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Series operation of power MOSFETs for high-speed, high-voltage switching applications

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Series operation of power metal-oxide semiconductor field-effect transistors (MOSFETs) to increase their effective hold off voltage is described. The design procedure presented is a modification of a recently reported [Baker and Johnson, Rev. Sci. Instrum. **63**, 5799 (1992)] method. Comments are made on implementing MOSFET stacks in various types of instrumentation.

Power metal-oxide semiconductor field-effect transistors (MOSFETs) are finding uses in instrumentation[1–3] which until recently were reserved for vacuum tubes. Signals with amplitudes in the range of hundreds of volts and rise and fall times in the nanosecond regime can now be generated using power MOSFETs. Bernius and Chutjian[1,2] have shown that power MOSFETs can be used in series or alone for fast switching between high voltages which are required in time-of-flight, coincidence, and beam modulation experiments.

Recently[4] a reliable method of stacking power MOSFETs was demonstrated. The basic circuit configuration is shown in Fig. 1(a). The operation of this circuit relies on a voltage division between the effective gate-source capacitance of each MOSFET with the gate capacitance connected to ground. We have recently found that this circuit can be modified as shown in Fig. 1(b).

For the circuit of Fig. 1(a), the gate capacitor current and the MOSFET gate electrode current are the same. This same current flows into the gate of each MOSFET in Fig. 1(b), while the current flowing in each of the capacitors has changed. If the current flowing into the MOSFET gate is I, then a current 3I flows through 3C, 2I through 2C, and I through C, where C is determined by the method given in Ref. 4. The advantage of this configuration is a simpler board layout and a relaxed specification on the working voltage of the gate capacitors.

As an example, an 8-kV MOSFET stack was recently described[3] for re-referencing the beam potential in ion beam experiments. Using the method presented in Ref. 4 to perform a similar function would require gate capacitors with working voltages up to 8 kV. This type of capacitor may not be readily available in the capacitance value needed for the design. With the design presented here 1-kV ceramic capacitors can be used. These are available in a wide variety of values. An alternative would be to parallel a single value of capacitance until the desired value is reached. Also, since the MOSFETs must be arranged in a stack, the gate capacitors in a stack do not complicate board layout.

The main disadvantage of this method occurs when trying to apply it to linear applications, i.e., ramp or amplifier design. In practice each MOSFET has slightly different current-voltage characteristics resulting in differing gate currents which will lead to different drain-source voltages. The end result is that the MOSFETs will not turn on at the same rate. Since switching applications are nonlinear the differences in drain-source voltages will not be a problem.

The value of the resistors used for biasing the MOSFETs is not critical, but the wattage is. The wattage of the resistor is related to the maximum voltage has can be applied across the resistor. When using higher than 500-V MOSFETs, 1-W resistor should be used. It is best to place

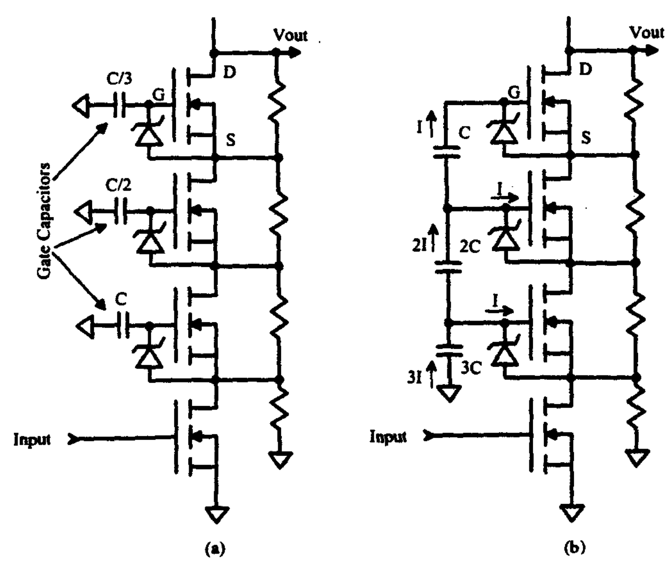

FIG. 1. (a) Basic circuit configuration for stacking power MOSFETs; (b) modified method.

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the biasing resistors between the drain and source to avoid biasing on the gate side. Gate side biasing adjusts the drain source voltage as the MOSFET turns on. It should also be noted that no additional protection is needed between the drain and source due to the integral body diode present in power MOSFETs. This diode limits the maximum potential which can be applied between the drain and source.

A Zener diode between the gate and source is used to set the dc operating potential of the gate to the same potential as the source and to protect against overvoltages between the gate and source. The capacitance of the diode must be added in equation two in Ref. 4 for proper selection of the gate capacitors.

This method has been used successfully to design many different types of high-voltage pulse generators without MOSFET failures. In some cases the MOSFET strings can be used to replace tubes performing similar functions. The advantages of the MOSFET when compared to a tube are unlimited lifetime when properly operated, lower power dissipation, and faster switching speed.

Finally, in order to generate rectangular pulses many instruments built with tubes use charge lines. Varying the pulse width requires a physical change in the length of the charge line cable. Instruments using power MOSFETs can employ electronic methods to vary the pulse width.[1,2]

Future work will concentrate on applying these procedures to the design of instrumentation; for beam experiments, gating of electro-optic loads such as Pockel's cells, driving streak cameras, microchannel plates, and high-power tubes such as the thyratron.

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