Experimenting with VMOS Power Transistors

By Forrest M. Mims

ABOUT a year ago, in a "Solid-State Developments" column, I discussed the design, fabrication, and operating advantages of various kinds of VMOS field-effect transistors ("The New Power FETs," POPULAR ELECTRONICS, February 1982, p. 94). The key advantages of these VMOS devices include ultra-low "on" resistance, ultra-high input impedance, nanosecond switching time, high power capability, and both linear- and switching-mode operation. I also described practical circuits for a linear VMOS lamp dimmer, a pulse-modulated lamp dimmer, and a variable-rate lamp flasher.

This month, we'll examine in some detail the design and operation of a basic common-source VMOS amplifier. We'll also experiment with both unidirectional and bidirectional VMOS analog switches. Then we'll conclude with a brief look at a VMOS high-power variable resistor.

Where to Get Them. When I first wrote about VMOS power transistors, Radio Shack was the only major hobby dealer that carried the new devices. That still holds true today. They sell two Siliconix products, the VN20KM ($1.59) and the VN67AF ($2.49), both of which can be used in all the circuits that follow. Figure 1 gives the pin outlines for the transistors and lists some of their key specifications. (Additional information on the devices is available in the data sheets.)

Although Radio Shack remains the only major hobby source of VMOS transistors, the devices are available through industrial distributors who represent VMOS manufacturers. In addition to Siliconix, major domestic manufacturers of VMOS transistors include International Rectifier, Intersil, and Motorola.

Operating Precautions. Though the drain-source channel of a VMOS transistor can safely handle very high currents and voltages, the gate connection retains the usual vulnerability of MOSFET devices to electrostatic discharge damage. To avoid this problem, handle VMOS FETs like any other MOS device, and make sure to store loose components in conductive foam. Some VMOS power FETs include a protective zener diode between the gate and the source. Although the diode protects the input from static electricity, it can also impair the performance of the device.

If you use VMOS power FETs in high-power applications, be sure to observe all appropriate temperature and power ratings. In some cases a heat sink may be necessary. See the manufacturer's specifications for detailed information.

A Basic VMOS Amplifier. Figure 2 shows a basic VMOS common-source amplifier. The amplifier is so named because *Q1*'s source is common to both the input and the output of the circuit. It is therefore the MOSFET counterpart to the bipolar transistor common-emitter amplifier.

In operation, *R1* and *R2* form a voltage divider that biases *Q1's* gate to a point where the drain-source voltage (V_{DS}) is half the supply voltage (V_{DD}). The required gate voltage (V_{GS}) can be measured with the help of a test circuit, or it can be found by referring to the family of curves that shows the output characteristics for individual power MOSFETs as a function of drain current (I_D) and V_{DS}.

Let's assume we wish to use the circuit in Fig. 2 as a tone amplifier that directly drives a small 8-ohm speaker. If V_{DD} is 9 V and if the speaker is rated at 2 W, then the maximum forward current (I_D) through *Q1* and the speaker is, from Ohm's law, the power divided by the voltage (2/9) or 222 mA.

Incidentally, knowing I_D and V_{DD}, we can apply Ohm's law to find the necessary resistance for *R3.* Discounting the channel resistance of the VMOS FET (typically 0.5 to 5 ohms when fully on) to provide a safety margin, it is V_{DD} divided by I_D (9/0.222) or 40.5 ohms.

Now that we know I_D and V_{DS}, we can refer to the manufacturer's output characteristics curves for *Q1* to find the required V_{GS}. For Siliconix's VN10KM, V_{GS} is typically about 3.5 V when I_D is 222 mA and V_{DS} is 4.5 V. (The output characteristics curves are printed in Siliconix's *VMOS Power FETs Design Catalog* and in the 1982 and 1983 editions of Radio Shack's *Semiconductor Reference Guide.)*

Knowing the V_{GS} required to bias *Q1* so that V_{DS} is one-half V_{DD} means that the values for *R1* and *R2* can now be selected. Since V_{GS} is 3.5

SPECIFICATION	VN10KM	VN67AF
MAXIMUM DRAIN-SOURCE VOLTAGE	60 V	60 V
MAXIMUM DRAIN CURRENT	0.5 A	2.0 A
DRAIN-SOURCE ON RESISTANCE	5 Ω	3.5 Ω
TURN-ON DELAY TIME	2 ns	2 ns
RISE TIME	5 ns	2 ns

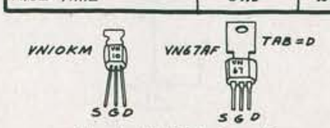

Fig. 1. VMOS pin outlines.

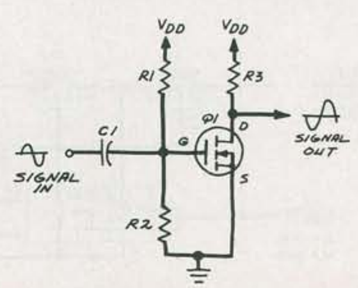

Fig. 2. Basic common-source amplifier.

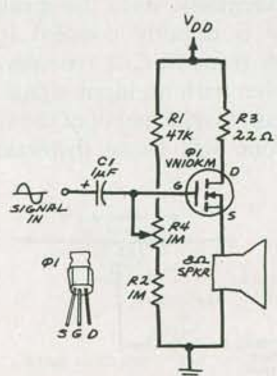

Fig. 3. VMOS audio amplifier.

V and V_{DD} is 9 V, V_{GS} is 0.39 V_{DD}. Therefore, the resistance of *R2* should be 0.39*(R1 + R2)*. Assuming we wish to keep the circuit's input resistance high, a reasonable approximation using standard resistance values would be to use 750 kilohms for *R2* and 1.2 megohms for *R1*. This will provide a V_{GS} of 3.46 V.

We can calculate the voltage gain (A_v) of the basic amplifier by multiplying load resistor *R3* times *Q1's* transconductance (g_{fs}). The typical g_{fs} of Siliconix's VN10KM is 200 millimhos. Therefore, A_v is 40.5×0.2 or 8.1.

Though a voltage gain of 8.1 may seem very small, the amplifier's power gain can be *considerably* higher. For example, assume the input signal is a 1-V peak-to peak sine wave originating from a source having an output impedance of 10 kilohms. The equivalent input power (P_i) of this ac signal is found by dividing the square of the signal's rms voltage by the source's resistance. The rms value of the signal is 0.3535 times its peak-to-peak amplitude (or 0.707 times the peak amplitude). For the values given above, P_i is $(1 \times 0.3535)^2/10{,}000$ or 12.5 μW.

The output power (P_o) is found by dividing the square of the rms output voltage by the load resistance *(R3)*. Since the voltage gain (A_v) of the amplifier is 8.1, then the output voltage is 1×8.1 V peak-to-peak. Therefore, P_o is $(8.1 \times 0.3535)^2/40.5$ or 0.202 W. The power gain is P_o/P_i or 16,195.

Incidentally, since the speaker in Fig. 3 is directly coupled to the VMOS transistor, it receives a dc bias even with no input signal. The resultant displacement of the speaker's cone will cause distortion of high-level audio signals. This distortion can be eliminated by inserting a transformer between the circuit and the speaker at *R3*. It may then be necessary to recalculate the circuit parameters.

For more information about predicting the performance of a common-source power MOSFET amplifier, see *Design of VMOS Circuits* by Robert Stone and Howard Berlin (Howard Sams & Co., 1980). This excellent book provides detailed step-by-step design procedures in chapter 4. It also contains a wealth of information about various VMOS circuits. Incidentally, the examples given on pp. 39-40 of this book multiply peak-to-peak signal values by 0.707 instead of 0.3535. While this gives incorrect values for P_i and P_o, it does not affect the example calculation of power gain.

A Real VMOS Amplifier. If you enjoy working with numbers, the preceding discussion probably makes the design of a common-source MOSFET amplifier seem relatively straightforward. But for those of us who also enjoy experimenting with real circuits, the mathematical approach has a serious drawback since the predictions are based on "typical" values of transconductance (g_{fs}) and gate voltage (V_{GS}).

Since the voltage gain (A_v) of the amplifier is the product of the load resistance *(R3)* and g_{fs} ($g_{fs} = A_v/R3$). A_v can be found by measuring the voltage at the input and output and dividing the latter by the former. Now g_{fs} can be easily determined for individual MOSFETs under specific operating conditions. (Incidentally, g_{fs} is sometimes designated g_m.)

V_{GS} can be found by injecting a sine wave into the amplifier while watching the waveforms at the input and output of the amplifier on a dual-trace scope. The voltage divider network (*R1* and *R2*) should be trimmed until the output waveform is a maximum-amplitude, undistorted version of the input waveform.

Figure 3 shows a practical version of the amplifier that works quite well. Note the addition of *R4* to permit quick adjustment of V_{GS}. The data sheet specifies for the VN10KM used in the circuit minimum and typical values of g_{fs} (or g_m) of, respectively, 100 and 200 millimhos. The *typical* value gives a predicted A_v of 4.4 ($A_v = R3 g_{fs}$).

I measured an A_v of only 3.0 when the speaker was shorted to leave a load resistance of 22 ohms. This corresponds to a g_{fs} of 140 millimhos. As you can see, using the "typical" data sheet value can be misleading.

Applications for the VMOS Amplifier. The simple circuit in Fig. 3 is well suited for use as a high input impedance small speaker driver. The input impedance can be increased by increasing *R1* and *R2* in the proper proportion to permit *R4* to determine V_{GS}.

In audio applications a scope is not always necessary to adjust *R4*. Simply feed a tone or a voice signal into the input and listen to the speaker while adjusting *R4* for maximum undistorted volume.

The circuit in Fig. 3 also makes an excellent LED driver for an amplitude-modulated lightwave communications transmitter. Simply replace the speaker with a LED and increase *R3*'s resistance to limit the current through the LED to a safe value. For maximum optical power output, select an AlGaAs or GaAs:Si LED.

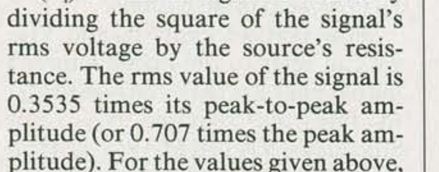

Fig. 4. Basic unidirectional analog switch.

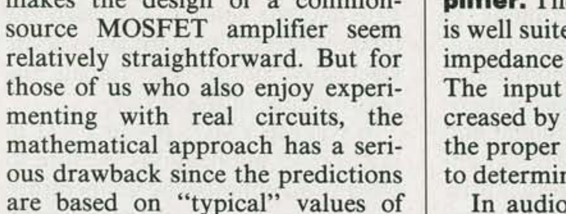

Fig. 5. Simple analog switch.

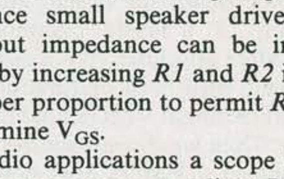

Fig. 6. High-current pot.

To operate the circuit as a LED audio transmitter, connect a signal source or microphone preamplifier to the input. Then adjust *R4* for best reception while monitoring the transmitted signal with a lightwave receiver.

The circuit in Fig. 3 works very well at high frequencies. With the values shown and with the speaker removed, the frequency response is virtually flat to beyond a megahertz, the limit of my Heath function generator. When *R4* is properly adjusted, the circuit faithfully reproduces 1-MHz sine and triangle waves. When a fast risetime (50-ns) 1-MHz square wave is fed into the amplifier, the output experiences a delay of only 5 ns. The ringing that occurs at the leading and trailing edges of the output signal can be minimized by careful adjustment of R_{GS} and, at very high frequencies, careful, point-to-point wiring.

A VMOS Unidirectional Gate. A VMOS FET can easily be used as a one-way gate for a positive-polarity, variable-amplitude analog signal. Figure 4 shows how such a gate can be turned on or off by a CMOS gate. Any gate signal having sufficient amplitude to turn *Q1* on can be used.

Since a VMOS FET can handle currents in excess of an ampere, the basic circuit in Fig. 4 is ideal for many different applications. It may not be well suited, however, for low distortion audio applications. Furthermore, if a waveform having both positive and negative components is applied to the gate in Fig. 4, as much as half the signal will pass through the gate even when it is off.

A VMOS Bidirectional Analog Gate. Siliconix's Application Note AN72-2 (Walt Heinzer, "VMOS—A Solution to High Speed, High Current, Low Resistance Analog Switches") describes a bidirectional VMOS gate made from two VN88AF VMOS FETs and a DG300 dual analog switch. Figure 5 shows a modified version of the Siliconix circuit that I assembled with two VN10KM's and a CMOS 4066 analog gate. This circuit transmits ac analog signals at frequencies up to and exceeding a megahertz.

The circuit in Fig. 5 provides excellent input-output isolation in the off state when the output load is a low resistance (a few hundred ohms). When the output load is 10 kilohms, about 4% (−30 dB) of the input signal appears at the output when the gate is off.

A VMOS Variable Resistor. The drain-source channel of a VMOS transistor can be considered a variable resistor when the drain-source voltage is about 3 V. According to *Design of VMOS Circuits,* the book cited earlier, in this mode a VMOS FET ". . .exhibits a fairly linear inverse relationship between drain-source resistance and gate-source voltage. For the 2N6656, for example, its gate-source resistance can vary from about 2 ohms ($V_{GS} = 10$ V) to essentially infinity."

Figure 6 shows how a VMOS power transistor can be used as a variable resistor having a much higher power rating than some miniature trimmer resistors. This circuit suggests many interesting applications, particularly since *R1* can be replaced by temperature- or light-sensitive resistors. ◇