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THE DUAL-GATE MOSFET

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Semiconductor developments produce many items of only passing interest. The dual-gate MOSFET, however, appears to be an item that is bound to have important and long term applications, particularly in receiver circuits.

DEVELOPMENTS in transistor technology seem almost to outspace the ability of builders to incorporate them into their designs. For many amateurs, this is certainly true as regards amplifiers using field effect transistors. Just as many amateurs are starting to commonly use FET circuits, the single gate FET's being used must often be regarded as already being somewhat obsolete in view of dual gate FET technology.

Fortunately, dual gate FET's are only slightly more complicated to use than single gate FET's but they offer some rather significant advantages over the latter type in applications as r.f. amplifiers, mixers and detectors. The advantages, moreover, are obtained at an extremely small increase in cost since dual gate devices have come out of the laboratories and are now being produced in quantity by various manufacturers.

The purpose of this article is to explain the basic composition of the dual gate MOSFET's and to present various circuits in which the device can be used. Comparisons are made between the dual gate MOSFET and both regular junction transistors and single gate FET's.

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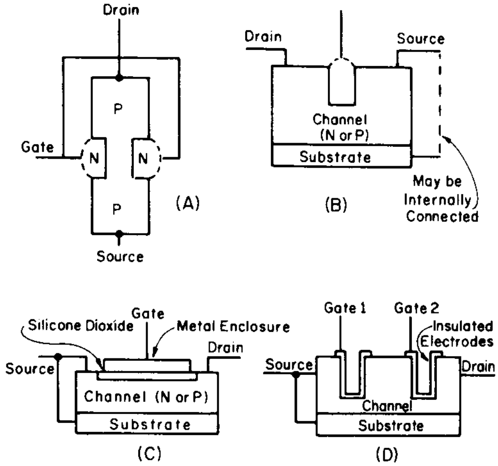

Fig. 1—Construction cross section of various junction FET's, (A) and (B), and MOS type FET's, (C) and (D).

Basic Dual Gate FET

One often hears the single gate FET referred to as the transistor equivalent of the triode vacuum tube. In this sense, the dual gate FET is then the solidstate analog of the multigrid vacuum tube. The comparison can't be carried too far but, in general, it is true that the dual gate FET can perform best in those applications where multigrid vacuum tubes are frequently used. Unlike the vacuum tube, however, where all sorts of problems develop because of transit time effects between elements and which cause noise and distortion, these effects are not present in the dual gate FET.

Figure 1 (A) is a representation of a single gate FET. This type is usually called a junction type because there exists an NP junction between the gate and the drain-source P-type semiconductor material. Although the gate is operated biased to the source so that no current flows through the junction, the presence of the interface creates problems which reduce the gate input impedance to less than its optimum value.

Figure 1 (B) is an extension of fig. 1 (A), a so-called four terminal junction gate FET. In effect it can be considered to have two parallel gates, or at least a construction which allows a form of two gate operation. Usually the small gate which has the lower capacitance to other elements was used as the signal input gate and the larger gate was used for bias and a.v.c. purpose.

Junction type FET's are giving way in most r.f. applications now to MOS (metal oxide semiconductor) type FET's. Figure 1 (C) shows the representative construction of a single gate MOSFET. The gate actually consists of a metal electrode which is separated from the N-type drain-source material by a very thin layer of silicon dioxide. The oxide layer perfectly insulates the gate and no interface effects take place. This allows the input impedance of the gate to be as high as 1000 megohms. The fact that the gate is insulated also allows "field effect" control of the current flowing between the drain and source terminals by either enhancing or depleting the current carriers in the gate controlled portion of the N-type material. Thus, one may find a voltage of either polarity specified for the gate control voltage, depending upon the FET's construction.

Figure 1 (D) is a representation of the dual gate MOSFET. In this case, the gates are in series and either one can exercise independent control of the FET's operation. There is some capacitance between the gates which results in mutual coupling but it is rarely of significance until frequencies of 400-500 mc are considered. Many, but not all, dual gate MOSFET's operate in a depletion mode and so the polarity of the bias on the gates is opposite to what one expects after having been used to simple junction type FET's. Generally, most dual gate MOSFET circuits are arranged so that the gate nearest the drain is fix-biased and the gate nearest the source is used for the signal input, similar to the usual vacuum tube tetrode circuit.

Advantages

The dual gate MOSFET is not a cure-all for all transistor problems but its list of advantages is impressive. For amplifier applications, the list includes low noise, good power gain, excellent dynamic range, good a.v.c.

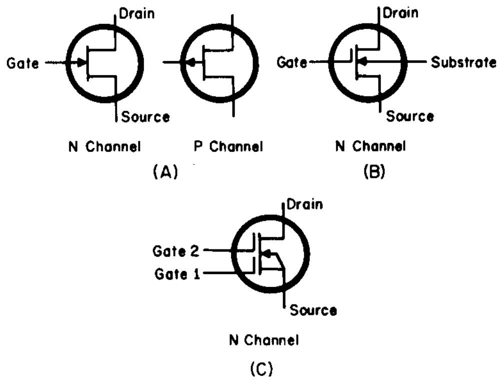

Fig. 2—Simple FET symbols (A are clear enough. Single gate MOSFET symbol (B) can have arrow on either substate or source lead. Dual gate MOSFET symbol (C) shows internal connection of substrate to source.

range and low feedback capacitance. Unlike a conventional transistor where the application of an a.v.c. voltage is reflected in a change in the transistors input impedance, this effect does not take place and input circuit detuning does not occur. Since the dual gate MOSFET can be turned off by an a.v.c. voltage applied at the non-signal input gate, the dynamic range is very great and essentially equals that obtained with a vacuum tube amplifier. Since the gate nearest the drain can be grounded for r.f., it acts as a shield between the input gate and the drain output circuit. As a result, feedback capacitances of less than 0.02 mmf occur and neutralization is not necessary up to at least 400-500 mc.

Power gains are not extraordinary but certainly sufficient, usually ranging from 15 to 20 db. Noise figures vary from 3.5 to 5 db.. even up to 500 mc.

As a mixer, the dual gate MOSFET really shines. The two gates allow distinct coupling to the FET for each signal input. The signal applied to one gate actually modulates that applied to the input gate by effecting a change in the input gate's transfer characteristics. The process is different from the usual diode mixing where the diode is operated in its nonlinear "square-law" region and a forest of spurious responses occur as a result of the mixing action. The frequency spectrum output of the dual gate MOSFET is particularly "clean" with only the main mixing products being essentially present. For this reason, most manufacturers who are starting to in-

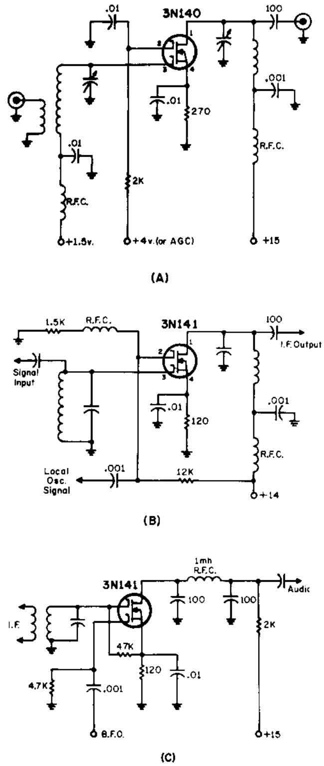

Fig. 3—Dual gate MOSFET applications as a r.f. amplifier (A), frequency mixer stage (B) and product detector (C).

corporate r.f. amplifiers in a receiver using a dual gate MOSFET almost invariably follow the r.f. stage with another dual gate MOSFET as the mixer stage.

The low distortion mixing features of the MOSFET are usable in many other applications as well, product detectors, for instance.

Disadvantages

The only real disadvantage of the MOSFET is really more a handling one than an electrical one. The MOSFET is quite stable when wired in a circuit, but when by itself it is very sensitive to electrostatic charges which could cause a current flow and rupture the than oxide coating between the gate and the semiconductor channel. Its leads must be kept connected together during storage and handling of the leads should be avoided. During equipment construction, the soldering iron used should be grounded.

Circuit Symbols

Since more and more dual gate MOSFET circuits are being developed, it would seem that the circuit symbols would be standardized but the actual situation is that most manufacturers create their own symbols. Figure 2 (A) presents the single gate junction type FET symbols. For a dual parallel gate unit usually two arrowed leads are shown, each entering from one side. Figure 2 (B) presents the most commonly used symbol for a single gate MOSFET. The gate is shown separated to indicate that it is insulated from the channel material. The direction of the arrow on the substrate lead indicates N or P-type channel material. If the substrate lead is internally connected to the source, it is usually shown as such within the circle. The circuit symbol for the dual gate MOSFET (fig. 2 (C)) is a simple extension of that for the single gate MOSFET.

Typical Circuits

Figure 3 shows three typical applications to which inexpensive RCA or similar dual gate MOSFET's can be put. The bias voltages shown for the r.f. amplifier stage of fig. 3 (A) may seem complicated but they can all be derived from the drain voltage with simple resistor voltage divider networks. The drain current should be from 7-10 ma. The amplifier will work at lower drain voltages but the voltage should not be reduced below 7.5 volts or else the noise figure will increase rapidly.

The basic mixer circuit shown in fig. 3 (B) may be used up through the 220 mc band with suitable tuned circuits and r.f. chokes. Figure 3 (C) is particularly simple but effective product detector circuit.

Summary

MOSFET's should definitely be considered by anyone who is in the process of building a transistorized preselector, v.h.f. converter, *etc.* Most likely, one will find these transistors will outperform and cost less than most simple junction transistors or FET's.

For those who enjoy historical notes, by the way, it is interesting to observe that the basic idea for the MOSFET was patented in the U.S. in 1930 by Julius E. Lilenfeld. He proposed a copper sulfide type construction which was sort of a cross between an NPN transistor and a MOSFET. Needless to say, his idea was never developed. ■