Designer's Notebook: VMOS FETS

The mysterious MOSFET dymystified, by Don Keighley.

FIELD EFFECT TRANSISTORS (FETs) are peculiar brutes. If you've used them you'll know what I mean — negative bias voltages, depletion layers, pinch-off voltages and so on, ad infinitum. If you haven't used a FET before, the theory is simple enough: a FET is essentially a doped-silicon resistor (Fig. 1), much like a normal carbon resistor. The doped-silicon, however, exhibits a change of resistance if an electric field through the resistor varies. The electric field depends on the voltage present at the gate of the FET (Fig. 2), so a change of gate voltage changes the current through (and hence the resistance across) the device. Essentially a FET forms a voltage controlled resistance. In the example shown in Fig. 2 (a P-channel FET) a gate voltage of OV will produce a resistance of approximately 100R and a gate voltage of 5V will produce a ⊣ MO resistance. For a N-channel FET the opposite is true; a gate voltage of OV will give a resistance of 100R, - 5V gives ⊣ MO. For low drain-source voltages and low drain-source currents, the resistance change is linearly related to the gate voltage.

FETs have two enormous advantages over bipolar transistors. First, the gate input resistance is very high, meaning that virtually no current needs to be drawn from preceding circuitry. Second, FETs can exhibit very fast switching speeds — they can be used quite easily up to frequencies of many megahertz.

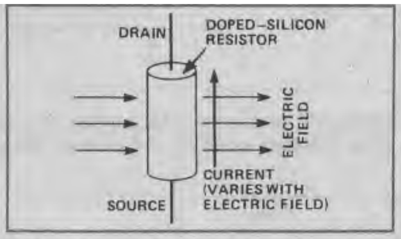

Fig. 1 A field effect transistor (FET) is a doped-silicon resistor, the resistance of which can be varied by changing the electric field through it.

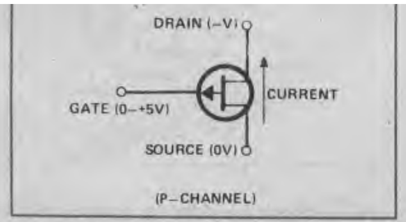

Fig. 2 The symbol for a FET. Current through the FET and hence the resistance across it is controlled by the voltage at the gate.

Problems, Problems

So, everything is fine — as long as you follow the rules. In low-power applications there is no reason why FETs can't be used anywhere a bipolar transistor can (they are, in fact, more versatile than bipolars — in low-power applications). But, therein lies the rub — power. It is very difficult (and expensive) to make a FET which can pass large currents: the main reason being the horizontal make-up of ordinary FETs. Bipolar transistors have vertical current flow and can pass larger currents because of it. Figure 3a shows the theoretical cross-section of a bipolar transistor and a similar cross-section of a FET is shown in Fig. 3b. Current flow in the bipolar is vertically upwards from collector to emitter and the large area through which the current passes allows large currents. FET current flow is from left to right (drain to source) and the small area of current flow means smaller currents than in a similar-sized bipolar transistor.

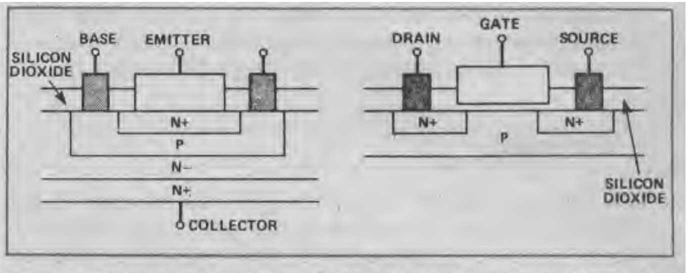

Fig. 3. Cross-sections through a) a bipolar transistor; b) a field effect transistor.

Recently, VMOS FETs have been manufactured which overcome the power problems normally associated with FETs. A typical VMOS FET cross-section is shown in Fig. 4. Current flow is now vertically upwards, from drain to source, in much the same way as in bipolar transistors. The larger chip area means large current. Hence we have transistors exhibiting all the advantages of FETs without the usual power limits. VMOS FETs also have some other very interesting advantages:

- low ON resistance — good for audio switching purposes.
- power amplification — as high as 10^{6},
- positive temperature coefficient on the ON resistance — as the temperature goes up the transistor passes less current, therefore remaining thermally stable.
- easily operated in parallel to increase overall current flow — due to the inherent thermal stability no 'current hogging' by one device occurs.

We'll see applications using these advantages shortly.

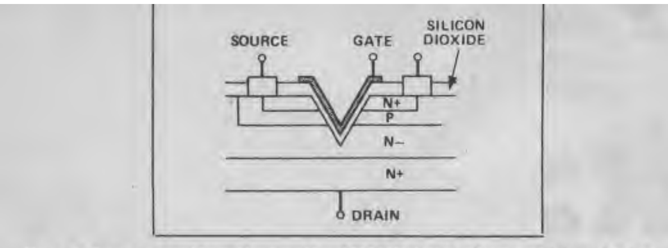

Fig. 4 Cross-section through a VMOS FET. Current flow is vertical, as in a bipolar transistor.

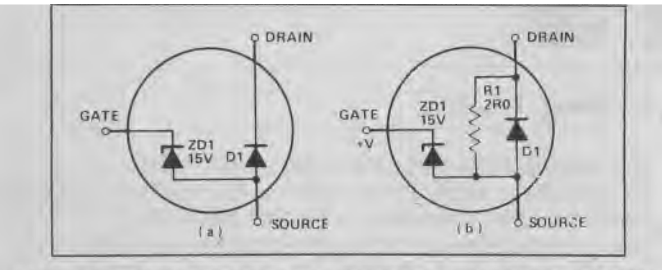

Fig. 5 Equivalent diagrams of a VMOS FET a) in the OFF state; b) in the ON state.

The equivalent circuits of a VMOS FET (such as the VN67AF) in its OFF and ON states, are shown in Fig. 5. The zener diode protects the transistor from over-voltage on the transistor gate — it is a feature on many VMOS FETs but not all! If a VMOS transistor does not have such a gate-protection zener diode, it must be handled as a CMOS IC. You must take care to avoid static build-up between connections.

In the VMOS FET's OFF state (gate is low), diode D1 is reverse-biased and no current can flow from drain to source. In the ON state the diode is effectively shorted by a 2R0 resistor, allowing current flow from drain to source. With gate-voltages between OV and +V the resistor value is within the range 2R0 to cut in.

Applications

Low ON resistances and high OFF resistances make VMOS FETs ideal for use in audio switching networks. Figure 6 shows a simple on/off audio switch controlled by the voltage on the transistor gate: + 15V turns the switch on and OV turns it off. Audio signals can only pass in one direction, from drain to source, but any audio voltage of about — 1/2V to + 5V can be switched.

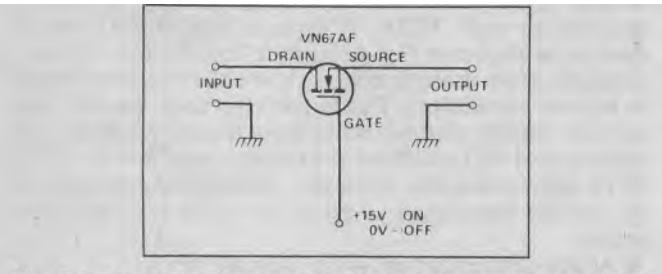

Fig. 6 A simple unidirectional audio switch formed by a single VMOS FET.

The extremely high gate-input resistance of VMOS FETs means that they can be switched by virtually any control method, such as CMOS, TTL, op-amps and so on. A four-channel audio multiplexer is shown in Fig. 7, which uses a bank of four VMOS FETs as input switches with the transistors being clocked in turn by a 4017 decade counter. The fourth output of the 4017 is connected to the reset pin, giving a 1-2-3-4 count to control the VMOS FETs. As each FET is enabled by the 4017 counter the audio input at its drain is connected, via the source and a 10k resistor, to the op amp.

If TTL logic is used to control VMOS FETs, gate pull-up resistor must be inserted (Fig. 8) to ensure that the gate voltage is pulled up to +5V when on — sufficient to give about 500 mA of current through the transistor. Figure 8 also shows the principle of VMOS current control through a load, in this case an indicatorlamp. The load can, however, be virtually anything requiring current e.g. relays, LEDs or loudspeakers.

an astable (formed by CMOS gates), a VMOS FET and a loudspeaker. When the transistor is on, its drain to source resistance is about 3R0 so about 1A (i.e. V/R = 11/11) passes through the loudspeaker. The average current (assuming a 50% duty cycle from the astable) is therefore about 500 mA. Audio output power is thus about 2W.

Paralleling two or more VMOS FETs in an output stage easily increases current-handling capacity. The siren circuit of Fig. 9 is redrawn in Fig. 10 with four paralleled output transistors. This more powerful siren will produce an output power in the region of 6W. You can see that no ballasting resistors are needed (as you would require with a similar circuit using bipolar transistors) because of the positive temperature coefficient of the drain-to-source 'on' voltage. The explanation of parallel operation is very simple: if any one of the VMOS transistors begins to conduct a larger than average current it will tend to get warmer and so current flow will reduce.

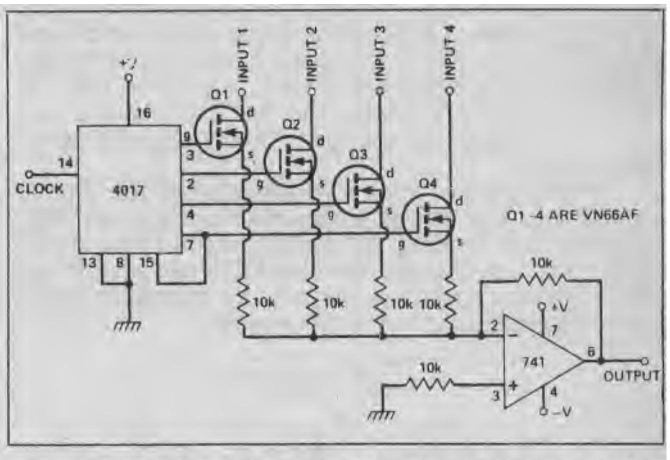

Fig. 7 Four VMOS FETs used in a four-channel audio multiplexer giving a time division multiplexed output signal.

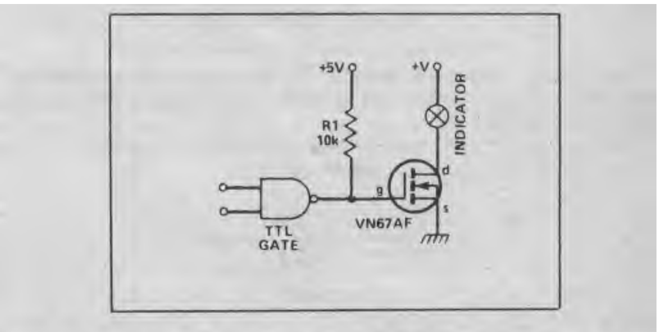

Fig. 8 TTL gate logic can be used to control VMOS FETs but a gate pull-up resistor must be used to ensure that the FET gate reaches a high enough voltage to allow sufficient current flow through the FET.

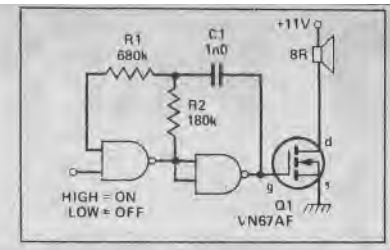

Fig. 9 Simple audio siren. An astable oscillator provides drive to switch the VMOS FET on and off at an audible rate.

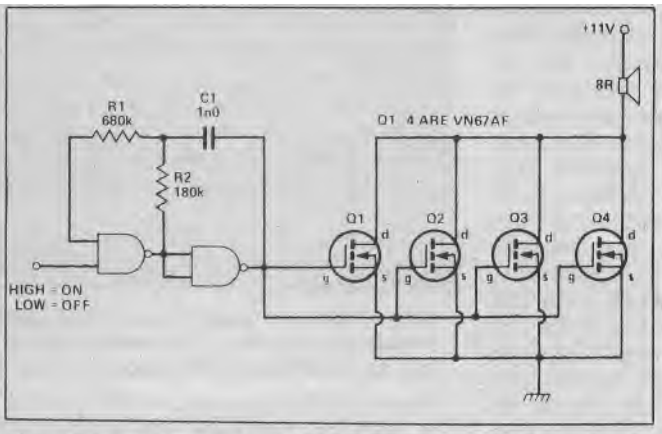

Fig. 10 Paralleling output VMOS FETs can be done simply because they are inherently thermally stable.

Linear Applications

So far we've only considered switching applications using VMOS FETs (i.e. on or off), but they can just as easily be operated in a linear mode (to act as voltage controlled resistors) in the same way as ordinary FETs.

Linear regulators in power supplies are easily constructed: such a circuit is shown in Fig. 11. An op-amp compares the output voltage with a reference voltage derived from a zener diode and parallel variable resistance. The reference voltage is thus variable from OV to about 11V. If the output voltage is less than the reference voltage, the op-amp increases the drive voltage to the VMOS FET, and vice versa, in a negative-feedback controlled loop.

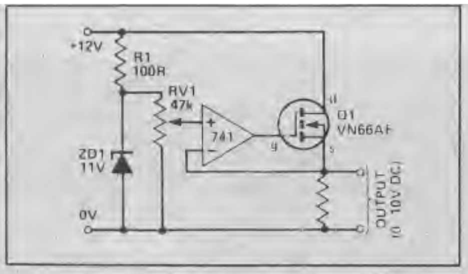

Fig. 11 A VMOS FET used in a linear voltage regulator. An op-amp is used in a negative feedback loop to provide the controlling gate voltage for the VMOS FET.

Constant-current sources suitable for charging Nicad cells can be made easily using VMOS FETs, and a simple unregulated circuit is shown in Fig. 12. The current output is defined primarily by the gate voltage of the transistor by altering the ratio of the two resistors R1 and R2. By varying the gate voltage between OV and 5V, a range of currents of approximately 0-250 mA will be obtained. Although the high output impedance of the transistor (relative to that of a bipolar) provides a level of current regulation, differing loads will produce differences in current flow.

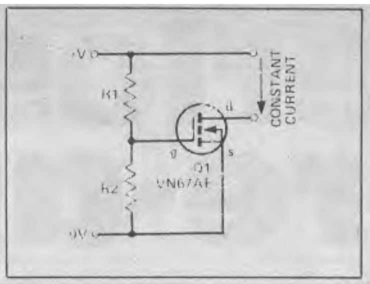

Fig. 12 Unregulated constant current source formed around a VMOS FET.

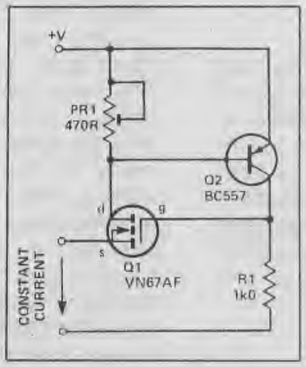

Fig. 13 Transistor Q2 holds the gate-to-source potential of the VMOS FET constant for any load. The current is therefore constant.

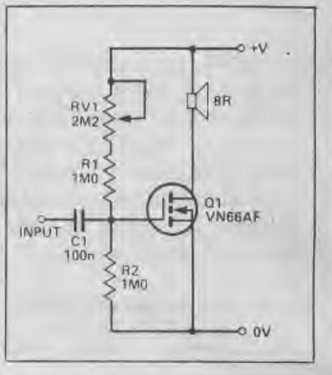

Fig. 14 A simple class A power amplifier.

The circuit of Fig. 13 overcomes this problem with a negative feedback loop formed by Q2. This transistor holds the gate-to-source potential of the VMOS FET constant for any load. Thus the current flow is constant whatever the load.

A Class A power amplifier can be constructed with a VMOS transistor and because of the inherent thermal stability of the FET, very few precautions need be taken with the circuit (Fig. 14). The high transistor input resistance allows very high value biasing resistors. Although obviously an audio power amplifier (the transistor load is a loudspeaker!) the circuit itself will operate up to the megahertz regions.

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