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LM381 LOW NOISE DUAL PREAMPLIFIER

INTRODUCTION

The LM381 is a dual preamplifier expressly designed to meet the requirements of amplifying low level signals in low noise applications. Total equivalent input noise is typically 0.5 μV rms (R_S = 600Ω, 10–10, 000 Hz).

Each of the two amplifiers is completely independent, with an internal power supply decoupler-regulator, providing 120 dB supply rejection and 60 dB channel separation. Other outstanding features include high gain (112 dB), large output voltage swing (V_{CC} −2V) p–p, and wide power bandwidth (75 kHz, 20 $V_{p\text{-}p}$). The LM381 operates from a single supply across the wide range of 9 to 40V. The amplifier is internally compensated and short-circuit protected.

Attempts have been made to fill this function with selected operational amplifiers. However, due to the many special requirements of this application, these recharacterizations have not adequately met the need.

With the low output level of magnetic tape heads and phonograph cartridges, amplifier noise becomes critical in achieving an acceptable signal-to-noise ratio. This is a major deficiency of the op amp in this application. Other inadequacies of the op amp are insufficient power supply rejection, limited small-signal and power bandwidths, and excessive external components.

TABLE 1. T_A = 25°C, V_{CC} = 14V, unless otherwise stated.

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
Voltage Gain	Open Loop (Differential Input)		160,000		V/V
	Open Loop (Single Ended Input)		320,000		V/V
Supply Current	V_{CC} 9 to 40V, $R_L = \infty$		10		mA
Input Resistance (Positive Input)			100		kΩ
(Negative Input)			200		kΩ
Input Current (Positive Input)			0.2		μA
(Negative Input)			0.5		μA
Output Resistance	Open Loop		150		Ω
Output Current	Source		8		mA
	Sink		2		mA
Output Voltage Swing	Peak-to-peak		V_{CC} −2		V
Small Signal Bandwidth			15		MHz
Power Bandwidth	$20V_{p\text{-}p}$ (V_{CC} = 24V)		75		kHz
Maximum Input Voltage	Linear Operation			300	mVrms
Supply Rejection Ratio	f = 1 kHz		120		dB
Channel Separation	f = 1 kHz		60		dB
Total Harmonic Distortion	75 dB Gain, f = 1 kHz		0.1%		%
Total Equivalent Input Noise	R_S = 600Ω, 10-10, 000 Hz (Single Ended Input)		0.5		μVrms
Noise Figure	50 kΩ, 10-10, 000 Hz (Single Ended Input)		1.0		dB
	10 kΩ, 10-10, 000 Hz (Single Ended Input)		1.3		dB
	5 kΩ, 10-10, 000 Hz (Single Ended Input)		1.6		dB

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CIRCUIT DESCRIPTION

To achieve low noise performance, special consideration must be taken in the design of the input stage. First, the input should be capable of being operated single ended; since both transistors contribute noise in a differential stage degrading input noise by the factor $\sqrt{2}$. Secondly, both the load and biasing elements must be resistive; since active components would each contribute as much noise as the input device.

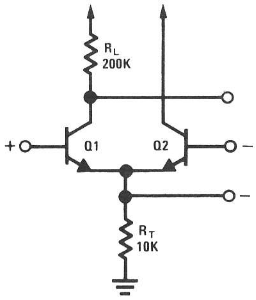

FIGURE 1. Input Stage

The basic input stage, Figure 1, can operate as a differential or single ended amplifier. For optimum noise performance Q_2 is turned OFF and feedback is brought to the emitter of Q_1.

In applications where noise is less critical, Q_1 and Q_2 can be used in the differential configuration. This has the advantage of higher impedance at the feedback summing point, allowing the use of larger resistors and smaller capacitors in the tone control and equilization networks.

The voltage gain of the single ended input stage is given by:

$$A_{V(AC)} = \frac{R_L}{re} = \frac{200k}{1.25k} = 160 \qquad (1)$$

Where:

$$re = \frac{KT}{qI_E} \approx 1.25 \times 10^3 \text{ at } 25^\circ C \quad I_E \approx 20\,\mu A$$

The voltage gain of the differential input stage is:

$$A_V = \frac{1}{2}\frac{R_L}{re} = \frac{1}{2}\frac{R_L\,qI_E}{KT} \approx 80 \qquad (2)$$

The schematic diagram of the LM381, Figure 2, is divided into separate groups by function; first and second voltage gain stages, third current gain stage, and the bias regulator.

The second stage is a common-emitter amplifier (Q_5) with a current source load (Q_6). The Darlington emitter-follower Q_3, Q_4 provides level shifting and current gain to the common-emitter stage (Q_5) and the output current sink (Q_7). The voltage gain of the second stage is approximately 2000 making the total gain of the amplifier typically 160,000 in the differential input configuration.

The preamplifier is internally compensated with the pole-splitting capacitor, C_1. This compensates to unity gain at 15 MHz. The compensation is adequate to preserve stability to a closed loop gain of 10. Compensation for unity gain closure may be provided with the addition of an external capacitor in parallel with C_1 between Pins 5 and 6, 10 and 11.

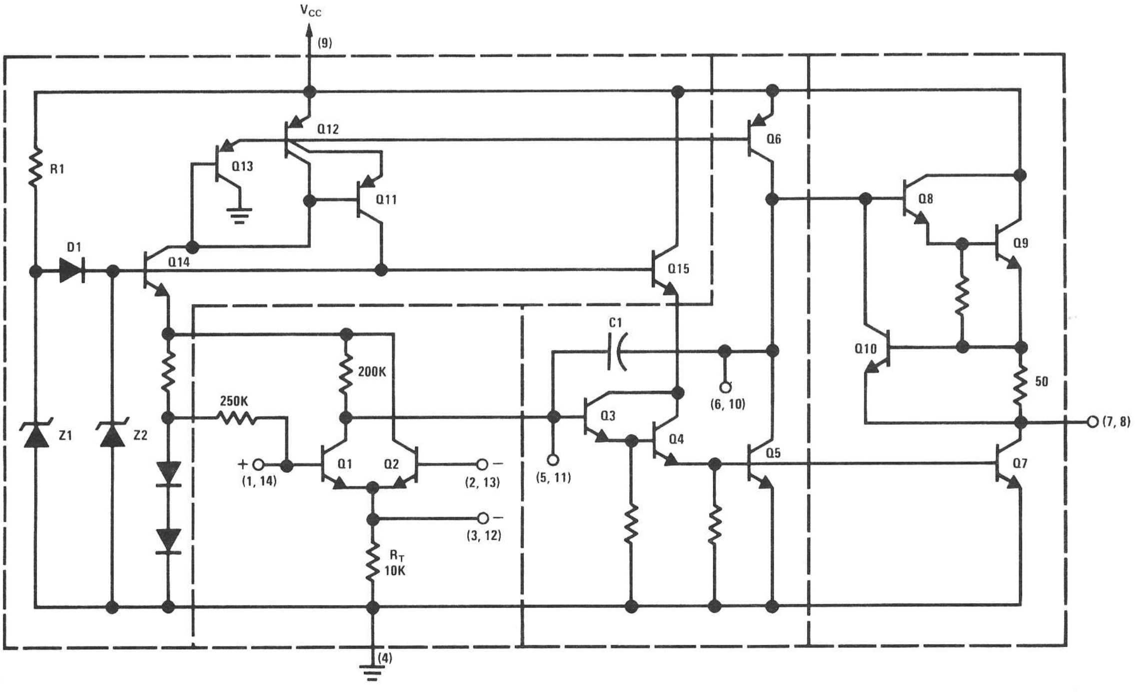

FIGURE 2. Schematic Diagram

Three basic compensation schemes are possible for this amplifier: first stage pole, second stage pole and pole-splitting. First stage compensation will cause an increase in high frequency noise because the first stage gain is reduced, allowing the second stage to contribute noise. Second stage compensation causes poor slew rate (power bandwidth) because the capacitor must swing the full output voltage. Pole-splitting overcomes both these deficiencies and has the advantage that a small monolithic compensation capacitor can be used.

The output stage is a Darlington emitter-follower (Q_8, Q_9) with an active current sink (Q_7). Transistor Q_{10} provides short-circuit protection by limiting the output to 12 mA.

The biasing reference is a zener diode (Z_2) driven from a constant current source (Q_{11}). Supply decoupling is the ratio of the current source impedance to the zener impedance. To achieve the high current source impedance necessary for 120 dB supply rejection, a cascode configuration is used (Q_{11} and Q_{12}). The reference voltage is used to power the first stages of the amplifier through emitter-followers Q_{14} and Q_{15}. Resistor R_1 and zener Z_1 provide the starting mechanism for the regulator. After starting, zero volts appears across D_1 taking it out of conduction.

Biasing

Figure 3 shows an AC equivalent circuit of the LM381. The non-inverting input, Q_1, is referenced to a voltage source two V_{BE} above ground. The output quiescent point is established by negative DC feedback through the external divider R_4/R_5 (Figure 4).

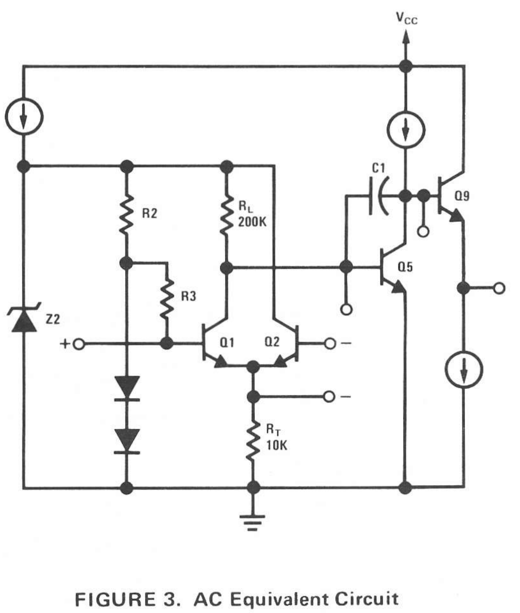

FIGURE 3. AC Equivalent Circuit

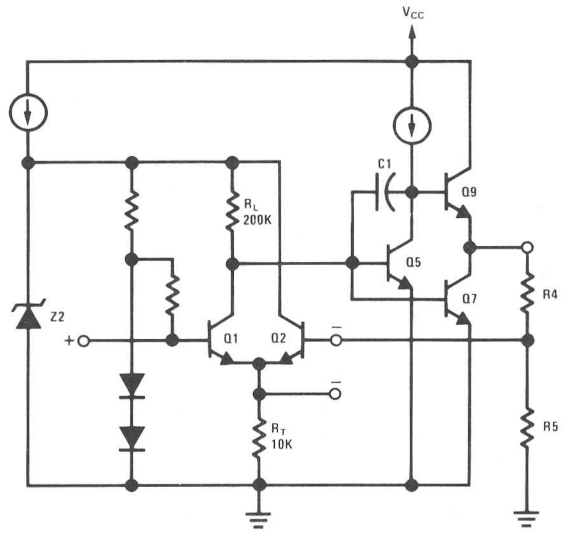

FIGURE 4. Differential Input Biasing

For bias stability, the current through R_5 is made ten times the input current of Q_2 ($\approx$0.5 μA). Then, for the differential input, resistors R_5 and R_4 are:

$$R_5 = \frac{2V_{BE}}{10\ I_{Q2}} = \frac{1.2}{5 \times 10^{-6}} = 240\ \text{k}\Omega\ \text{MAXIMUM} \tag{3}$$

$$R_4 = \left(\frac{V_{CC}}{2.4} - 1\right) R_5. \tag{4}$$

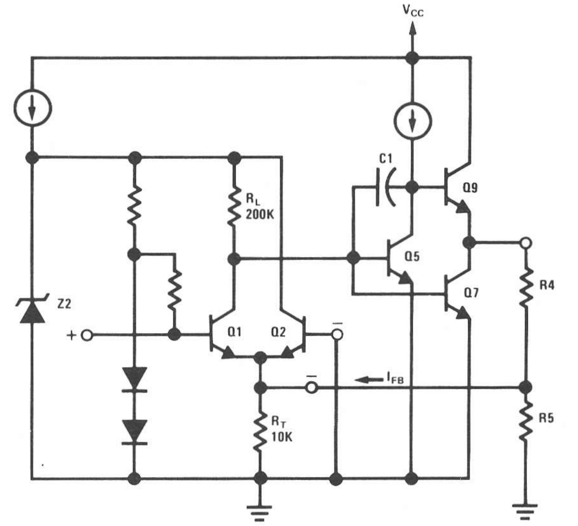

FIGURE 5. Single Ended Input Biasing

When using the single ended input, Q_2 is turned OFF and DC feedback is brought to the emitter of Q_1 (Figure 5). The impedance of the feedback summing point is now two orders of magnitude lower than the base of Q_2 ($\approx$10 kΩ). Therefore, to preserve bias stability, the impedance of the feedback network must be decreased. In keeping with reasonable resistance values, the impedance of the feedback voltage source can be 1/5 the summing point impedance.

The feedback current is $<100\ \mu A$ worst case. Therefore, for single ended input, resistors R_5 and R_4 are:

$$R_5 = \frac{V_{BE}}{5\,I_{FB}} = \frac{0.6}{5 \times 10^{-4}} = 1200\Omega \text{ MAXIMUM} \tag{5}$$

$$R_4 = \left(\frac{V_{CC}}{1.2} - 1\right) R_5. \tag{6}$$

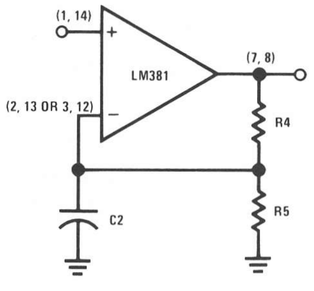

FIGURE 6. AC Open Loop

The circuits of Figures 4 and 5 have an AC and DC gain equal to the ratio R_4/R_5. To open the AC gain, capacitor C_2 is used to shunt R_5 (Figure 6). The AC gain now approaches open loop. The low frequency 3 dB corner, f_o, is given by:

$$f_o = \frac{A_o}{2\pi\, C_2 R_4} \quad \text{where: } A_o = \text{open loop gain} \tag{7}$$

Tape Playback Preamplifier

Figure 7 shows the LM381 in a flat response tape playback configuration. The mid-band gain is set by resistor ratio

$$(R_4 + R_6)/R_6 \tag{8}$$

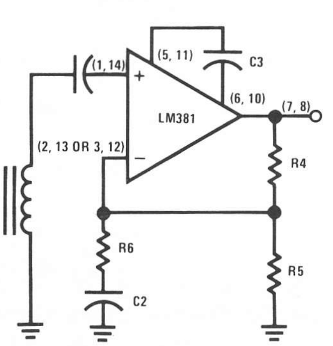

FIGURE 7. Flat Response Tape Amplifier

Capacitor C_2 sets the low frequency 3 dB corner where $X_{C2} = R_6$.

$$C_2 = \frac{1}{2\pi f_o R_6} \tag{9}$$

The small-signal bandwidth of the LM381 is 15 MHz making the preamp suitable for wide-band instrumentation applications. However, in narrow-band applications it is desirable to limit the amplifier bandwidth and thus eliminate high frequency noise. Capacitor C_3 accomplishes this by shunting the internal pole-splitting capacitor (C_1), limiting the bandwidth of the amplifier. Thus, the high frequency 3 dB corner is set by C_3 according to equation 10.

$$C_3 = \frac{1}{2\pi f_3\, re\, 10^{\frac{A}{20}}} - 4 \times 10^{-12} \tag{10}$$

f_3 = high frequency 3 dB corner

re = first stage small-signal emitter resistance $\approx 2.6\ k\Omega$

A = mid-band gain in dB

For music applications, response shaping is required to provide the NAB standard tape playback equalization. Figure 8 shows the NAB equalization characteristic.

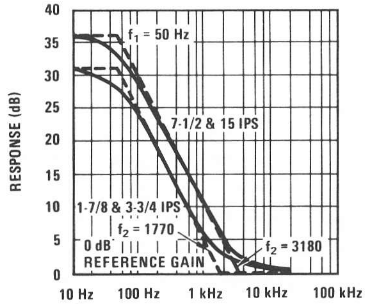

FIGURE 8. NAB Equilization Characteristic

The NAB response is achieved with the circuit of Figure 9. Resistors R_4 and R_5 set the DC bias and are chosen according to equations 3 and 4 for

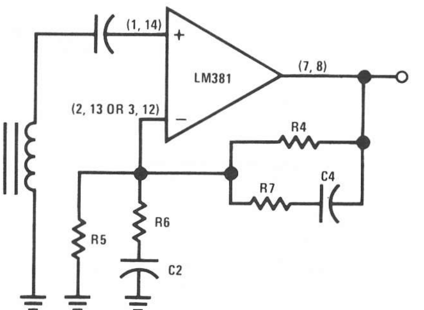

FIGURE 9. NAB Tape Preamp.

differential input operation and equations 5 and 6 for the single ended input. The reference gain of the preamp, above corner frequency f_2 (Figure 8), is set by the ratio:

$$0 \text{ dB reference gain} = \frac{R_7 + R_6}{R_6}. \qquad (11)$$

The corner frequency f_2 (Figure 8) is determined where $X_{C4} = R_7$ and is given by:

$$f_2 = \frac{1}{2\pi C_4 R_7}. \qquad (12)$$

Corner frequency f_1 is determined where $X_{C4} = R_4$:

$$f_1 = \frac{1}{2\pi C_4 R_4}. \qquad (13)$$

The low frequency 3 dB roll-off point, f_o, is set where $X_{C2} = R_6$:

$$f_o = \frac{1}{2\pi C_2 R_6}. \qquad (14)$$

Example: Design a NAB equalized preamp for a tape player requiring 0.5V rms output from a head sensitivity of 800 μV at 1 kHz, 3-3/4 IPS. The power supply voltage is 24V and the differential input configuration is used.

1. From equation (3) let $R_5 = 240\ k\Omega$.
2. Equation (4) $R_4 = \left(\frac{V_{CC}}{2.4} - 1\right) R_5$

   $$R_4 = \left(\frac{24}{2.4} - 1\right) 2.4 \times 10^5$$

   $$R_4 = 2.16 \times 10^5 \approx 2.2\ M\Omega$$
3. For a corner frequency, f_1 equal to 50 Hz, equation (13) is used.

   $$(13)\quad C_4 = \frac{1}{2\pi f_1 R_4} = \frac{1}{6.28 \times 50 \times 2.2 \times 10^6}$$

   $$= 1.44 \times 10^{-9}$$

   $$C_4 \approx 1500 \text{ pF}.$$
4. From Figure 8, the corner frequency $f_2 = 1770$ Hz at 3-3/4 IPS. Resistor R_7 is found from equation (12).

   $$(12)\quad C_4 = \frac{1}{2\pi\ f_2 R_7}$$

   $$R_7 = \frac{1}{6.28 \times 1770 \times 1.5 \times 10^{-9}} = 6 \times 10^4$$

   $$R_7 \approx 62\ k\Omega.$$
5. The required voltage gain at 1 kHz is:

   $$A_V = \frac{0.5\text{V rms}}{800\ \mu\text{V rms}} = 6.25 \times 10^2 \text{ V/V} = 56 \text{ dB}.$$
6. From Figure 8 we see the reference frequency gain, above f_2, is 5 dB down from the 1 kHz value or 51 dB (355 V/V).

   Equation (11)

   $$0 \text{ dB Reference Gain} = \frac{R_7 + R_6}{R_6} = 355$$

   $$R_6 = \frac{R_7}{355-1} = \frac{62k}{354} = 175$$

   $$R_6 \approx 180\Omega.$$
7. For low frequency corner $f_o = 40$ Hz, equation (14)

   $$C_2 = \frac{1}{2\pi\ f_o R_6} = \frac{1}{6.28 \times 40 \times 180} = 2.21 \times 10^{-5}$$

   $$C_2 \approx 20\ \mu\text{F}.$$

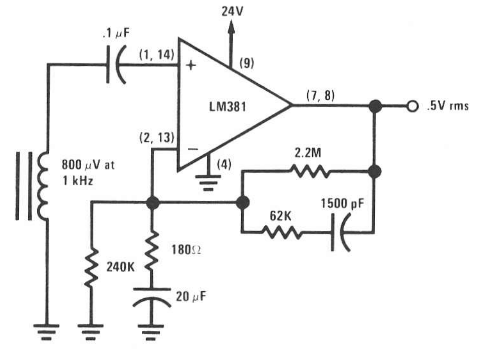

FIGURE 10. Typical Tape Playback Amplifier

This circuit is shown in Figure 10 and requires approximately 5 seconds to turn-ON for the gain and supply voltage chosen in the example. Turn-ON time can closely be approximated by:

$$t_{ON} \approx -R_4 C_2 \ln\left(1 - \frac{2.4}{V_{CC}}\right). \qquad (15)$$

As seen by equation (15), increasing the supply voltage decreases turn-ON time. Decreasing the amplifier gain also decreases turn-ON time by reducing the $R_4 C_2$ product.

Where the turn-ON time of the circuit of Figure 9 is too long, the time may be shortened by using the circuit of Figure 11. The addition of resistor R_D forms a voltage divider with R_6'. This divider is chosen so that zero DC voltage appears across

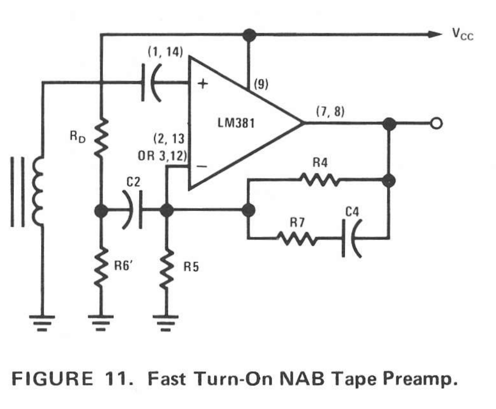

FIGURE 11. Fast Turn-On NAB Tape Preamp.

C_2. The parallel resistance of R_6' and R_D is made equal to the value of R_6 found by equation (11). In most cases the shunting effect of R_D is negligible and $R_6' \approx R_6$.

For differential input, R_D is given by:

$$R_D = \frac{(V_{CC} - 1.2)\, R_6'}{1.2}. \qquad (16)$$

For single ended input:

$$R_D = \frac{(V_{CC} - 0.6)\, R_6'}{0.6} \qquad (17)$$

In cases where power supply ripple is excessive, the circuit of Figure 11 cannot be used since the ripple is coupled into the input of the preamplifier through the divider.

The circuit of Figure 12 provides fast turn-ON while preserving the 120 dB power supply rejection.

The DC operating point is still established by R_4/R_5. However, equations (3) and (5) are modified by a factor of 10 to preserve DC bias stability.

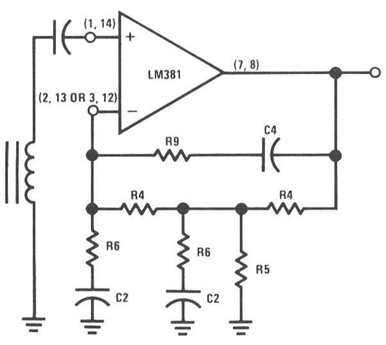

FIGURE 12. Two-Pole Fast Turn-On NAB Tape Preamp.

For differential input, equation (3) is modified as:

$$\text{(3A)}\quad R_5 = \frac{2\,V_{BE}}{100\, I_{Q2}} = \frac{1.2}{50 \times 10^{-8}}$$

$$= 24\text{ k}\Omega \text{ MAXIMUM.}$$

For single ended input:

$$\text{Equation (5A)}\quad R_5 = \frac{V_{BE}}{50\, I_{FB}} = \frac{0.6}{50 \times 10^{-4}}$$

$$= 120\Omega \text{ MAXIMUM.}$$

Equations (11), (12) and (14) describe the high frequency gain and corner frequencies f_2 and f_o as before. Frequency f_1 now occurs where X_{C4} equals the composite impedance of the R_4, R_6, C_2 network as given by equation (18).

$$C_4 = \frac{1}{2\pi f_1 R_6 \left[\left(\frac{R_4 + R_6}{R_6}\right)^2 - 1\right]} \qquad (18)$$

The turn-ON time becomes:

$$t_{ON} \approx -2\sqrt{R_4 C_2}\, \ln\left(1 - \frac{2.4}{V_{CC}}\right). \qquad (19)$$

Example: Design an NAB equalized preamp with the fast turn-ON circuit of Figure 12 for the same requirements as the previous example.

1. From equation (3A) let $R_5 = 24\text{ k}\Omega$.

2. Equation (4) $R_4 = \left(\frac{V_{CC}}{2.4} - 1\right) R_5$

$$= \left(\frac{24}{2.4} - 1\right) 24 \times 10^3$$

$$R_4 = 2.16 \times 10^5 \approx 220\text{ k}\Omega.$$

3. From the previous example the reference frequency gain, above f_2, was found to be 51 dB or 355 V/V.

   Equation (11) $\frac{R_7 + R_6}{R_6} = 355.$

4. The corner frequency f_2 is 1770 Hz for 3-3/4 IPS.

   Equation (12) $C_4 = \frac{1}{2\pi f_2 R_7}$

5. The corner frequency f_1 is 50 Hz and is given by equation (18).

$$\text{(18)}\qquad C_4 = \frac{1}{2\pi f_1 R_6 \left[\left(\frac{R_4 + R_6}{R_6}\right)^2 - 1\right]}$$

6. Solving equations (11), (12), and (18) simultaneously gives:

$$R_6 = \frac{R_4\, (f_1 + \sqrt{f_1{}^2 + f_1 f_2\, (\text{Ref. Gain})}}{f_2\, (\text{Ref. Gain})} \qquad (20)$$

$$R_6 = \frac{2.2 \times 10^5\, (50 + \sqrt{2500 + 50 \times 1770 \times 355})}{1770 \times 355}$$

$$= 1.98 \times 10^3$$

$R_6 \approx 2\text{ k}\Omega.$

7. From equation (11) $R_7 = 354\, R_6 = 708 \times 10^3$
   $R_7 \approx 680\text{ k}\Omega.$

8. Equation (12) $C_4 = \frac{1}{2\pi f_2 R_7}$

$$= \frac{1}{6.28 \times 1770 \times 680 \times 10^3}$$

$$C_4 = 1.32 \times 10^{-10} \approx 120\text{ pF.}$$

9. Equation (14) $C_2 = \frac{1}{2\pi f_o R_6}$

$$= \frac{1}{6.28 \times 40 \times 2 \times 10^3}$$

$$C_2 = 1.99 \times 10^{-6} \approx 2\,\mu\text{F.}$$

This circuit is shown in Figure 13 and requires only 0.1 seconds to turn-ON.

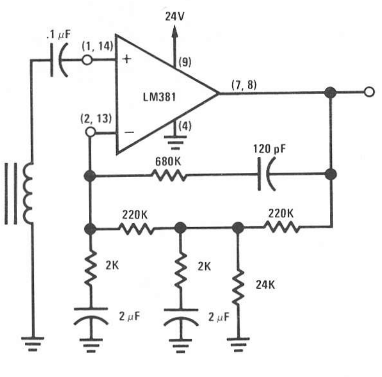

FIGURE 13

TAPE RECORD PREAMPLIFIER

When recording, the frequency response is the complement of the NAB playback equalization, making the composite record and playback response flat. Figure 14 shows the record characteristic superimposed on the NAB playback response.

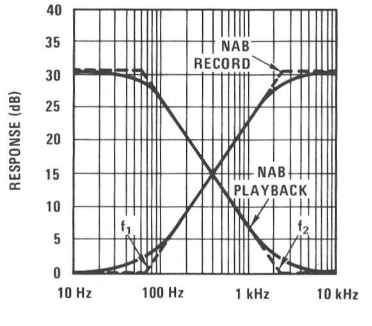

FIGURE 14. NAB Record & Playback Equilization

Curve A of Figure 15 shows the response characteristics of a typical laminated core, quarter-track head.

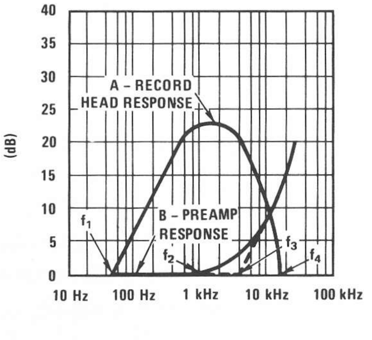

FIGURE 15. Recording Head & Preamp. Response for NAB Equilization

Curve B shows the required preamplifier response to make the composite, A + B, provide the NAB recording characteristic. This response is obtained with the circuit of Figure 16. Resistors R_4 and R_5

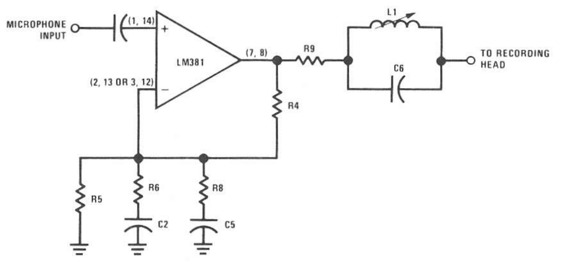

FIGURE 16. Tape Recording Preamp.

set the DC bias as before using equations (3) and (4) for the differential input and equations (5) and (6) for the single ended input. Resistor R_6 and capacitor C_2 set the mid-band gain as before (equations (8) and (9)). Capacitor C_5 sets the high frequency 3 dB point, f_3, (Figure 15) as:

$$f_3 = \frac{1}{2\pi C_5 R_6} \tag{21}$$

The preamp gain increases at 6 dB/octave above f_3 until $R_8 = X_{C5}$.

$$R_8 = \frac{1}{2\pi f_4 C_5} \tag{22}$$

f_4 = desired high frequency cutoff

Resistor R_9 is chosen to provide the proper recording head current.

$$R_9 = \frac{V_o}{i_{RECORD\,HEAD}} \tag{23}$$

L_1 and C_6 form a parallel resonant bias trap to present a high impedance to the recording bias frequency and prevent intermodulation distortion.

Example: A recorder having a 24V power supply uses recording heads requiring 30 μA AC drive current. A microphone of 10 mV peak output is used. Single ended input is desired for optimum noise performance.

1. From equation (5) let $R_5 = 1200\Omega$.

2. Equation (6) $R_4 = \left(\frac{V_{CC}}{1.2} - 1\right) R_5$

   $R_4 = \left(\frac{24}{1.2} - 1\right) 1200.$

   $R_4 = 2.28 \times 10^4 \approx 22\ k\Omega.$

3. The maximum output of the LM381 is $(V_{CC} - 2V)_{p\text{-}p}$. For a 24V power supply, the maximum output is $22V_{p\text{-}p}$ or 7.8V rms. Therefore, an output swing of 6V rms is reasonable.

From equation (23) $R_9 = \dfrac{V_o}{i_{RECORD\,HEAD}}$

$$R_9 = \frac{6V}{30\,\mu A} = 200\ k\Omega.$$

4. Let the high frequency cutoff f_4 = 16 kHz (Figure 15). The recording head frequency response begins falling off at approximately 4 kHz. Therefore, the preamp gain must increase at this frequency to obtain the proper composite characteristic. The slope is 6 dB/octave for the two octaves between f_3 (4 kHz) and the cutoff frequency f_4 (16 kHz). Therefore, the mid-band gain lies 12 dB below the peak gain.

   We are allowing 6V rms output voltage swing.

   Therefore, the peak gain $= \dfrac{6V}{10\ mV} = 600$ or 55.6 dB.

   The mid-band gain = 43.6 dB or 150.

5. From equation (8) the mid-band gain =

$$\frac{R_4 + R_6}{R_6} = 150.$$

$$R_6 = \frac{R_4}{149} = \frac{22 \times 10^3}{149} = 147.7$$

$$R_6 \approx 150\Omega$$

6. Equation (9) $C_2 = \dfrac{1}{2\pi f_o R_6}$

$$= \frac{1}{6.28 x 50 x 150}$$

$$= 2.12 x 10^{-5}$$

$$C_2 \approx 20\,\mu F.$$

7. Equation (21) $C_5 = \dfrac{1}{2\pi f_3 R_6}$

$$= \frac{1}{6.28 x 4 x 10^3 x 150}$$

$$= 2.66 x 10^{-7}$$

$$C_5 \approx 0.27\,\mu F.$$

8. Equation (22) $R_8 = \dfrac{1}{2\pi f_4 C_5}$

$$= \frac{1}{6.28 x 16 x 10^3 x 2.7 x 10^{-7}}$$

$$= 36.8$$

$$R_8 \approx 33\Omega.$$

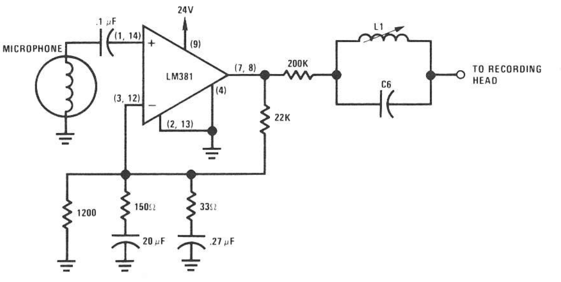

FIGURE 17. Typical Tape Recording Amplifier

PHONO PREAMPLIFIER

Crystal and ceramic phono cartridges provide output levels of 100 mV to 2V and therefore do not require preamplification. Magnetic cartridges, however, provide much lower outputs as shown in Table 2.

TABLE 2.

MANUFACTURER	MODEL	OUTPUT AT 5 cm/sec
Empire Scientific	999	5 mV
	888	8 mV
Shure	V-15	3.5 mV
	M91	5 mV
Pickering	V-15 AT3	5 mV

Output voltage is specified for a given modulation velocity. The magnetic pickup is a velocity device, therefore, output is proportional to velocity. For example, a cartridge producing 5 mV at 5 cm/sec will produce 1 mV at 1 cm/sec and is specified as having a sensitivity of 1 mV/cm/sec.

In order to transform cartridge sensitivity into useful preamp design information, we need to know typical and maximum modulation velocity limits of stereo records.

The RIAA recording characteristic establishes a maximum recording velocity of 25 centimeters per second in the range of 800 to 2500 Hz. Typically, good quality records are recorded at a velocity of 3 to 5 cm/sec.

Figure 18 shows the RIAA playback equalization. This response is obtained with the circuit of Figure 19.

Resistors R_4 and R_5 set the DC bias (equations (3) and (4), or (5) and (6)). The 0 dB reference gain is set by the ratio:

$$0\ dB\ Ref\ Gain = \frac{R_{10} + R_6}{R_6}. \qquad (24)$$

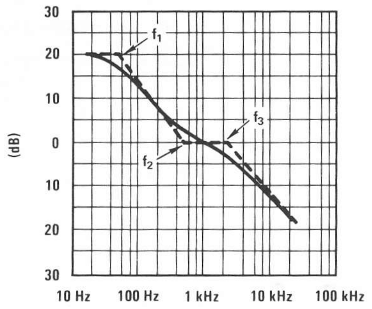

FIGURE 18. RIAA Playback Equilization

The corner frequency, f_1, (Figure 18) is established where $X_{C7} = R_4$ or:

$$C_7 = \frac{1}{2\pi f_1 R_4}. \qquad (25)$$

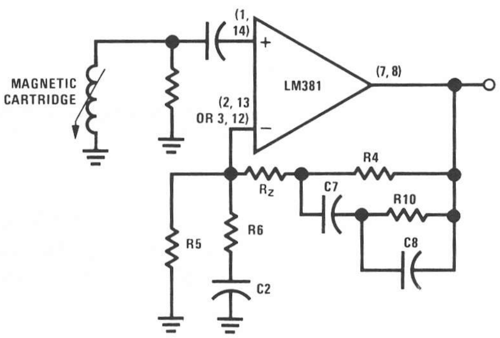

FIGURE 19. RIAA Phono Preamp.

Likewise, frequency, f_2 occurs where $X_{C7} = R_{10}$ or:

$$C_7 = \frac{1}{2\pi f_2 R_{10}}. \qquad (26)$$

The third corner frequency, f_3, is determined where $X_{C8} = R_{10}$:

$$C_8 = \frac{1}{2\pi f_3 R_{10}}. \qquad (27)$$

Resistor R_Z is used to insert a zero in the feedback loop since the LM381 is not compensated for unity gain. Either R_Z is required to provide a zero at or above a gain of 20 dB ($R_Z = 10\ R_6$), or external compensation is provided for unity gain stability according to equation (10).

Example: Design a phonograph preamp operating from a 30 volt supply, with a cartridge of 0.5 mV/cm/sec sensitivity, to drive a power amplifier of 5V rms input overload limit.

1. From equation (3) let $R_5 = 100\ k\Omega$.

2. Equation (4) $R_4 = \left(\frac{V_{CC}}{2.4} - 1\right) R_5$

$$= \left(\frac{30}{2.4} - 1\right) 10^5$$

$$R_4 = 11.5\text{x}10^5 \approx 1.2\ M\Omega.$$

3. Equation (25) $C_7 = \frac{1}{2\pi f_1 R_4}$

$$= \frac{1}{6.28\text{x}50\text{x}1.2\text{x}10^6}$$

$$= 2.65\text{x}10^{-9}$$

$$C_7 \approx .003\ \mu F.$$

4. Equation (26) $C_7 = \frac{1}{2\pi f_2 R_{10}}$;

$$R_{10} = \frac{1}{6.28\text{x}500\text{x}3\text{x}10^{-9}}$$

$$= 1.03\text{x}10^5$$

$$R_{10} \approx 100\ k\Omega.$$

5. The maximum cartridge output at 25cm/sec is:

(.5 mV/cm/sec) x (25 cm/sec) = 12.5 mV. The required mid-band gain is therefore:

$$\frac{5V\ rms}{12.5\ mV\ rms} = 400.$$

6. Equation (24)

$$0\text{ dB Ref. Gain} = \frac{R_{10} + R_6}{R_6} = 400;$$

$$R_6 = \frac{100k}{399} = 251 \approx 240\Omega$$

$$R_Z = 10\ R_6 = 2400\Omega.$$

7. Equation (9)

$$C_2 = \frac{1}{2\pi f_o R_6} = \frac{1}{6.28\text{x}40\text{x}\ 240} = 1.7\text{x}10^{-5}$$

$$C_2 \approx 20\ \mu F.$$

8. Equation (27)

$$C_8 = \frac{1}{2\pi f_3 R_{10}} = \frac{1}{6.28\text{x}2200\text{x}6.8\text{x}10^4}$$

$$= 7.23\text{ x }10^{-10}$$

$$C_8 \approx 0.001\ \mu F.$$

The completed design is shown in Figure 20 where a 47 kΩ input resistor has been included to provide the RIAA standard cartridge load.

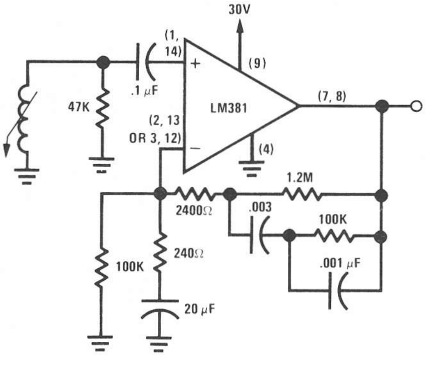

FIGURE 20. Typical Magnetic Phono Preamp.

TONE CONTROLS

Most tape and phonograph applications require bass and treble tone controls. Due to the insertion loss of the tone control, (equal to the available boost), it has been normal to use two preamplifiers with the control placed between them. However, due to the excellent gain and large output capability of the LM381, only a single preamp is required.

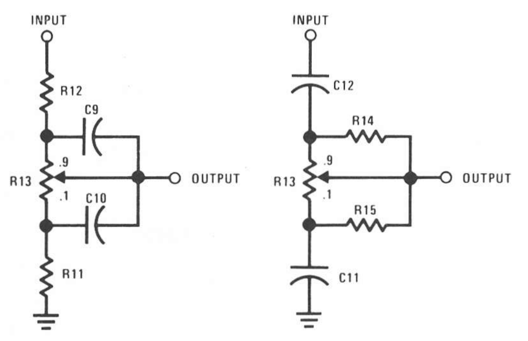

FIGURE 21. Bass & Treble Controls

Figure 21 shows the bass and treble tone controls. The potentiometers, R_{13}, are audio taper; i.e., at the center of shaft rotation the wiper is at the 90%–10% point of the total resistance. Both controls are simple AC dividers, with the flat response position where the signal is attenuated from the "full boost".

In the bass control the ratio of resistors R_{11}/R_{12} and R_{12}/R_{13} determine the degree of "boost" and "cut". For example, if 20 dB of "boost" and "cut" is desired, the ratio R_{11}/R_{12} and R_{12}/R_{13} is 20 dB or 10:1. The low frequency control point, f_1, (Figure 22) is set where $X_{C9} = R_{12}$ and $X_{C10} = R_{11}$.

$$C_9 = \frac{1}{2\pi f_1 R_{12}}, \qquad (28)$$

$$C_{10} = \frac{1}{2\pi f_1 R_{11}}. \qquad (29)$$

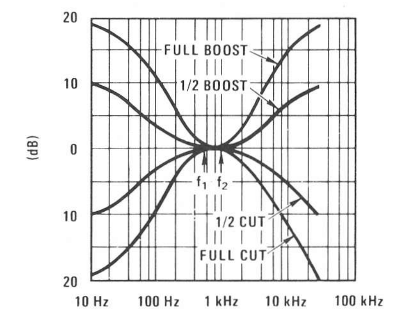

FIGURE 22. Bass & Treble Tone Control Response for 20 dB Boost & Attenuation

The treble control is the analogue of the bass control with the resistor and capacitor dividers reversed. The ratio of reactance of C_{11}/C_{12} is set equal to the amount of "boost" and "cut". The high frequency control point, f_2, is established where $X_{C12} = R_{13}$.

$$C_{12} = \frac{1}{2\pi f_2 R_{13}}. \qquad (30)$$

$$R_{14} = \frac{1}{2\pi f_2 C_{12}}. \qquad (31)$$

$$R_{15} = \frac{1}{2\pi f_2 C_{11}}. \qquad (32)$$

Figure 23 shows one channel of a practical preamplifier for a stereo phonograph. The preamp is complete with RIAA equalization, bass and treble tone control, balance control and volume control.

AUDIO MIXER

In many audio applications it is desirable to provide a mixer to combined or select several inputs. Such applications include public address systems where more than one microphone is used; tape recorders, high fidelity phonographs, guitar amplifiers, etc.

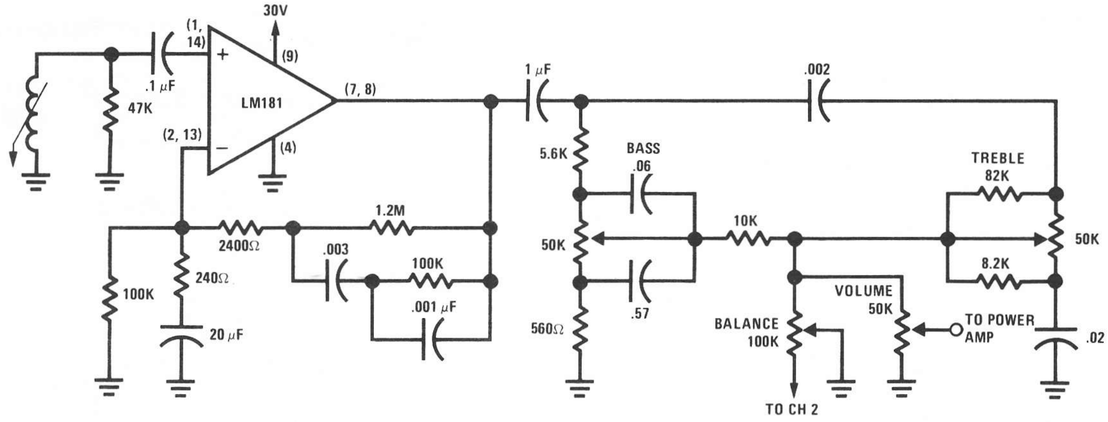

FIGURE 23. Single Channel of Complete Phono Preamp.

Figure 24 shows the LM381 in a mixer configuration. Inputs at A, B, C, $-N$ can be selected and combined (summed) with potentiometers R_A, R_B, R_C, $-R_N$. Resistors R_4 and R_5 establish the DC quiescent point in accordance with equations (3A) and (4). (Only the differential input configuration is used in the mixer application since the high source impedance of the input potentiometers would negate any advantage of the single ended input.) Input bias current is supplied through resistor R_F. Therefore, an upper limit of R_F should be established to avoid output offset voltage problems. A safe upper limit is to let:

$$R_F = R_4 \text{ MAXIMUM} \tag{33}$$

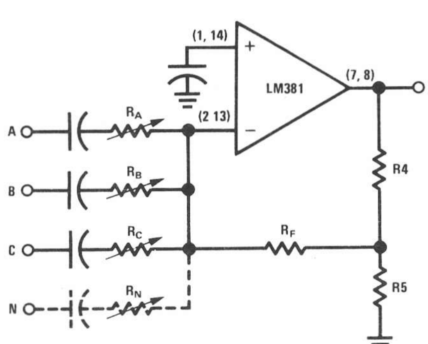

FIGURE 24. Audio Mixer

The voltage gain of the mixer is:

$$A_{V_{A,B,C}} = \frac{R_4 R_F}{R_5 \left(R_{A,B,C} + R_{S_{A,B,C}}\right)} \tag{34}$$

Where the values of R_F and the source impedance, R_S, are such that the gain of the circuit of Figure 24 is inadequate, the configuration of Figure 25 may be used.

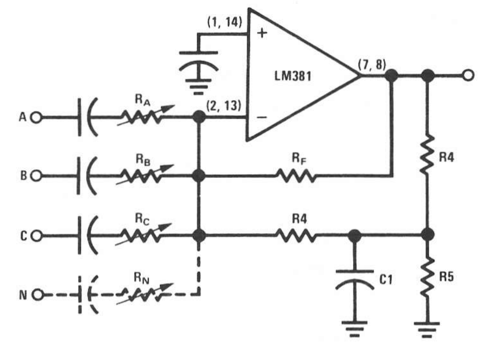

FIGURE 25.

The voltage gain of the mixer is now:

$$A_V = \frac{R_F}{R_{A,B,C} + R_{S_{A,B,C}}} \tag{35}$$

Since resistor R_F is no longer required to supply the input bias current, it does not have the upper limit as in the previous circuit. Therefore, the open loop gain of the LM381 can be realized. Capacitor C_1, shunts the AC feedback of the $R_4 - R_5$ network and is found by:

$$C_1 = \frac{10^{\frac{A_o}{20}}}{2\pi f_o R_4}$$

A_o = amplifier open loop gain in dB

f_o = low frequency 3 dB corner

Example: Design a microphone mixer for use with 600Ω dynamic microphones with an output level of 10 mV. The mixer should operate from a 24V supply and deliver 5 volts output. A dynamic range of 80 dB is desired.

1. From equation (3A) $R_5 = 24\ k\Omega$

2. Equation (4)

$$R_4 = \left(\frac{V_{CC}}{2.4} - 1\right) R_5$$

$$R_4 = \left(\frac{24}{2.4} - 1\right) 24 \times 10^3$$

$$R_4 = 2.16 \times 10^5 \approx 220\ k\Omega$$

3. For 5V output:

$$\text{Gain} = \frac{5V}{10\ mV} = 500$$

4. For 80 dB dynamic range:

$$\text{Attenuation} = \frac{500}{80\ dB} = 5 \times 10^{-2}$$

5. Equation (34)

$$A_V = \frac{R_4 R_F}{R_5 (R_{A,B,C} + R_S)}$$

$$R_F = \frac{A_V R_5 (R_{A,B,C} + R_S)}{R_4}$$

At maximum volume: $R_{A,B,C,} = 0$, Gain = 500

$$R_F = \frac{500 \times 2.4 \times 10^4 (0 + 600)}{2.2 \times 10^5}$$

$$R_F = 3.27 \times 10^3 \approx 3.3\ k\Omega$$

At maximum attenuation:

$$R_{A,B,C} = \frac{R_4 R_F}{A_V R_5} - R_S \quad \text{(from Equation 34)}$$

$$R_{A,B,C} = \frac{2.2 \times 10^5 \times 3.3 \times 10^3}{5 \times 10^{-2} \times 2.4 \times 10^4} - 600$$

$$R_{A,B,C} = 6.05 \times 10^5 \approx 500\ k\Omega$$

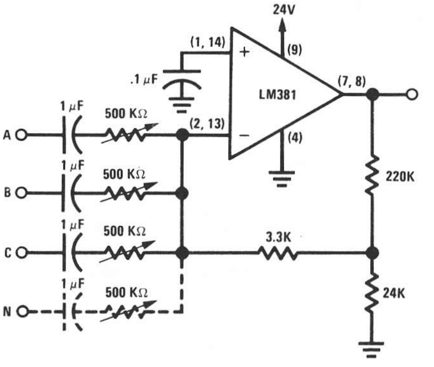

FIGURE 26.

CONCLUSION:

The applications presented in this note are by no means exhaustive. The LM381 is a widely versatile low noise, high gain, wide band gain block and, as such has many applications outside the audio spectrum.

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