A Self-Contained Condenser Microphone with Improved Transient Response*

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A small battery-operated cardioid condenser microphone is described in which polarization voltage is provided by a solid-electrolyte battery with a lifetime of 20 years. The remarkable transient response obtained is discussed, along with the low-noise FET preamplifier.

INTRODUCTION Condenser microphone technology is making significant advances. The availability of low-noise solid-state preamplifiers has helped give the condenser microphone wider applicability by making it less bulky and more convenient to use. Recent capsule designs have produced improvements in stability, frequency response, and front-to-back ratio. One of the last stumbling blocks to complete versatility and ease of operation has been the power supply. This problem is being solved by using battery-operated designs; some of these are self-contained units, which for the majority of uses is the ideal packaging arrangement.

The microphone under consideration embodies all of these developments.

POWER SUPPLY

Apart from the truly minimum power requirements for a well-designed FET amplifier, the most serious problem is to polarize a capacitor element in the capsule. At least 50 V dc is needed, and the voltage must be stable in order to maintain uniform output. Four systems for polarization of a self-contained condenser microphone are worth considering.

The first is the use of conventional mercury batteries. Since a large number of cells is needed to obtain the required voltage, the microphone will be excessively bulky if self-contained. In order to have a compact microphone, the batteries may be relegated to a separate power pack. This can be cumbersome; moreover, a typical shelf life of only two years is a further inconvenience.

A second system for polarization is the dc to dc converter. Three problem areas are evident. First, complex circuitry is required, with decreased overall reliability. Second, high current drain from the supply battery is required. This yields short battery life, with the inconvenience of frequent battery changes. Third, leakage of local oscillator frequency into signal circuits can occur.

The third polarization system which has come under extensive consideration in the past few years is the electret. To date, fabrication of electret capsules is complex, and their quality is inconsistent. High temperature and humidity conditions, often encountered, can cause deterioration of the polarizing voltage with a subsequent loss of output.

The fourth system is use of a solid electrolyte battery. It is the one chosen for the microphone described here, since it provides the most reliable and compact method of polarization.

The solid electrolyte battery has small cup-shaped cells of silver, silver chloride, and chlorine. The cells are

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wired together and potted permanently in epoxy. The major obstacle to long life is tarnishing of the silver electrodes. This has been minimized so that a shelf life of *50 to 100 years* is possible. The stack of cells yielding the required 62 V has a very high internal impedance for a battery, so that very little current can be drawn. Since capsule polarization draws virtually no current, this is not a problem. On the contrary, it is the main reason for the successful application of this unusual battery.

Assuming that high humidity or dirt in the capsule should cause up to 0.1 μA average current to be drawn from the battery, it should still last well over 20 years. Fortunately, typical leakage currents are much less than 0.1 μA.

The one problem that has been occasionally encountered with the solid electrolyte battery is noise due to its high internal impedance. This has been suppressed completely by shunting the battery with a .05 μF capacitor.

CIRCUIT DESIGN

The preamplifier circuit diagram of the new microphone is shown in Fig. 1. A very large amount of

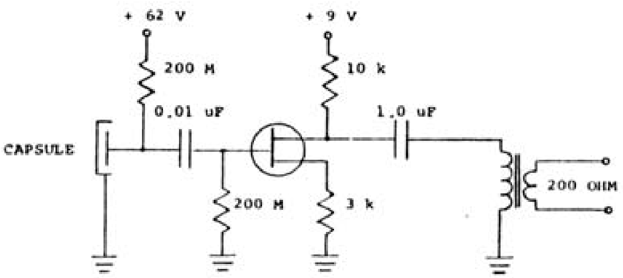

Fig. 1. Schematic diagram of self-contained condenser microphone.

negative feedback is used to minimize gain variations with different FETs and to guarantee stability at any reasonable operating temperature. No source current adjustment is needed. The 200 ohm balanced output is fixed and will drive any load from below 50 ohm to high impedance without adverse effect on frequency response or increase in distortion.

The only problem when using this type of FET preamplifier is to avoid overloading the following stages of amplification if signals are unusually high. No pad is needed ahead of the FET for music or voice since the overload point of FETs is 10 or 20 dB higher than that of the tubes which were formerly used. With a properly chosen FET, the noise of the microphone is comparable to that of the best tube units. This is 23 dB SPL. Fortunately, the increased overload capacity yields a much wider total dynamic range, on the order of 110 dB.

With the solid electrolyte battery for polarization, this FET preamplifier can run for 1000 hours on a single mercury battery that is readily available for a little over one dollar. For most uses, this would be a year's service. On a 24 hour a day basis, this amounts to 45 days of continuous operation. Standard two-wire shielded cable is used, a further system advantage. In those locations where battery operation is difficult, dc may be phantomed on the balanced signal line from a central power

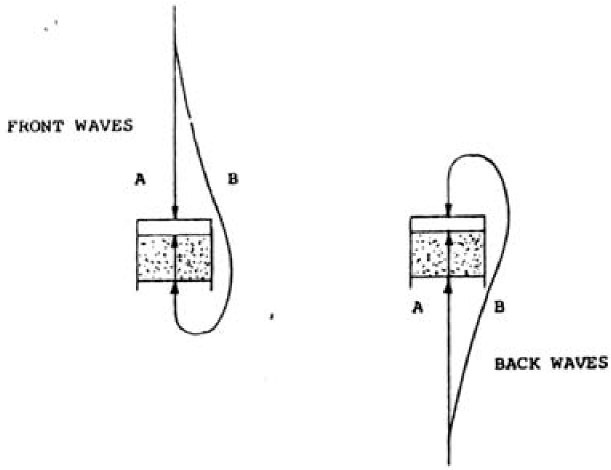

Fig. 2. Simplified diagram illustrating the principle underlying the operation of a cardioid microphone.

supply. This feature along with the use of the solid electrolyte battery is covered in a patent.

CAPSULE DESIGN

The capsule embodies some refinements which permit extremely smooth frequency response along with a generous front-to-back ratio. On a production basis, this means between 25 and 30 dB at 1 kHz, falling to 15 to 20 dB at high frequencies.

A simplified description of the operation of the cardioid capsule is illustrated in Fig. 2. Consider sound waves of just a single frequency with wavelength much longer than capsule dimensions. Front waves can be considered as splitting into two parts upon reaching the microphone. Part A reaches the diaphragm directly, and pushes downward on it. Part B goes around to the back and reaches the surface of the acoustical delay network at some time later than the time Part A reached the diaphragm surface. Part B then passes through the acoustical delay network, which causes the wave to arrive at the bottom of the diaphragm pushing up on it at a later time than when Part A pushed down on it. Since the signal is sinusoidal, there results a considerable phase difference and hence a pressure difference on the diaphragm. The diaphragm moves and a signal is generated.

Consider now waves from the back, depicted in the second half of the figure. When Part A reaches the surface of the delay path, Part B starts to go around to the front. Part B reaches the front of the diaphragm and pushes down on it some time later. Meanwhile Part A has passed through the delay path. If the parameters of that path are chosen properly, Part A reaches the back side of the diaphragm and pushes up on it the same time Part B is pushing down. The diaphragm does not move and no signal results.

Waves approaching from the side produce diaphragm motion with half the amplitude of the front waves. That is because the relative phase shift between the front and rear parts of the wave is just half as much, being caused by the delay path only.

Of course, real signals contain many frequencies, so that parameters for the delay path must be chosen very carefully to provide the same amount of delay at each band of frequencies. Also, the high-frequency waves must be attenuated relative to the low-frequency waves as they pass through the delay section. This is shown in the following equations, where P = acoustic pressure:

$$P = P_0 \sin \omega t \qquad (1)$$

where $\omega = 2\pi f$ with f = frequency; and

$$\Delta P = \Delta t (dP/dt) = \Delta t P_0 \omega \cos \omega t \qquad (2)$$

with Δt = delay time.

Equation (1) gives the amplitude of a typical acoustic wave; in Eq. (2), ΔP was obtained by using the first term of a Taylor's expansion.

The pressure difference on the diaphragm caused by phase delay ΔP is proportional to the frequency of the wave. Therefore, the delay section must discriminate against the higher frequencies in order to obtain a flat frequency response.

Trouble can result at very high frequencies when wavelengths become comparable to capsule dimensions. As a result the thickness of the capsule is made as small as practical, less than ¼ in. which is about half wavelength at 20 kHz. The result of careful capsule dimensioning has been a 5 to 10 dB improvement in front-to-back ratio at higher frequencies.

One of the special features of the capsule is its unusually high "live-to-dead" capacitance ratio. This is the ratio of capacitance that can be varied to the stray capacitance ahead of the FET gate. A higher "live-to-dead" ratio yields a higher signal-to-noise ratio. This is accomplished by designing the back electrode so that capsule capacitance is about 60 pF, which is about twice that of other typical ¾ in. diameter units. Also, almost all of the material used for the delay path is insulating. This minimizes stray capacitance between the back electrode and ground. Design of capsule is shown in Fig. 3.

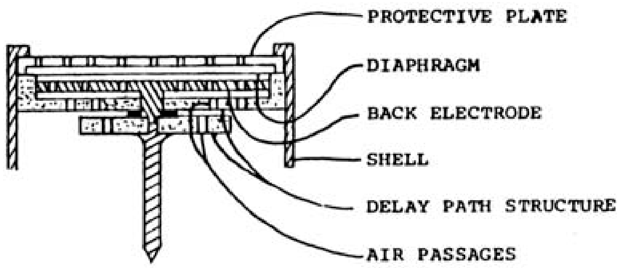

Fig. 3. Simplied cutaway view of cardioid head.

TRANSIENT RESPONSE

The transient response of the capsule is aided in two ways: by making the diaphragm as thin as practical, i.e., ¼ mil or less, if possible, and by structuring the back electrode to provide maximum air damping.

The microphone was designed primarily for music and voice. These sounds are composed mainly of transients, and contain very few continuous waveforms. Thus transient response is a vitally important measureable characteristic of microphones relating to their ability to reproduce musical sounds most faithfully.

The technique of transient response measurement, though repeatable, is difficult. The equipment needed includes, in addition to a suitable anechoic chamber, a dual-beam oscilloscope with a camera, and a reference microphone having a transient response that is an order of magnitude better than that of the microphone under test. Also, a suitable source of acoustic transients is required.

The setup used for transient response measurements is illustrated in Fig. 4. The reference microphone is a capacitive pressure transducer of the type described by Wright [1]. These small-diameter air-stiffness-controlled devices have resonant frequencies on the order of 500 kHz, with very good damping. This means that one can obtain flat response beyond 200 kHz, or ten times the desired bandwidth of the microphone under test.

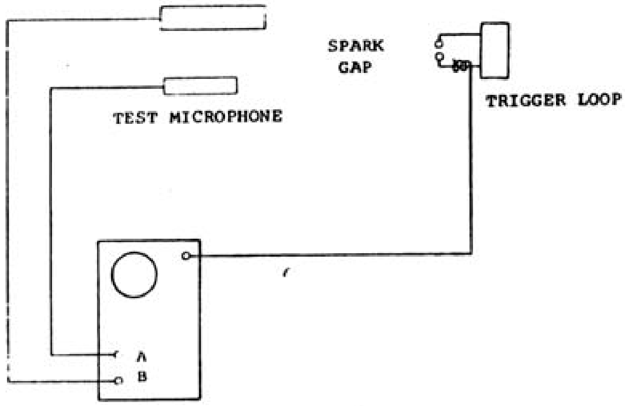

Fig. 4. Arrangement of equipment for the measurement of transient response.

The source of transients is a spark gap through which a large capacitor is discharged. With a suitable choice of capacitor and spark gap parameters, a single shockwave can be obtained. A 150 μF, 200 V dc capacitor can be used for this purpose.

Meaningful comparisons have been made between microphones using the setup shown. The microphone under test is placed the same distance away from the spark-gap transient source as the reference microphone. The trigger wire loop creates a pulse of induced current that triggers the oscilloscope. Oscilloscope photographs are made showing the responses of the reference and test microphones. Parameters to be measured are pulse rise time and overshoot, as well as ringing after the pulse.

Figure 5 shows some of the oscilloscope patterns. The photograph on the left is of the reference microphone and it shows the rise time of the pulse to be about 5 μsec. A negative pressure pulse follows at about one-half the positive pulse amplitude, and there is negligible ringing. The rise time of the new microphone, shown top right in Fig. 5, is about 15 μsec, again showing a negative pressure pulse at about one-half amplitude, and very little ringing. The lower right photograph shows the response of a high-quality cardioid dynamic microphone. The rise time is 40 μsec. Considerable negative overshoot and ringing occur, giving a transient response behavior that is far from faithful.

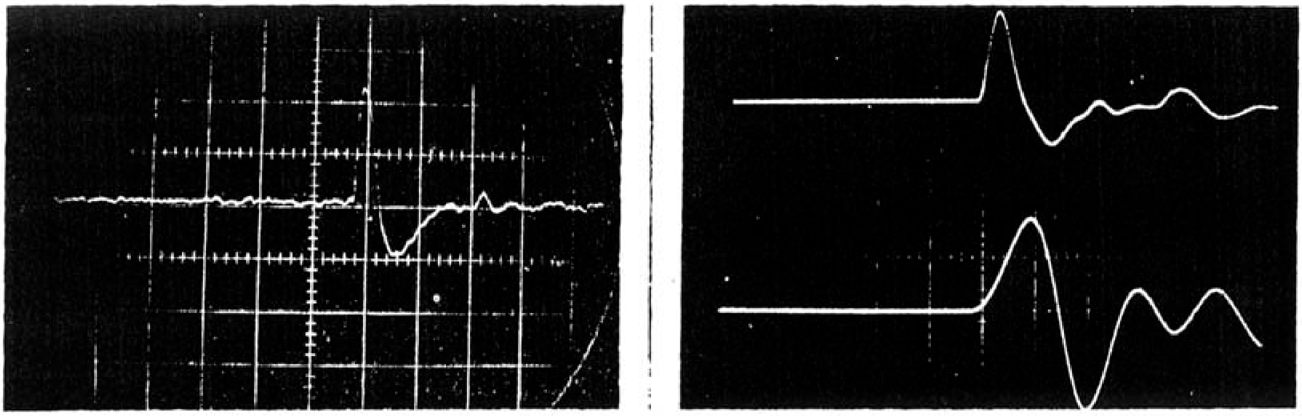

Fig. 5. Oscilloscope photographs of microphone transient response tests. **Left,** reference microphone; **lower right,** conventional dynamic microphone; **upper right,** S-10 condenser microphone.

The improved transient response is especially helpful in stringent music recording applications, where it results in a warmer, more natural quality which is easily appreciated by today's critical listener. It further helps account for the significant difference between condenser and dynamic microphones having nearly identical frequency response curves.

CONCLUSION

The microphone described appears to yield the best transient response and directional characterisistics so far attained. The use of FET circuitry and solid electrolyte battery has resulted in wider dynamic range and elimination of bulky power supplies, making the condenser microphone suitable for a much wider variety of applications.

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2. *Solid Electrolyte Battery Systems Quarterly Report No. 8,* (Sprague Electric Co., North Adams, Mass., 1956), ASTIA Report AD 109-550.

3. For a description of the operation of the cardioid condenser microphone, see: Leo Beranek, *Acoustics* (McGraw-Hill Book Co., New York, 1954), pp. 149-150; Harry F. Olson, *Acoustical Engineering* (D. Van Nostrand Company, Princeton, N. J., 1957), pp. 252-257.

4. Transient response testing using an electric spark is described in Leo Beranek, *Acoustic Measurements* (John Wiley & Sons, New York, 1949), p. 429.

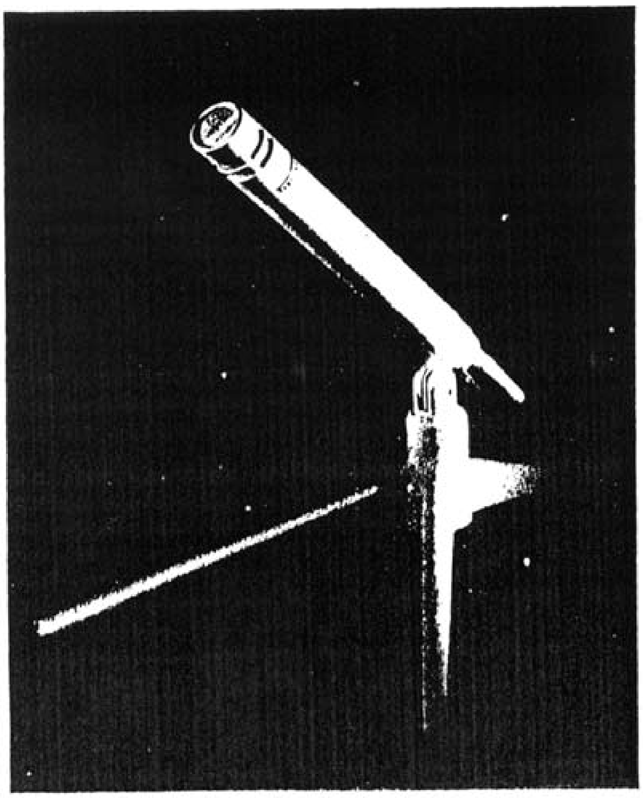

Fig. 6. Complete cardioid condenser microphone. Battery in case permits 1000-hour continuous operation.

THE AUTHORS

Alan Dauger received the B.S. degree in physics from the California Institute of Technology in 1962 and the M.S. degree in electrical engineering from University of California at Los Angeles in 1968. He is enrolled in the Ph.D. program in engineering at UCLA, where he plans to engage in laser research.

Mr. Dauger joined Pratt and Whitney Aircraft in 1962 where he developed pressure transducers for shock wave measurement. In 1965 he was Director of Research and Development at the Syncron Corporation where he was engaged in the design of condenser microphones. He joined Varian Associates in 1966 to aid in the development of rubidium frequency standards. He is currently investigating radiation effects in semiconductors for the McDonnell Douglas Astronautics Company.

He is a member of the Audio Engineering Society and the Institute of Electrical and Electronic Engineers.

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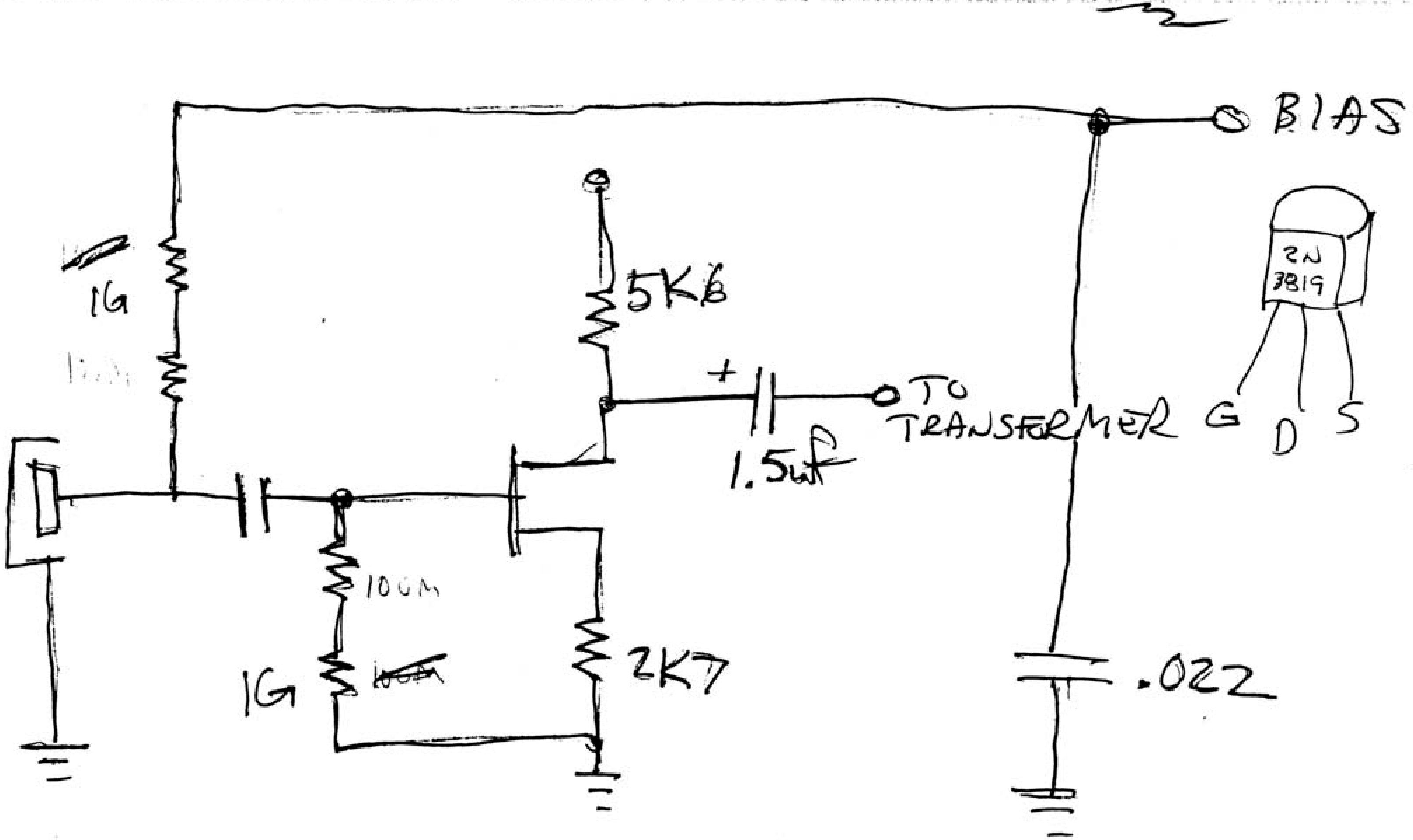
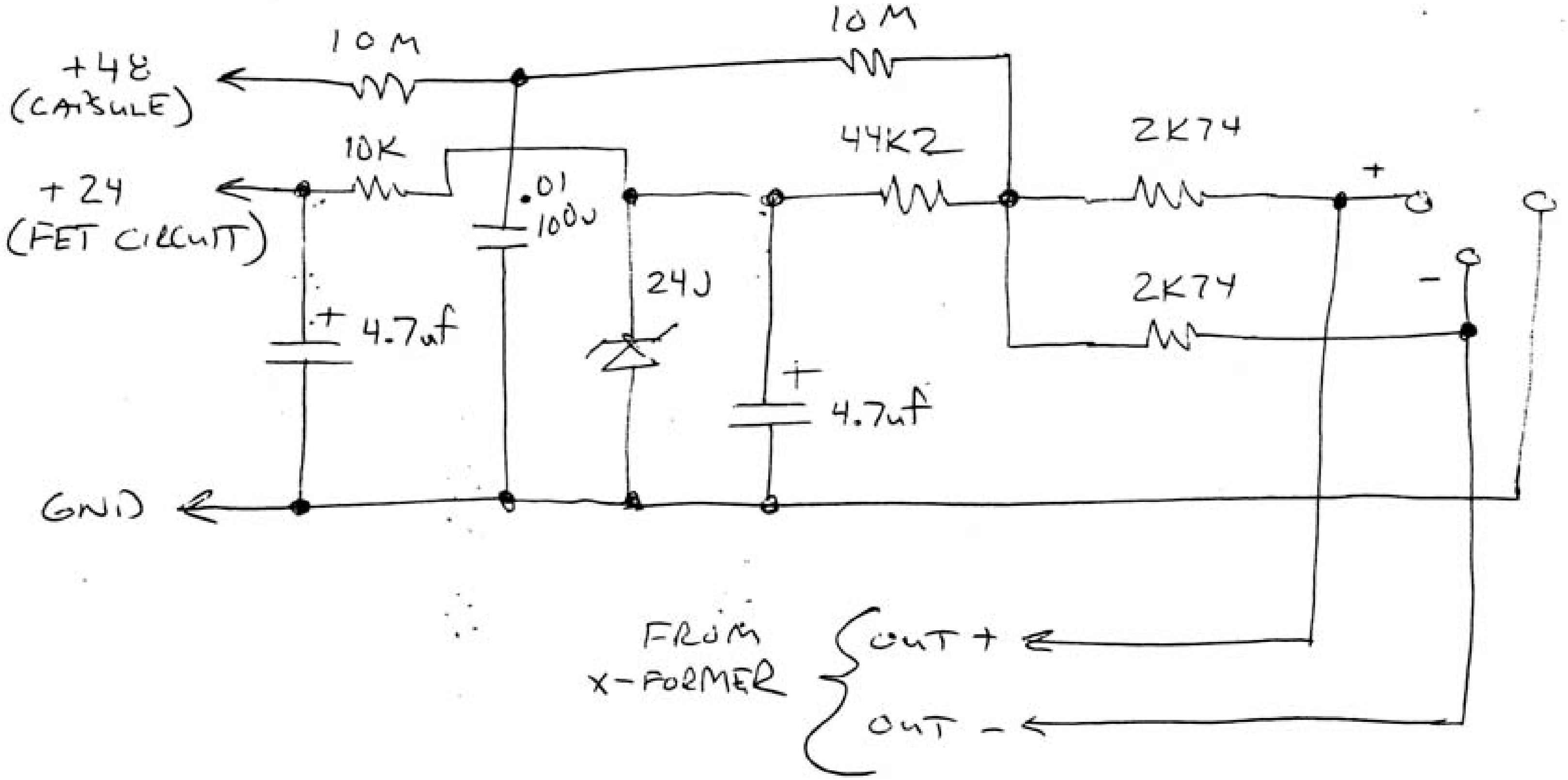
Mr. Swisher's biography appears on page 449.



S-10 FET CIRCUIT

1G Resistor is mod.



S-10 POWER SUPPLY
TO REPLACE POLARIZING BATTERY