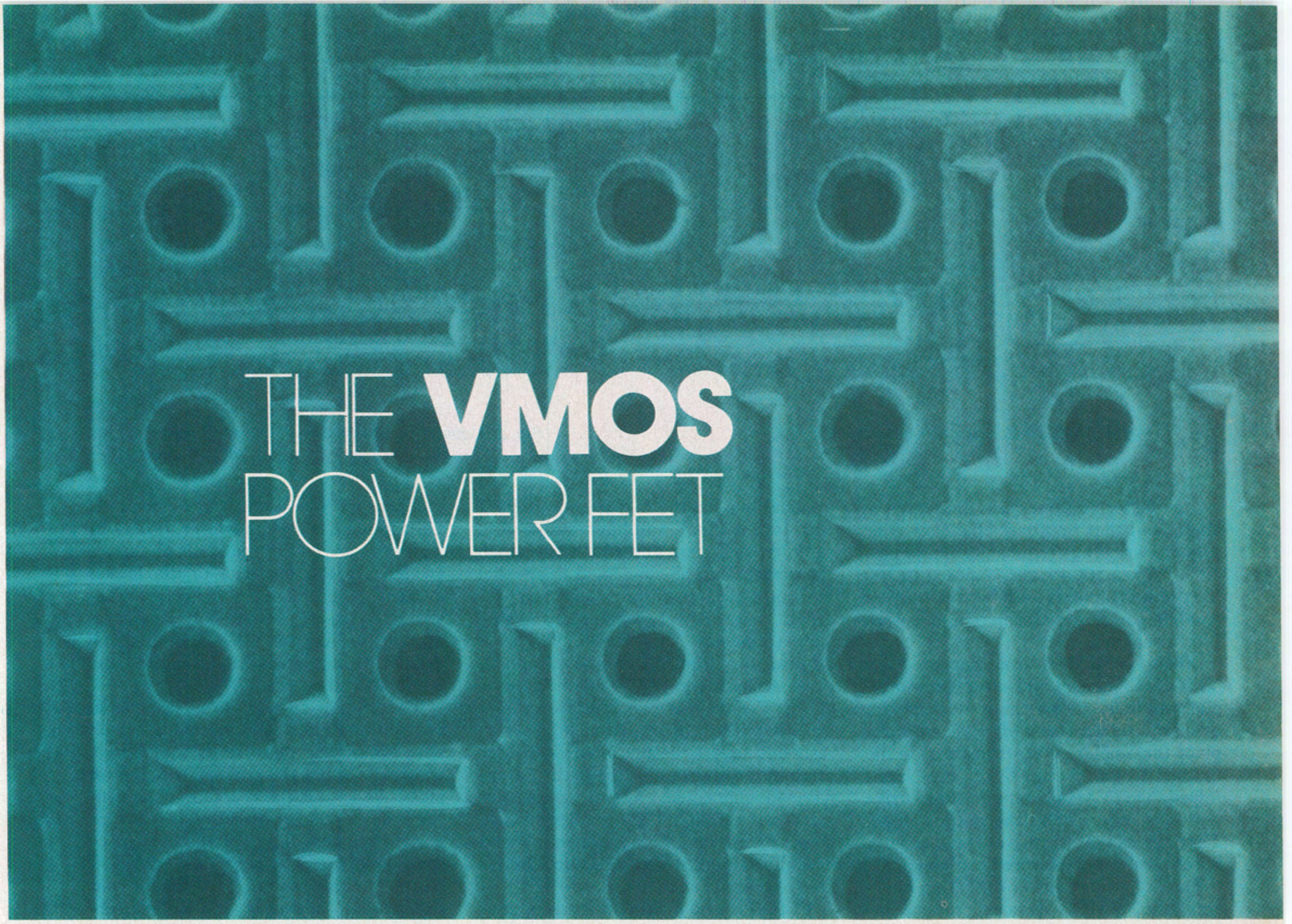
THE VMOS POWER FET



An up-and-coming rival to bipolar devices, VMOS offers advantages in circuit simplicity and improved performance

BY GARY McCLELLAN

VMOS power FETs are being designed into more and more electronic equipment, promising better performance, using less support circuitry, and permitting savings in cost. So far, they have replaced bipolar power transistors in some switching power supplies and audio amplifiers, with applications in power switching and power conversions soon to come.

Compared with its bipolar counterpart, a VMOS power FET has numerous advantages: its input impedance is higher, its bandwidth wider, and its inherent linearity greater. In addition, its temperature coefficient of gain is negative. That is, with a fixed level of drive at its gate, a VMOSFET conducts less and less current as it gets hotter.

Of course, VMOS devices offer a few tradeoffs to challenge the circuit designer. For one, the gate saturation voltage of the VMOSFET runs somewhat higher than that of an equivalent bipolar device. Second, the relatively high gate capacitance (500-800 pF) means that the input will tend to draw appreciable current at the higher audio frequencies and beyond.

Finally, there is the matter of cost. VMOS devices cost more, but, according to designers, the reductions in support circuitry that they allow can make them in the long run, a better bargain than bipolar.

Typical Applications.

Power Supplies. When the series-pass stage consists of several bipolar devices in parallel, at least two power resistors per transistor are required to prevent the devices from sharing the load current unequally should their temperatures differ. With the negative temperature coefficient, VMOS devices are free of this "current-hogging" tendency and require no power resistors. Another bonus of VMOS is that very high input impedance, makes the high drive currents that bipolar power transistors would require unnecessary. As a result of this, driver circuits that have lower power ratings and thus are less expensive to fabricate can be used.

Switching power supplies also benefit from VMOS. While many bipolar power transistors—especially the rugged ones—have a bandwidth of 2 or 3 MHz, VMOS devices can operate to 30 MHz and above. Because the VMOS devices

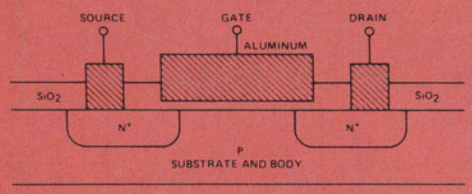


Fig. 1. Cross section of a conventional MOSFET.

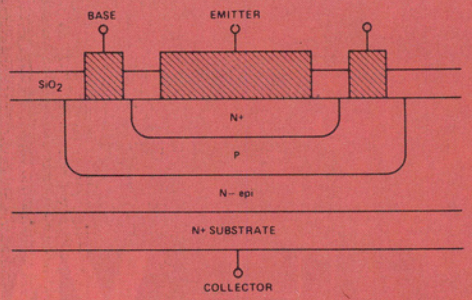


Fig. 2. A double-diffused epitaxial planar transistor.

switch faster, less energy is dissipated in them, and that improves efficiency. The higher switching frequencies made possible—up to 500 kHz as opposed to 100 kHz with bipolars—allow the use of smaller power transformers and output filter capacitors.

Audio Amplifiers are improved by VMOS technology and several commercial products using these devices are available. Here the VMOS devices replace the bipolar power transistors in the output stage. Because of the high-impedance VMOS inputs, less drive power is required by the output stage. That means that the driver stage can use lower-cost, lower-powered components.

Having a more linear operating characteristic, VMOS devices produce inherently less distortion. They are also free of the tendency of bipolar devices to "stick" to the power supply rails, and they come out of saturation faster with no extra drive current required. The result is a "cleaner" power amplifier. Another advantage of VMOS devices in audio amplifiers, is the freedom from "second breakdown," basically a situation in which momentary overvoltage or overcurrent will cause the device to heat up, draw more current, and then heat up some more, until it breaks down.

R-F Amplifier circuits such as those found in transmitters are likely places for VMOS technology. One of the first applications for the VMOS power FET was in the final amplifier stage of a radio transmitter. The ease with which the devices can be connected in parallel to obtain greater output power, the reduced drive power required, and the wide frequency range make VMOS a natural for transmitter (r-f) applications. At least one VMOS manufacturer claims the devices can tolerate infinite VSWR without destruction! (This corresponds to a situation where the user attempts to transmit without the antenna load connected.) Usually this subjects the output r-f stage to excessive power dissipation. Freedom from second breakdown makes VMOS devices better able to tolerate such abuse.

VMOS is also making inroads in double-balanced mixer circuits, normally a low-power receiver application. Because of their approximately square-law transfer characteristics, VMOS devices deliver more of the desired mixer products and fewer troublesome high-order products, providing more overload margin.

Power-switching applications for VMOS include control of displays, solenoids, and motors. Conventional designs use transistors in most low-power applications and change to SCRs and relays for high power. A good example of a VMOS power switching application lies in display control. At the present time, most display interfacing is done with inexpensive low-power transistors. If CMOS logic is used, however, it may be necessary to buffer the CMOS signals (which are low current) to the higher current requirements of the driver transistors. With VMOS, no buffering is required; in fact, one CMOS output can drive 100 or more VMOSFETs to the point of saturation!

VMOS can be used to advantage in controlling motors and solenoids, which pose difficulties because of the voltage transients when the current through an inductive load is interrupted. With conventional bipolar transistors, it is necessary to use very high-voltage devices or special networks to suppress the transients. Neither solution is cheap, and suppression networks reduce performance in high-frequency applications. Since VMOS devices are free from second breakdown, and can withstand back emf better, lower voltage FETs can be used and suppression networks simplified. In some low-power circuits, the traditional diode across the motor or solenoid can be removed.

For the area of power control in which SCRs and relays are presently used, VMOS shows promise. Even now, devices to handle high-voltages and high currents are under development. The future will tell whether VMOS will substitute for SCRs and relays, but 450-volt devices are already being advertised.

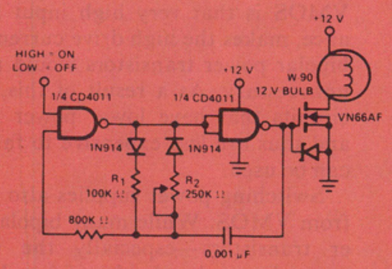


Fig. 5. A simple lamp dimmer circuit.

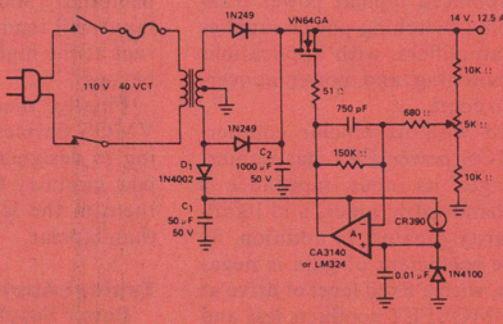


Fig. 6. An automatic battery charger.

Illustrations courtesy of Siliconix, Inc.

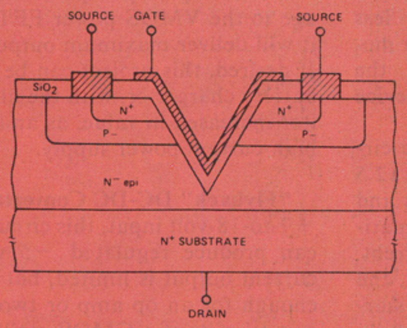


Fig. 3. Cross section of a VMOS channel.

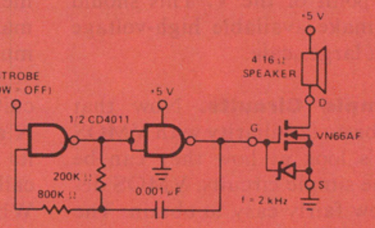


Fig. 4. Circuit for a 2-kHz audio alarm.

Anatomy of a VMOSFET. Although it would appear that a VMOS power FET would just be a conventional MOSFET on a larger scale, this is not the case. Such a device could be built, but it would be costly and inefficient. Figure 1 shows a cross section of a conventional MOSFET "die," stripped of all nonessentials. Several things prevent this FET from being used effectively for power handling, among them the fact that the current flow is horizontal through the substrate of the device. This is due to the horizontal positions of the drain and source connections, and the relatively great distance between their electrical connections. Both of these cause high resistance—and loss.

As a result of the characteristics of the semiconductor material, current densities are lower when current flows horizontally, and power dissipation is increased. A conventional bipolar power transistor die is shown in Fig. 2. Note that the emitter and collector are in a vertical plane. Because of this arrangement, current densities are higher, and more current can flow between these two points. Since the collector is also the substrate, the die can be thermally bonded to a heat sink for cooling. This is why TO-3 power transistors have the collector connected to the metal case.

The VMOS power FET is a variation on the vertical theme used by conventional power transistors, but it has some key differences. As shown in Fig. 3, four vertical layers are used, with a V-shaped channel etched in the material (which gives the VMOS its name) as the gate connection. A layer of silicon dioxide (SiO_2) insulates the conductive gate channel from the semiconductor materials, and gives the device its high-impedance characteristics. The source connection rests over the *n* and *p* materials, and provides the remaining power connection. These are the basics of the fabrication of the VMOS device. In practice, many "V" channels and source connections are paralleled on the die to produce the high current capability.

In use, the drain and gate are biased positive with respect to the source. The insulated gate produces an electric field, which allows the *n*-type material next to it to permit electrons to travel through the layers from the source to the drain. Increasing the field intensity of the gate (raising its voltage) increases its influence on the *n*-type material, causing a greater current flow. Conversely, reducing the gate field intensity reduces the source-to-drain current flow.

There are many advantages inherent in this type of construction. Since the substrate forms the drain connection, there is one less connection on the top of the die. As a result, the die can be made smaller. Also, since the drain connection is so large, saturation resistance can be made very low. This means the completed VMOS power FET can be inexpensive (small die) and handle high power (large drain surface). Another benefit is that each V groove creates two channels, one on each side of the groove, so current density can be doubled. In other words, the VMOS devices can have high sensitivity, with shorter length channels, than conventional MOSFETs. For example, the standard MOSFET needs at least a 5-micrometer channel. VMOS devices, on the other hand, require only about 1.5 micrometers for good results, and shorter V grooves mean less stray capacitance and improved high-frequency performance. The 2N6657 VMOS power FET, for example, switches 1 ampere on or off in 4 nanoseconds. That's 10 to 200 times faster than a bipolar power transistor!

Finally, the VMOS power FET has built-in, high-voltage capabilities. This is because of the *n*-epi (taxial) layer, which absorbs the depletion region from the *pn* junction above it, thus acting as a highly effective insulator when the device is turned off. Also, in VMOS construction, the SiO_2 layer under the V groove need withstand only 25% of the gate-drain voltage. (In a conventional MOSFET, the oxide must withstand the entire gate-drain voltage.) Although the point of the V groove can create high

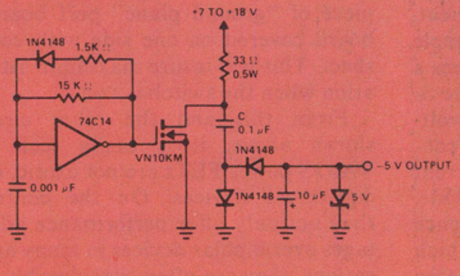


Fig. 7. A "flyback" dc-dc converter.

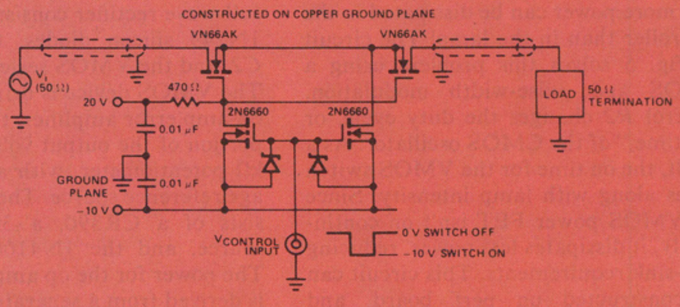


Fig. 8. An r-f switch using VMOS.

electrostatic fields which can break down the oxide layer, work is in progress to solve this problem. One solution is to flatten the point of the V. This should ultimately make available high-voltage devices on a large scale.

Some Simple Circuits. Now that you have a basic familiarity with VMOS devices, let's look at how they can be used in some simple circuits. VMOS devices are now fairly easy to obtain. The VN66AF used in many of these circuits is available nationally through Radio Shack stores. Basically, the circuits run the gamut from simple gadgets where the VMOS power FET simply replaces a conventional power transistor, to a high performance r-f switch where only VMOS will work properly. In all of the circuits, simplicity is apparent, particularly in the drivers for the VMOS devices. This is one of the benefits of high-impedance inputs.

Audio Alarm. A circuit that can be used as a burglar alarm, keyboard beeper, timer alert, or audio tone generator is shown in Fig. 4. The CMOS gate is wired as an oscillator, whose pitch is variable by changing the 200-kΩ resistor, or the 0.001-μF capacitor. The VMOS power FET is wired as a simple switch that drives the speaker directly. Note a zener diode connected across the gate and source of the VMOS device. This component is internal to the VMOS, and protects the input against overvoltage. A zener is built into most VMOS devices to make them less sensitive to static, so fewer handling precautions are necessary.

The circuit can be built on a small piece of perf board and cemented to the rear of the speaker. If desired, the supply voltage can be raised to 12 V for higher output power. If you want to tinker with the design, you can wire the two unused gates in the CD-4011 for another lower-frequency oscillator. Connect the output of this oscillator to the "strobe" input of the first oscillator. This produces a two-tone "boop-beep" sound similar to some police sirens.

Lamp Dimmer. The problem in dimming conventional incandescent lamps is that more power can be dissipated in the controller than in the lamp! The circuit of Fig. 5 solves this problem using a VMOS and pulse-width modulation. Control *R2* changes the duty cycle, or "on time," of the CMOS oscillator. As a result, the on time for the VMOS switch varies along with lamp intensity. Since the VMOS power FET isn't on continuously, it dissipates less power, reducing heat-sink requirements. This circuit can be constructed on perf board, and adapted to many different applications. For example, it should work well controlling low-power dc motors. Freedom from second breakdown, means less chance of damage from back emf or momentary high current. Of course, the maximum ratings of the VMOS device must be observed!

Automatic Battery Charger. The circuit shown in Fig. 6 provides up to 12.5 A at 14 V. As the battery charges and its voltage rises, the circuit automatically reduces the charging current. When the battery is fully charged, the charger cuts off. Thus, a lead-acid storage battery can be maintained fully charged at all times.

FOR MORE INFORMATION ON VMOS TECHNOLOGY

The following publications are available from Siliconix, Inc., 2201 Laurelwood Rd., Santa Clara, CA 95054:

Document number	Title
AN79-1	A 500 KHz Switching Inverter for 12 V Systems
AN79-3	Dynamic Input Characteristics of a VMOS Power Switch
AN79-4	Driving VMOS Power FETs
AN79-5	Using the VN64GA High Current, High Power VMOS Power FET
AN79-6	Using VMOS Transistors to Interface from IC Logic to High Power Loads
AN79-7	Applications of the VN10KM VMOS Power FET
AN80-1	A Key to the Advance of Switching Power Supplies
AN80-2	Meet the VMOS FET Model
AN80-3	Ultralinear Broadband Amplifier
AN80-4	Enjoy VHF Power Amplifier Design
AN80-5	An Alternative Power Amplifier Design

Basically, the battery charger is a full-wave rectifier consisting of a pair of 1N249 silicon diodes, filter capacitor *C2*, and the VMOS series-pass element. The VMOS device is driven by a simple op-amp error amplifier, that compares a portion of the output voltage, via the 5-kΩ potentiometer, with a constant-voltage reference source. The reference consists of a CR390, a 390-μA current source, and the 1N4100 zener diode. The power for the op amp and reference is derived from a separate source, which produces a slightly higher operating voltage than the main dc source. This allows the op amp to provide more voltage to the VMOS power FET, insuring it will deliver maximum output current. If desired, this project can be built as a battery charger or, with the filter capacitor increased in value, as an adjustable high-current power supply.

"Flyback" DC-DC Converter. With a +7-to-18-volt input, this circuit (Fig. 7) can produce regulated −5 volts. The current output is limited, but should be enough for an op amp or two. The circuit consists of a CMOS oscillator driving a VMOS switch. A full supply voltage square wave appears across the 33-ohm resistor forming the VMOS load, and the negative, or "flyback" transition, is rectified, filtered, and zener regulated to −5 volts. Since the oscillator operates at a high frequency, the filter capacitor can have a small value, yet do a good job. The circuit can be assembled in little space and work with battery-powered op-amp projects.

VMOS R-F Switch. The circuit of Fig. 8 can switch r-f signals in 50 nanoseconds, far faster than any relay (20 to 50 ms typical). Other advantages include 60-dB isolation with a 10-MHz, 20-volt peak-to-peak input, and 1-dB insertion loss. These are impressive features for such a simple circuit.

Basically, the VMOS power FETs are wired as a "T" switch. When the V-control input is 0 volt, the two 2N6660 FETs are biased on, because 10 volts appear between their source and gate. The left 2N6660 turns off both power VMOS devices by pulling their gates to −10 volts. At the same time, the sources of both VMOS devices are pulled low by the right 2N6660. Thus, both VMOS devices are turned off, and the junction between them is grounded to reduce leakage through the switch. Making the V-control input −10 volts turns off the two 2N6660s and the VMOS devices are allowed to turn on because of the 470-ohm pull-up resistor. The input r-f signal passes through the VMOS devices to the output. This simple circuit can be used for many applications where high r-f frequencies are used. A good example would be in a low-power transceiver, or to switch several receivers to one antenna. Build it on a piece of "ground plane" perf board or board covered on one side with copper sheet. This will insure maximum attenuation when the switch is "off."

From this and the other circuits shown above, it is easily seen that VMOS power FETs are not exotic, difficult-to-use devices. On the contrary, they not only offer performance advantages over bipolar devices in many applications, they are often considerably easier to use. ◇