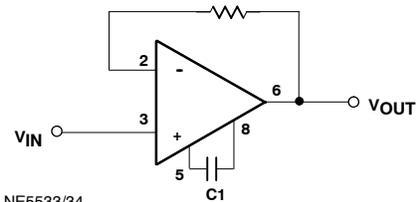
**Calculating the Lead-Lag Network**

$$C_1 = \frac{1}{2 \pi F_1 R_1} \text{ Let } R_1 = \frac{R_{IN}}{10}$$

where

$$F_1 = \frac{1}{10} (\text{UGBW})$$

$$\text{UGBW} = 30 \text{ MHz}$$



NOTES  
 C<sub>1</sub> = C<sub>C</sub>(1)  
 C<sub>C</sub> = 22 pF for NE5533/34  
 C<sub>C</sub> = 22 pF [See graph under typical performance characteristics]

Figure 10. Unity Gain Non-Inverting Configuration

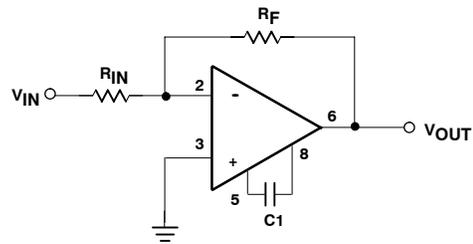


Figure 11. Unity Gain Inverting Configuration

**External Compensation for Wide-Band Voltage-Follower**

**Shunt Capacitance Compensation**

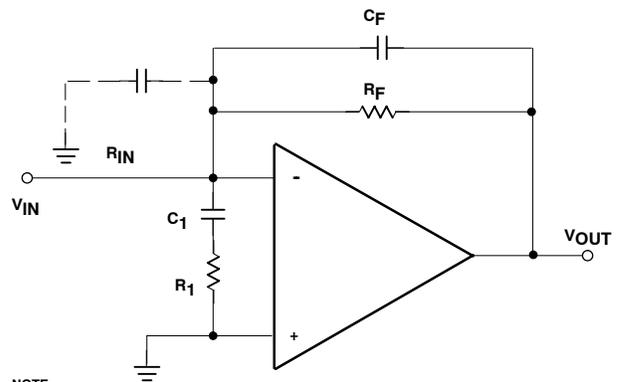
$$C_F = \frac{1}{2\pi F_F R_F}, F_F \approx 30\text{MHz}$$

or

$$C_F \approx \frac{C_{DIST}}{A_{CL}}$$

$C_{DIST} \approx$  Distributed Capacitance  $\approx 2 - 3$  pF

Many audio circuits involve carefully-tailored frequency responses. Pre-emphasis is used in all recording mediums to reduce noise and produce flat frequency response. The most often used de-emphasis curves for broadcast and home entertainment systems are shown in Figures 13 through 17 on the following page. Operational amplifiers are well suited to these applications because of their high gain and easily-tailored frequency response.



NOTE:  
Input diodes limit differential to <0.5V

**Figure 12. External Compensation for Wideband Voltage Follower**

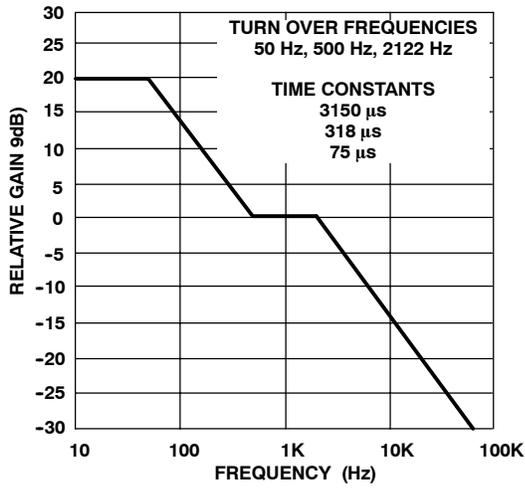


Figure 13. RIAA Equalization

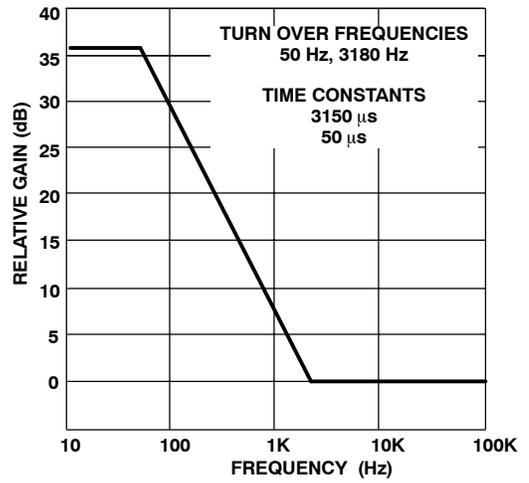


Figure 14. NAB Standard Playback 71/2 IPS

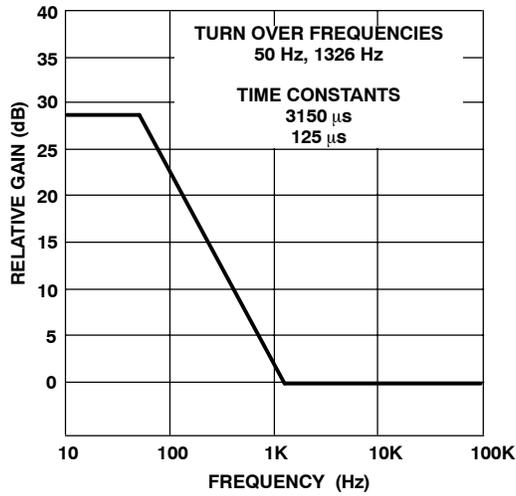


Figure 15. 3.75 IPS Tape Equalization

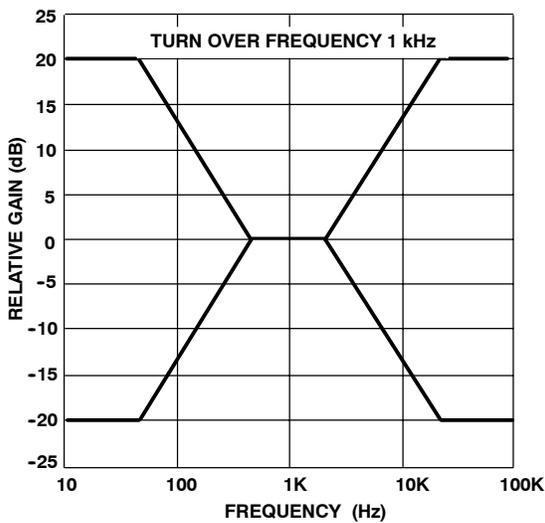


Figure 16. Base Treble Curve

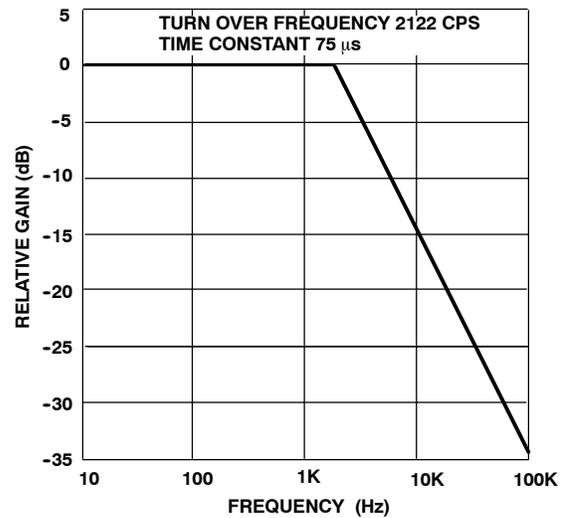
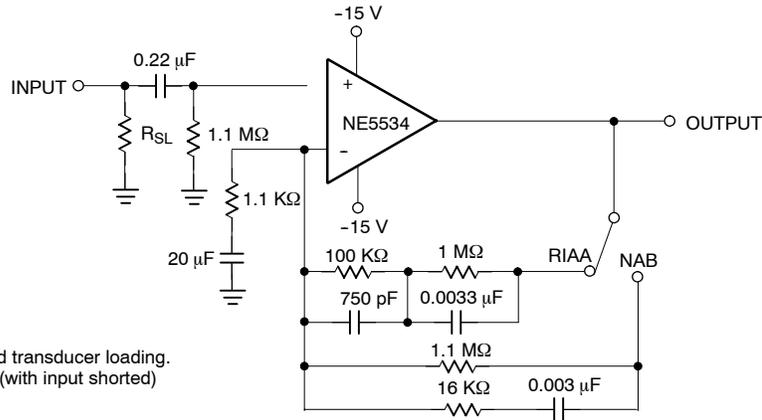


Figure 17. Standard FM Broadcast Equalization

**RIAA PREAMP USING THE NE5534**

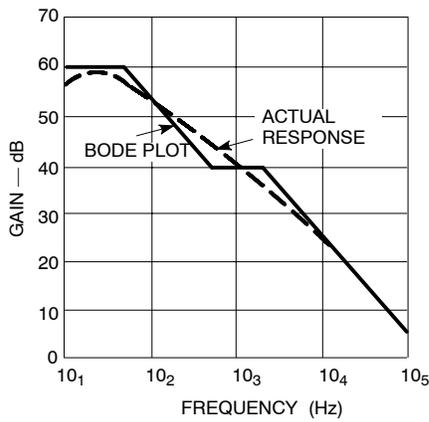
The preamplifier for phono equalization is shown in Figure 18 with the theoretical and actual circuit response.

Low frequency boost is provided by the inductance of the magnetic cartridge with the RC network providing the necessary break points to approximate the theoretical RIAA curve.

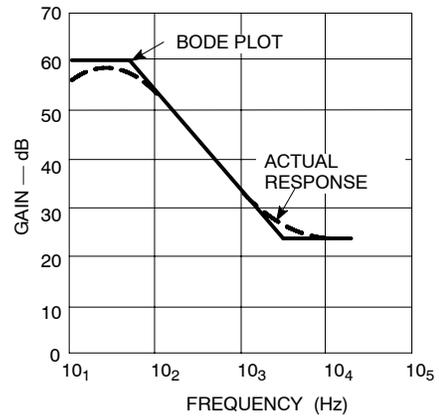


NOTES:  
 \*Select to provide specified transducer loading.  
 Output Noise  $\geq 0.8\text{mV}_{\text{RMS}}$  (with input shorted)

a.



b. Bode Plot of RIAA Equalization and the Response Realized in an Actual Circuit Using the 531.



c. Bode Plot of NAB Equalization and the Response Realized in the Actual Circuit Using the 531.

**Figure 18. Preamplifier - RIAA/NAB Compensation**

**RUMBLE FILTER**

Following the amplifier stage, rumble and scratch filters are often used to improve overall quality. Such a filter designed with op amps uses the 2-pole Butterworth

approach and features switchable break points. With the circuit of Figure 19, any degree of filtering from fairly sharp to none at all is switch-selectable.

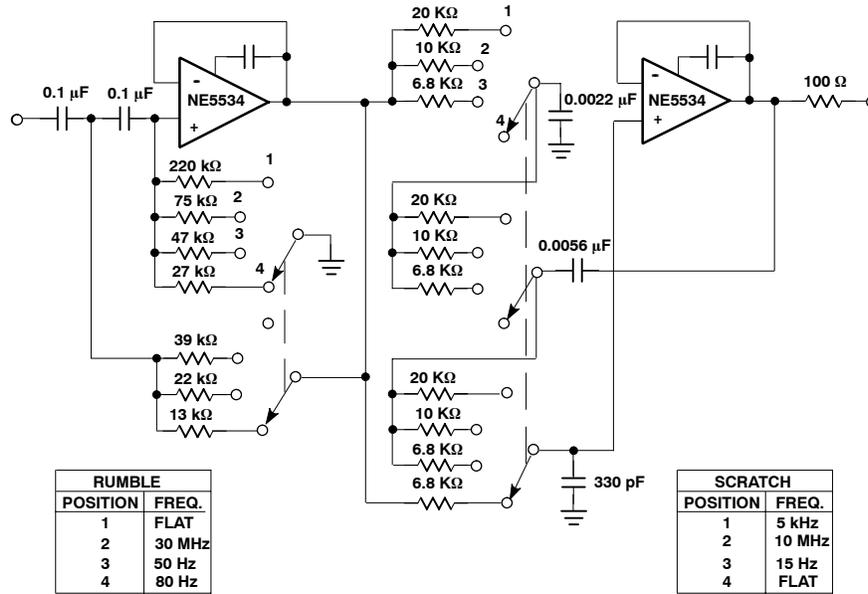
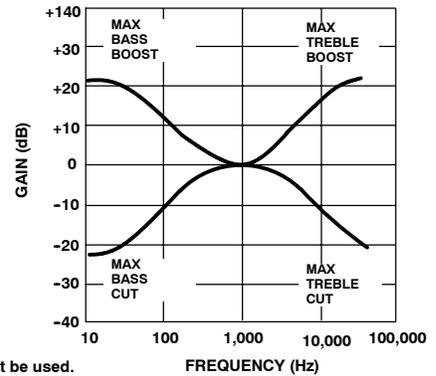
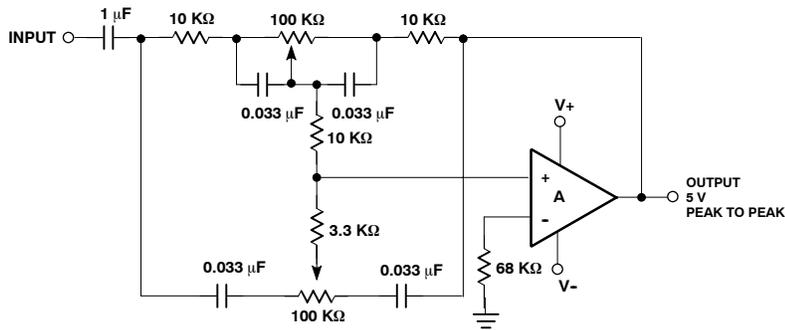


Figure 19. Rumble/Scratch Filter

**TONE CONTROL**

Tone control of audio systems involves altering the flat response in order to attain more low frequencies or more high ones, dependent upon listener preference. The circuit

of Figure 20 provides 20 dB of bass or treble boost or cut as set by the variable resistance. The actual response of the circuit is shown also.



- NOTES:  
 1. Amplifier A may be a NE531 or 301. Frequency compensation, as for unity gain non-inverting amplifiers, must be used.  
 2. Turn-over frequency - 1k Hz.  
 3. Base boost +20 dB, bass cut -20 dB, treble boost +19 dB at 20 Hz, treble cut -19 dB at 20 Hz.

Figure 20. Tone Control Circuit for Operational Amplifiers

**BALANCE AND LOUDNESS AMPLIFIER**

Figure 21 shows a combination of balance and loudness controls. Due to the non-linearity of the human hearing system, the low frequencies must be boosted at low listening

levels. Balance, level, and loudness controls provide all the listening controls to produce the desired music response.

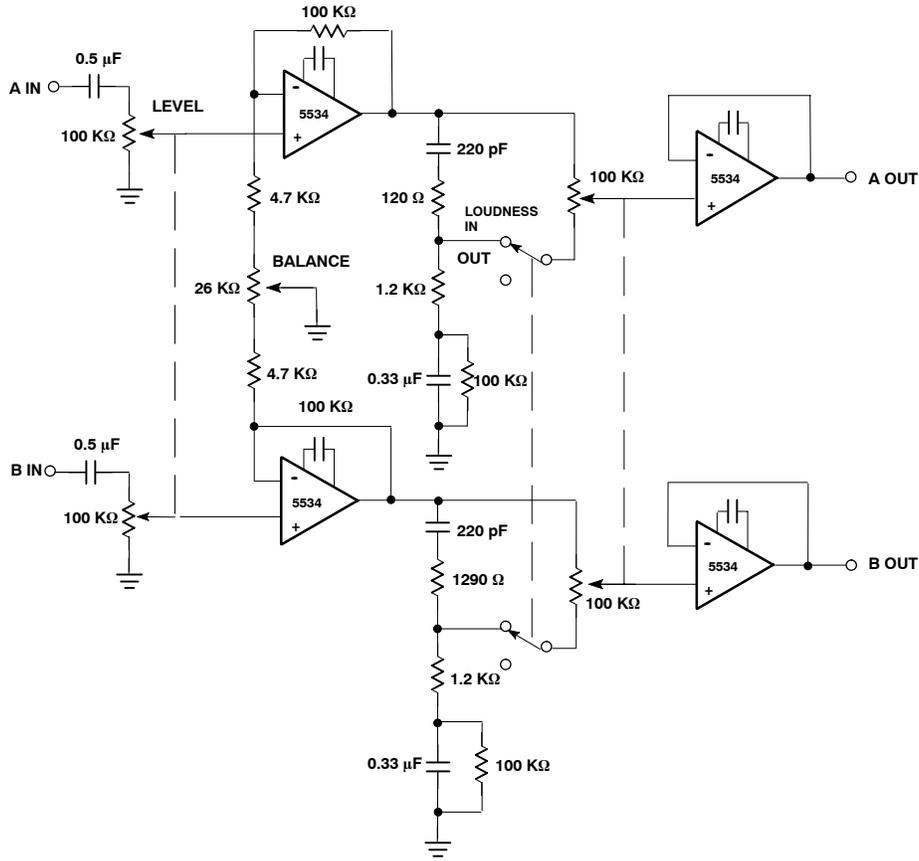
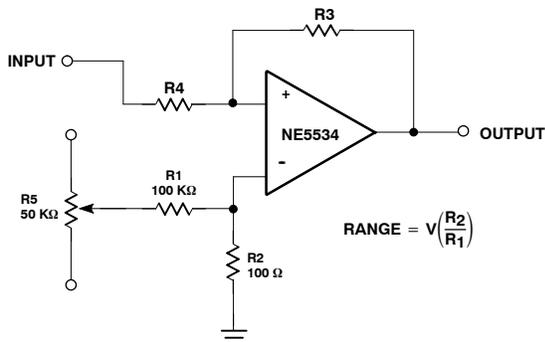


Figure 21. Balance Amplifier with Loudness Control

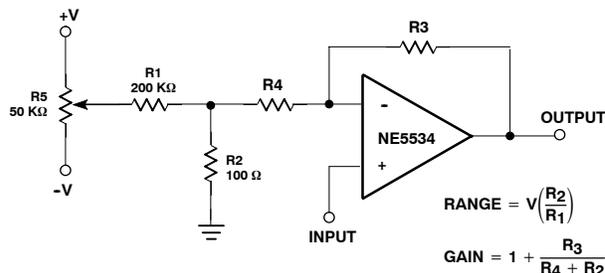
**VOLTAGE AND CURRENT OFFSET ADJUSTMENTS**

Many IC amplifiers include the necessary pin connections to provide external offset adjustments. Many times, however, it becomes necessary to select a device not possessing external adjustments. Figures 22, 23, and 24 suggest some possible arrangements for off-circuitry. The circuitry of

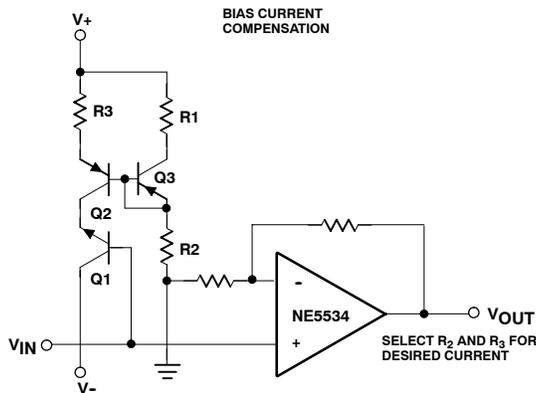
Figure 24 provides sufficient current into the input to cancel the bias current requirement. Although more simplified arrangements are possible, the addition of Q2 and Q3 provide a fixed current level to Q1, thus, bias cancellation can be provided without regard to input voltage level.



**Figure 22. Universal Offset Null for Inverting Amplifiers**



**Figure 23. Universal Offset Null for Non-Inverting Amplifiers**



**Figure 24. Bias Current Compensation**

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