COMMUNICATIONS

TRANSISTORS CAN SOUND BETTER THAN TUBES

DWIGHT O. MONTEITH, JR., AND RICHARD R. FLOWERS

Applied Research Laboratories, University of Texas at Austin, Austin, Tx. 78712

A design for a high-voltage preamplifier is presented in response to the debate taking place on the question of tube sound versus transistor sound. This design combines a low-noise input transistor with high-voltage output transistors to give noise performance comparable to an LM 381 and the large signal capability of tube circuits. When severely overloaded, this preamplifier produces harmonic distortion components which are comparable to, and perhaps more pleasing than, tube preamplifiers.

INTRODUCTION: A low-noise high-voltage transistor preamplifier has been designed to accommodate 1-volt peak input levels produced by microphones used on percussion instruments. This design exhibits the desirable overload characteristics of tubes in accordance with the investigations of Hamm[1]. Also, this circuit produces noise performance comparable to the LM 381, which was praised by Mintz [2], and the response of the circuit to large input signals should eliminate ''fussing'' over clipping, as discussed by Trumbull[3].

A goal realized by this design is to provide a low-noise microphone preamplifier transistor circuit which has the same large signal capability as tube designs. In accordance with the findings of Hamm, the overload or clipping characteristics of this circuit produce serendipitous results in that the psychoacoustic effects are tubelike. The large linear dynamic range exhibited by this preamplifier can be employed in recording and playback systems where compatible compression and expansion techniques are used to enhance the dynamic range of the recording medium. Use of this circuit as an input stage in many existing systems will provide the opportunity to shift undesirable overloading and/or dynamic range reduction to subsequent stages. However, when properly employed within a suitably designed system, this circuit can provide the overall capability for an excess of 100 dB linear dynamic range.

CIRCUIT DESCRIPTION

The unique feature of the circuit shown in Fig. 1 is the method by which a low-voltage, low-current, and low-noise input transistor was used in conjunction with large-signal, high-voltage transistors. This circuit will operate with a supply voltage from 50 to 300 volts dc. All the data taken for this paper were obtained using a 200-volt d-c supply.

Q_1, with a collector voltage from 4 to 8 volts and a current of 100 microamperes, is biased for optimum noise performance with low-impedance input sources. Q_1 is protected from the high-voltage supply by the base–

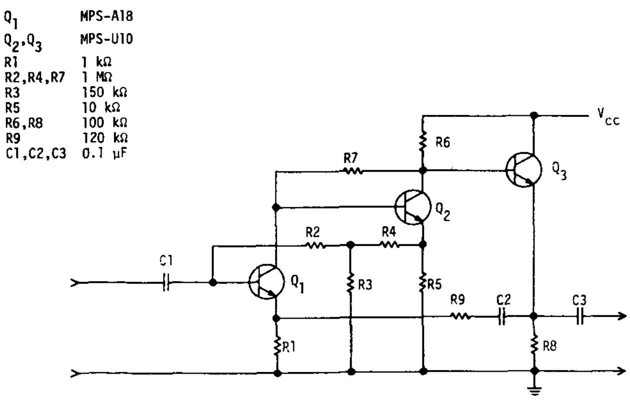

Fig. 1. Schematic diagram of high-voltage, low-noise preamplifier.

emitter junction of Q_2 and the emitter resistor R_5, which is selected to keep the Q_2 emitter voltage less than 10% of V_{cc}, the d-c supply voltage, when Q_2 saturates. R_6 is selected to give the Q_2 stage a 20-dB gain while maintaining a collector quiescent voltage of 0.45 to 0.65 of V_{cc} for maximum large-signal capability. Q_3 is an emitter follower used to reduce the output impedance and to isolate Q_2 gain from output loading.

D-c feedback is used to establish the collector operating voltage of Q_2 via the current shunt feedback T network formed by R_2, R_3, and R_4. A-c feedback used to set the voltage gain is provided by R_9 connected to R_1 with C_2 used to block dc from the emitter of Q_3.

An interesting characteristic of this design can be appreciated by noticing that, with the exception of the values of R_3 and R_9, the required performance characteristics were obtained using component values which are only integer powers of ten.

PERFORMANCE CHARACTERISTICS

The design objective for this circuit was to provide noise performance comparable to the best available solid-state circuits along with the large-signal capability of tube circuits. The circuit was built as indicated in Fig. 1, and the measured performance is shown in Table I. The design objective was met since the equivalent input noise for a 600-ohm source and for a 15.7-kHz noise bandwidth is less than 1 microvolt rms, and the maximum undistorted output into 10 kilohms or greater is 31 volts rms.

The maximum linear dynamic range of this circuit when used as a microphone preamplifier can be defined as the difference between the maximum output signal (3% total harmonic distortion) and the A-weighted broadband output noise and is equal to 119 dB.

The high input resistance, low distortion, and low power dissipation make this circuit suitable for use in studio-quality microphone mixing consoles. High-impedance microphones may require input transformers or pads. The parts cost for this circuit in OEM quantities is less than \$3.50.

Table I. Low-noise, high-voltage preamplifier measured performance characteristics.

V_{cc} = +200 volts dc
T_A = 24° C/(75° F)
0 dB = 0.775 volt rms

Voltage gain	40 dB
−3 dB bandwidth	6 Hz to 300 kHz
Noise bandwidth	471 kHz
Power dissipation	400 milliwatts
Supply current	2 milliamperes
Input resistance	400 kilohms
Output resistance	500 ohms
IM distortion (input = −9 dB)	1.2%
Total harmonic distortion (THD) (input = −9 dB)	0.2%
Input noise, R_s = 600 ohms (10 Hz–10 kHz, 15.7 kHz NBW)	0.9 microvolts rms
Output noise (A-weighted)	−83 dB
Maximum output (THD = 3%)	+36 dB
Minimum load resistance	10 kilohms

OVERLOAD CHARACTERISTICS

Following the investigation of the preamplifier's linear performance, the overload characteristics were measured for evaluation with respect to Hamm's criteria. Fig. 2 shows the total harmonic distortion (THD) as a function of input level. Hamm's scale, which arbitrarily places 24 dB at the 1% THD point, is shown to facilitate comparison with his published figures. The THD curve of Fig. 2 is lower than either of the published curves for operational amplifiers or "transistor" multistage amplifiers measured by Hamm. Our preamplifier reaches 30% THD at 37 dB[1], which is 8 dB greater than that for the "transistor" and 3 dB greater than that for the "pentode" multistage amplifiers measured by Hamm. This high-voltage preamplifier overloads more gently than any of those measured by Hamm.

We were surprised with the results from the harmonic analysis of the high-voltage preamplifier's output for overload conditions. Fig. 3 shows the voltage amplitude levels of the individual harmonics expressed in percent of the fundamental for various input levels. Notice that the second harmonic completely dominates all other harmonics for all input levels greater than −3 dB referred to 0.775 volts rms. The manner in which the second harmonic completely overwhelms the higher order harmonics, including the third, indicates that this preamplifier may sound good with large overloads. Fig. 4 shows the output waveforms for inputs of −3.5 dB referred to 0.775 volt rms (for 3% THD) and +8.5 dB referred to 0.775 volt rms (+12 dB overload). The clipping is unsymmetrical with a pronounced shift in duty cycle. Very tubelike, indeed.

COMPARISON WITH LM381 PREAMPLIFIER

Previous discussions have indicated that the LM 381 dual preamplifier integrated circuit may be, with the exception of its overload characteristics, the panacea for microphone preamplifier problems. Therefore, this device is appropriate for performance comparison with the high-voltage preamplifier.

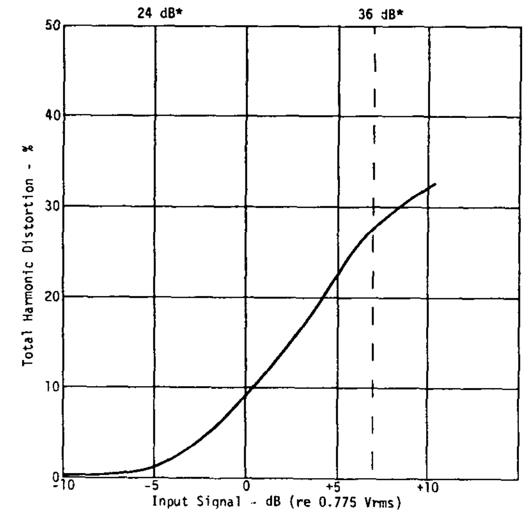

Fig. 2. Total harmonic distortion as a function of input level for high-voltage preamplifier. *Reference level per Hamm [1]

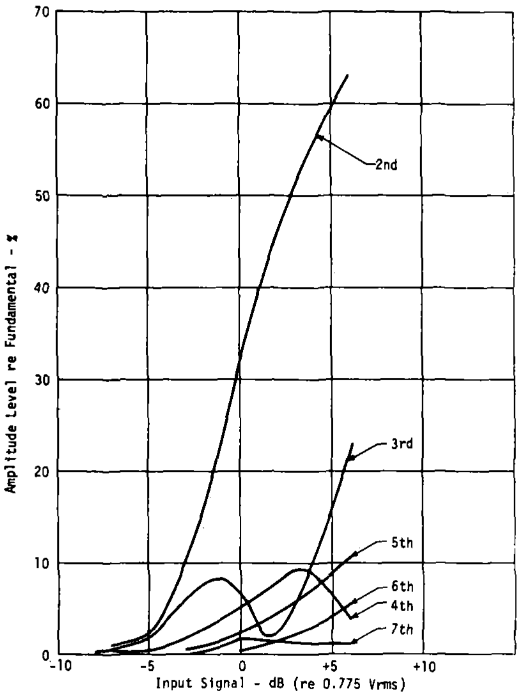

Fig. 3. Distortion components as a function of input level for high-voltage preamplifier.

Table II presents a performance comparison of the two preamplifiers. The major differences between the two preamplifiers occur in the open-loop characteristics. The LM 381 has a factor of 1000 (60 dB) greater gain and a factor of 350 less bandwidth, which may be desirable in some applications, but can cause transient intermodulation (TIM) distortion [4] in microphone preamplifier designs which require only 40 dB closed-loop gain.

The equivalent input noise calculated from the LM 381 and MPS-A18 data sheets is similar for both preamplifiers. Fig. 5 shows the total equivalent input noise voltage in a 1-Hz band as a function of frequency measured on the high-voltage preamplifier, computed for the LM 381,[1] and compared with an ideal 600-ohm resistor at 24°C. When a point was computed for the MPS-A18 at 1000 Hz from "typical" information supplied on the data sheets, the point was 11 dB below what was actually measured. This

[1] $$V_T = \left[\left(e_n^{\ 2} + i_n^{\ 2} + 4kTR_s\right)B\right]^{1/2}$$

where e_n is the input noise voltage,
i_n is the input noise current,
R_s is the source resistance, = 600 ohms,
$4kT = 1.639 \times 10^{-20}$ for $T = 24°C(75°F)$, and
B is the noise bandwidth, = 1 Hz.

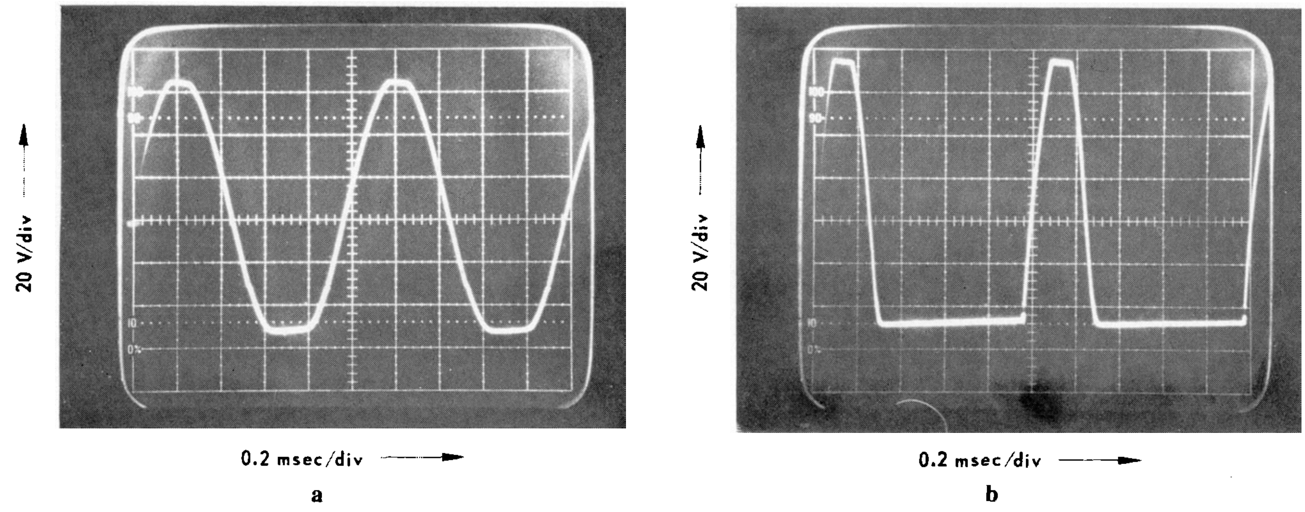

Fig. 4. High-voltage preamplifier output waveforms for input overloads.

Table II. Preamplifier performance comparison.

	LM381	High-Voltage Preamplifier
Open-loop gain	110 dB	50 dB
Open-loop bandwidth	100 Hz	35 kHz
Input resistance (single ended)	100 kilohms	400 kilohms
Output-resistance (open loop)	150 ohms	1.5 kilohms
Power dissipation	400 milliwatts	400 milliwatts
Equivalent input noise R_s=600 ohms, 10 Hz to 10 kHz (single ended)	1.0 microvolt rms*	0.9 microvolt rms†
Maximum output voltage swing	28 volts peak to peak for V_{cc}=30 volts	100 volts peak to peak for V_{cc}=200 volts

* Specified maximum.
† Measured.

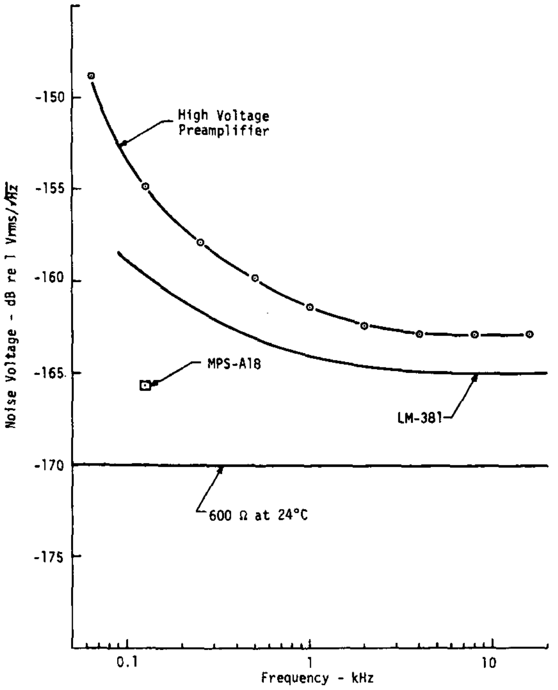

Fig. 5. Comparison of equivalent preamplifier input noise voltage with a 600-ohm white noise source.

indicates that lower noise may be expected by selecting the input transistor. However, the equivalent input noise "floor" for both the high-voltage preamplifier and the LM 381 devices can be expected to be within 3 dB of each other.

The large signal capability of the high-voltage preamplifier is 11 dB greater than the LM 381 for typical supply voltages. Therefore, the linear dynamic range of the high-voltage preamplifier is 11 dB greater than for the LM 381.

CONCLUSION

A high-voltage preamplifier design using transistors has been presented which exhibits the desirable large-signal characteristics of tubes while obtaining size, power, and noise performance comparable to the best transistor or integrated circuit designs. The overload characteristics of the circuit presented here indicate that this preamplifier may be musically useful 9 to 12 dB above its linear range, thereby providing the capability to accommodate the 0.775-volt peak microphone output signals observed by Hamm. The serendipitous overload characteristics were the result of the design that was required to connect a small-signal, low-noise transistor with high-voltage transistors for operation with a 100–300-volt supply.[2]

In conclusion, the high voltage transistor preamplifier presented here supports the viewpoint of Mintz[2]: "In the final analysis, the characteristic of a typical system using transistors depends on the design, as is the case in tube circuits. A particular 'sound' may be incurred or avoided at the designer's pleasure no matter what active devices he uses."

[2] An invention disclosure covering the unique aspects of this design has been submitted to the University of Texas at Austin.

REFERENCES

[1] R. O. Hamm, "Tubes versus Transistors—Is There an Audible Difference?" *J. Audio Eng. Soc.*, vol. 21, pp. 267-273 (May 1973).

[2] R. S. Mintz, "Comments on 'Tubes versus Transistors—Is There an Audible Difference?'" *J. Audio Eng. Soc.*, (Forum), vol. 21, p. 651 (Oct. 1973).

[3] R. H. Trumbull, "More about 'Tubes versus Transistors'", *J. Audio Eng. Soc.* (Forum), vol. 22, p. 24 (Jan./Feb. 1974).

[4] M. Otala and R. Ensomaa, "Transient Intermodulation Distortion in Commerical Audio Amplifiers," *J. Audio Eng. Soc.* (Project Notes/Engineering Briefs), vol. 22, pp. 244-246 (May 1974).

About the Authors:

Dwight O. Monteith, Jr., was born in the Panama Canal Zone in 1938, and received a BSEE degree in 1962 and a MSEE degree in 1966 from the University of Texas at Austin. During the last fourteen years he has had various positions as an electronic systems design engineer for radar, communication, and sonar equipment. Following several years of consulting, he returned to the University of Texas, Applied Research Laboratories, as a Research Engineer Associate. He is currently working on system reliability and performance monitoring and fault locating design for minehunting and submarine sonars.

Mr. Monteith is a member of the Audio Engineering Society, the Acoustical Society of America, and the Institute of Electrical and Electronics Engineers.

•

Richard R. Flowers was born in San Antonio, Texas, in 1952, and received a BSEE degree from Lamar University in 1974. He was a graduate student at the University of Texas at Austin. He was employed part time as a research engineer assistant at ARL and as a studio engineer for Austin Community Television (ACTV). His principal interests were computer-aided design, digital signal processing, and audio/music system development. His opportunity for further contributions to these areas was terminated by his untimely death on 19 October, 1976.

Mr. Flowers was a student member of the Audio Engineering Society and the Institute of Electrical and Electronics Engineers.

Comments on "Transistors Can Sound Better Than Tubes"

RUSSELL O. HAMM

Sear Sound Studios, New York, N.Y.

I would like to extend my personal praise to the authors of the above paper[1] for this fine work which I am pleased to see published in the *Journal of the Audio Engineering Society*. There are a couple points I would like to question,

[1] D. O. Monteith, Jr., and R. R. Flowers, *J. Audio Eng. Soc.*, Vol. 25, pp. 116-119 (Jan./Feb. 1976).

however. The last paragraph of the communication makes reference to a statement by Mintz which Monteith and Flowers claim to support with their new amplifier design. "A particular 'sound' may be incurred or avoided at the designer's pleasure no matter what active devices he uses." There is no definitive reference I know of that lists the psychoacoustic response of the ear in terms which an amplifier designer can use. Basically this whole controversy has surfaced because the "sound" of an amplifier is a hit or miss proposition, and I think this communication supports this fact. What Monteith and Flowers have designed is a low-noise, high-voltage amplifier which their electrical testing shows is similar to the characteristics I measured for tube type amplifiers. There is nothing that states that the author designed a dominant second-harmonic component in the overload region or that they designed a low feedback system to take advantage of certain transistor characteristics which sound good. Also, and this is my major point, they present no psychoacoustic data from real-live people which say, conclusively, that their amplifier lives up to the title of their paper.

Enough critism for some very fine work which definitely points the "state of the art" in the right direction. It certainly gives me a great deal of satisfaction to see some of my basic work being put to practice. In traveling about during the past couple years I have been amazed at the impact which my article made in recording circles. Engineers everywhere have read it and many have asked me why professional equipment manufacturers have not carried this work further. Indeed it is rather disturbing that the kind of work undertaken by Monteith and Flowers is not being supported in commercial circles. It seems to me that there is a distinct lack of significant papers coming from companies with a commercial interest in audio. Certainly there has been nothing lately that compares to the high-quality papers turned out by Ampex personnel on the MR-70 development (*Journal of the Audio Engineering Society*, October 1964). Lately Conventions of the Audio Engineering Society have been flooded with too many papers of a promotional nature which, as I recollect, were the exception in the past. It is hard to expect the editors of the *Journal* to keep our publication on a high level if it is not supported with the kind of papers which are its very foundation. In the final analysis the responsibility lies with the total membership who represent manufacturers and consumers. For any product there must be a demand. If our demand is for colored knobs rather than the advance of technology, then the result should be obvious.