A Low-Noise High-Output Capacitor Microphone System

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The dynamic range of a capacitor microphone has been considerably extended by means of an advanced FET feedback amplifier. This microphone delivers +20 dBm into 600 ohms at maximum sound pressure levels of 110, 125, or 140 dB. Its A-weighted noise level of 15 dB is contributed mostly by the capsule instead of the amplifier.

INTRODUCTION: Now that we have an audio signal processing system [1] capable of extending the dynamic range of a studio tape machine to 110 dB, the previously adequate noise levels of studio consoles and microphones have become too high. The extended dynamic range capacitor microphone system to be described is designed to solve this noise problem and, at the same time, increase the maximum acoustic input capability.

In recording, noise is most apparent in a multitrack mixdown and when microphones are picking up at a distance. The noise levels of today’s high-quality capacitor microphone systems are in the range of 20–30 dB sound pressure level. Although this noise may be somewhat comparable with the noise of a well constructed studio, the room noise does not mask the microphone noise because room noise occurs primarily at low frequencies and the audible microphone noise is a hiss at high frequencies.

In this new microphone system the noise level has been extended downward to 15 dB sound pressure level A-weighted. Its maximum input signal has been extended upward to 140 dB sound pressure level without taking the microphone apart and adding a capacitive pad. By designing the microphone for a line level output of 20 dBm into 600 ohms, cable noise pickup has been rendered insignificant, and the need for a low level console preamplifier with its attendant noise has been eliminated.

Many recording studios use a wide variety of microphone types in a single recording session because the sounds of certain microphones are considered optimum for the sound sources with which they are used. In the author’s recording system the same wide dynamic range microphone serves all purposes. In this case the sound is changed by means of an extremely flexible wide dynamic range program equalizer described in an earlier paper [2]. Directional patterns can be selected by using either pattern-switchable capsules providing either two or three directional patterns or by separate capsules having the desired directional patterns. Sufficient gain for close, medium, or distant miking is attained by means of a gain switch on the microphone itself which provides 20 dBm output for sound pressure level inputs of 140, 125, or 110 dB, respectively.

The following sections will describe the sources of noise, how the electronic system is designed, and its performance characteristics.
NOISE SOURCES

Fig. 1 shows the principal electronic noise sources in the capacitor microphone system. The desired signal is generated by the variable microphone capacitance which is biased by high voltage. In this particular microphone the capacitance is approximately 43 pF, which is fairly high for a capacitor microphone. One of the principal sources of noise is the voltage noise $E_{N4}$ generated within the amplifier A1. Also the amplifier has an input current noise $I_{N1}$ which develops a voltage across the source capacitance. Another factor which influences the signal and therefore influences the signal-to-noise ratio is the input capacitance of the amplifier system. This loads the microphone capacitance and attenuates the input signal, thereby making the voltage noise of the amplifier more significant relative to the microphone signal.

Hum pickup due to stray capacitance to an ac source $E_{N2}$ can be very serious if the microphone is not tightly shielded. Similarly stray capacitance to any noise source such as a power supply lead or even a zener diode can introduce significant noise into the microphone capacitance. Furthermore, capacitance to any dc source constitutes an unwanted capacitor microphone which must be rigidly supported and adequately damped mechanically to prevent vibration from altering the system frequency response.

Perhaps one of the largest sources of noise in capacitor microphone systems is the load resistor used for biasing the capsule. In a typical capacitor microphone system this resistor is about 250 megohms. This value is so low that it delivers an appreciable noise current into the microphone capacitance from its thermal agitation noise generator $E_{N3}$. By increasing the value of this resistance the current delivered into the microphone capacitance can be reduced by the square root of the resistance ratio. In the new microphone design one of the principal means of reducing noise is an increase in this load resistance to 20 000 megohms.

Another type of noise that has been troublesome in testing microphone amplifiers is a type of leakage current occurring, for example, within or on the surface of silver mica capacitors used to substitute for the microphone capsule. Leakage or dirt can generate quite a bit of noise, and considerable variation in noise occurred just from using different types of capacitors. In testing this system a Teflon capacitance eliminated most of this type of noise. Most capacitor microphone capsules are insulated with polystyrene or other low-loss insulation which takes care of this problem.

AMPLIFIER AND POWER SUPPLIES

A block diagram of the model 3000 low-noise capacitor microphone system is shown in Fig. 2 and the schematic diagram in Fig. 3. The system is designed around an existing microphone capsule, the Schoeps MKT-45, 60-V series, which was chosen for several reasons. This capsule has a pleasing subjective quality, excellent frequency response, a high capacitance which attenuates input noise currents previously described, and a fairly high output. Another important advantage is the three-wire floating capacitance arrangement which permits a feedback voltage to be added into the input by feeding it in series with the capsule. The capsule has been manufactured with single or switchable directional patterns, including omnidirectional, bidirectional, cardioid, and hypercardioid.

The system consists of an input preamplifier having two high transconductance field effect transistors (FET) in parallel, another low-noise amplifier, and a final output amplifier. This output amplifier is dc coupled to the load and delivers 7.7 volts rms into 200 ohms or more. Feedback around the entire system comes from the output through an attenuator to the low side of the capsule. To stabilize the dc output level, additional feedback at sub-audio frequencies, amplified 80 dB in a low-frequency amplifier, is delivered to the 20 000-megohm capsule load resistor to bias the FETs.

Power is supplied from an external ±15-volt source using ordinary regulated supplies. Ripple and noise are attenuated by additional low-noise regulators within the microphone which provide +12 volts and −11 volts for the low-level amplifiers. A +60 volt dc–dc converter is used to bias the capsule and is also powered from the −11-V regulator.

In the FET preamplifier, noise is minimized by using low-capacitance high-transconductance FETs operating at approximately 14 000 micromhos. With a short-circuited input the equivalent input noise voltage in the upper audio bandwidth is approximately 1/3 microvolt. Using high-transconductance FETs and a 20 000-megohm gate resistor results in an input leakage problem, and it may require a fairly substantial voltage delivered to R1 to offset this leakage current and properly bias the FETs. This voltage is supplied by the 80-dB low-frequency amplifier which senses the output dc offset, provides 80 dB of very-low-frequency gain, and can deliver from 0 to −9 volts into resistor R1. This voltage is sufficient to overcome a leakage current of 400 pA. The amplifier provides no feedback within the audio range, but only at direct current. Because of its high gain the output dc offset of the entire system is determined by the input dc offset of the 80-dB low-frequency amplifier which is trimmed to within ±3 millivolts.

Power supply noise, as mentioned, is important, and so the power for the first stage comes from a +12-volt regulator which has only 0.5 microvolt of noise output. The attenuation of noise from the external +15-volt
Fig. 2. Microphone amplifier block diagram.
Fig. 3. Microphone amplifier schematic diagram.
supply is 100 dB.

Not only must the FETs and power supply be designed for low noise but also the second amplifier must be a low-noise type for two reasons. One is the rather low gain of the first FET stage which reflects every microvolt of noise in the second amplifier back to the input as 0.12 microvolt. The main reason is that the gate to drain capacitance of the FETs feeds back into the capsule a noise voltage equal to a fraction of that appearing on the drains. Therefore the second amplifier has been designed for only 0.5-microvolt input noise. This amplifier is powered by both the +12-volt low-noise regulator and the −11-volt low-noise regulator. The −11-volt regulator has approximately 2-microvolts output noise and attenuates ripple and noise from the −15-volt external supply by 90 dB.

The low-noise amplifier feeds a unity gain dc output amplifier designed to provide the high output current capability along with low open-loop distortion and short-circuit protection. The overall gain of the amplifier system is determined by the feedback from this output amplifier through an attenuator that feeds the low side of the microphone capsule. The attenuator has three switch positions, 10, 25, and 40 dB, which determine the gain of the system from the capsule. These positions provide the full +20-dBm output at sound pressure levels of 140, 125, or 110 dB, respectively. Within the attenuator there is also a feedback equalizing network which boosts the system frequency response 2 dB at 20 kHz to partially compensate the natural high-frequency rolloff of the microphone capsule. Although the bandwidth of the feedback loop extends to 8 MHz at minimum gain, capacitive loads are isolated at high frequencies so that excellent loop stability is maintained with cable capacitances as high as 0.01 μF.

Bias for the capsule is produced by a +60-volt dc–dc converter which is unconventional in that it is completely shielded. It operates just below 500 kHz and has decoupling on the input power supply leads as well as good output filtering. The leakage from this power converter instead of being tens of millivolts is only a few microvolts. Its noise level is filtered at its output down to less than 0.1 microvolt, and the power converter has no effect on the system noise.

The output signal comes from a five-pin audio connector which is used to receive the input power as well. Note that this system has a single-ended output, but it can feed either a single-ended input amplifier at the far end of the cable, if the cable is short, or preferably a differential input amplifier. The entire system is double shielded in order to reduce the effects of hum pickup and RF pickup from switches on power lines and from light dimmers. The amplifier is contained within an inner shield which is the basic ground for the system, and the outer shield is completely isolated and grounded at a single point back at the studio console. The only portion of the inner shield that is exposed when handling the microphone is the capsule itself. To eliminate noise pickup the capsule has to be mounted on the inner shield rather than on the outer shield.

Most of the electronic circuitry is contained on a lengthwise printed circuit board mounted within a pair of concentric brass tubes approximately 10.4 inches (0.26 m) long and 0.8 inch (20 mm) in diameter. The tubes are insulated from one another and constitute the inner and outer shields. Figs. 4 and 5 show the finished unit and its interior construction.

**MEASURED PERFORMANCE**

The output noise level of the microphone system measured in one-third octave bands is plotted in Fig. 6. Curve C shows the spectrum for the amplifier alone when connected to a 40-pF source capacitance. Curves A and B show the noise levels produced with an omnidirectional cardioid two-way switchable capsule mounted. These curves were measured by inserting the microphone into a soundproof metal tank lined with absorptive material. They show that the major contributor of noise is the capsule itself which has some 6 to 12 dB more noise than the amplifier. In the capsule, noise may be contributed by the thin layer of air between the diaphragm and its back plate. However, the mechanical venting used to change the directional pattern has a considerable effect as shown by curve A for the cardioid pattern which is as much as 5 dB above the omnidirectional pattern in the vicinity of 300 Hz.

![Fig. 4. Low-noise capacitor microphone.](image)

![Fig. 5. Amplifier and regulator assembly inside the microphone.](image)
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Microphone noise is generally measured with one of several weighting filters that attenuate below 600 Hz and above 10 kHz. Using an A-weighting filter the equivalent input noise for the omnidirectional pattern is typically 15 dB sound pressure level. Using a flat response filter with cutoff at 20 Hz and 20 kHz, the noise increases by approximately 7.5 dB to 22.5 dB sound pressure level.

While the noise output, when switched to the cardioid pattern, is 2 to 2.5 dB higher, the overall acoustic signal-to-noise ratio is about the same because the on-axis sensitivity of the microphone increases by about 2 dB when switched from omnidirectional to cardioid. Referred to the microphone capsule, the amplifier electrical noise A-weighted is typically 0.56 microvolt and wideband is 1.5 microvolts. Harmonic distortion due to the amplifier varies with the gain setting, and the load but is at worst 0.05% when delivering 7.7 volts rms into 200 ohms. The frequency response measured by inserting a voltage in series with the low side of the capsule is up a maximum of 0.1 dB at 20 Hz and is up nominally 2 dB at 20 kHz. The acoustic frequency response depends upon the type of pattern and capsule selected. Some older types exhibited a slight peak at 7 kHz and rolloff at 20 kHz, while newer types are quite flat to 20 kHz.

CONCLUSION

A new low-noise series feedback amplifier has extended the dynamic range of an existing capacitor microphone capsule to its full capability of 125 dB. Used in conjunction with a flexible equalizer the microphone system is capable of performing all the tasks for which studios normally use several different types and brands of microphones simultaneously. Its high output of +20 dBm eliminates the need for a low-level microphone preamplifier with its dynamic range limitations and permits connection directly to a line level input. In many instances, either the microphone or the microphone plus equalizer can feed directly a 110-dB dynamic range recording system, thus circumventing the studio console. In multitrack recording the wide dynamic range and accuracy of these new tools raises a new standard of performance and reduces the effects of operator error. Future development in capsules, if directed toward reducing acoustic noise, might extend the dynamic range downward by another 6 dB.

REFERENCES


THE AUTHOR

Richard S. Burwen received the S.B. and A.M. degrees from Harvard University in 1949 and 1950, respectively. He was involved in circuit design at Bell Telephone Laboratories, Spencer-Kennedy Laboratories, Krohn-Hite Corporation, and Honeywell, Inc., until 1961. For the past fifteen years Mr. Burwen has been an independent circuit design consultant for over fifty companies in the areas of industrial control, medical electronics, power supplies, space vehicle equipment, television, automotive, airborne equipment, laboratory instruments, linear integrated circuits, and audio. He holds a number of patents and is the author of numerous papers on audio and analog circuits. At the same time Mr. Burwen was one of the founders of Analog Devices, Inc., and Ohmtec Corporation. He is currently technical consultant to Burwen Research, Inc., and several other companies.