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First, though, some motivation and perspective: The **FET's** nonexistent gate current is its most important characteristic. The resulting high input impedance (which can be greater than $10^{14}\Omega$) is essential in many applications, and in any case it makes circuit design simple and fun. For applications like analog switches and amplifiers of ultrahigh input impedance, FETs have no equal. They can be easily used by themselves or combined with bipolar transistors to make integrated circuits: In the next chapter we'll see how successful that process has been in making nearly perfect (and wonderfully easy to use) operational **amplifiers**, and in Chapters 8–11 we'll see how digital electronics has been revolutionized by MOSFET integrated circuits. Because many FETs using very low current can be constructed in a small area, they are especially useful for large-scale integration (LSI) digital circuits such as calculator chips, microprocessors, and memories. In addition, high-current MOSFETs (30A or more) of recent design have been replacing bipolar transistors in many applications, often providing simpler circuits with improved performance.

3.01 FET characteristics

Beginners sometimes become catatonic when directly confronted with the confusing variety of FET types (see, for example, the first edition of this book!), a variety that arises from the combined choices of polarity (n-channel or p-channel), form of gate insulation (semiconductor junction [JFET] or oxide insulator [MOSFET]), and channel doping (enhancement or depletion mode). Of the eight resulting possibilities, six could be made, and five actually are. Four of those five are of major importance.

It will aid understanding (and sanity), however, if we begin with one type only, just as we did with the npn bipolar transistor. Once comfortable with FETs, we'll have little trouble with their family tree.

FET V - I curves

Let's look first at the n-channel enhancement-mode MOSFET, which is analogous to the **nnp** bipolar transistor (Fig. 3.1). In normal operation the drain ($\sim$ collector) is more positive than the source ($\sim$ emitter). No current flows from drain to source unless the gate ($\sim$ base) is brought positive with respect to the source. Once the gate is thus "forward-biased" there will be drain current, all of which flows to the source. Figure 3.2 shows how the drain current I_D varies with drain-source voltage V_{DS} , for a few values of controlling gate-source voltage V_{GS} . For comparison, the corresponding "family" of curves of I_C versus V_{BE} for an ordinary **nnp** bipolar transistor is shown. Obviously there are a lot of similarities between n-channel MOSFETs and npn bipolar transistors.

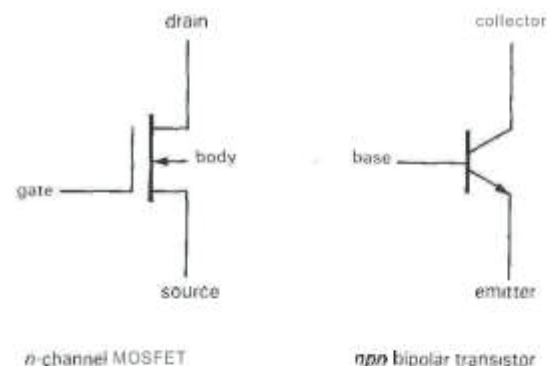


Figure 3.1

Like the **nnp** transistor, the FET has a high incremental drain impedance, giving roughly constant current for V_{DS} greater than a volt or two. By an unfortunate choice of language, this is called the "saturation" region of the FET and corresponds to the "active" region of the bipolar transistor. Analogous to the bipolar transistor, larger gate-to-source bias produces larger drain current. If anything, FETs behave more nearly like ideal transconductance devices (constant drain current for constant gate-source voltage) than do bipolar

Examples of tuned RF circuits

You will see tuned RF amplifiers in their natural element when we discuss communications circuits shortly. At this point we would simply like to illustrate the use of tuned circuits in oscillators and amplifiers with a few examples. Figure 13.23 illustrates the classic tuned amplifier. A

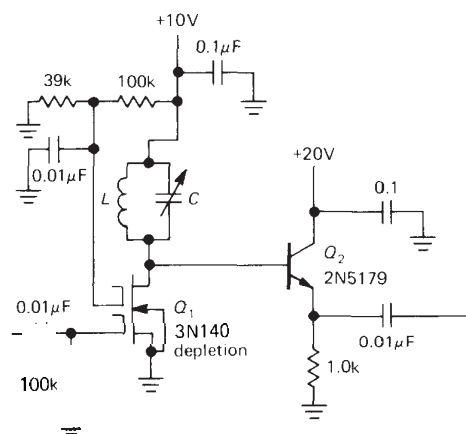


Figure 13.23. Dual-gate MOSFET (cascode) tuned amplifier.

dual-gate depletion-mode FET is used to eliminate the problems of Miller effect, since the input is untuned. By operating the lower gate at dc ground, the stage runs at I_{DSS} . The parallel tuned LC sets the center frequency of amplification, with output buffering via Q_2 . Since the drain sits at +10 volts, the output follower requires a higher collector voltage. This sort of circuit has quite high voltage gain at resonance, limited by the LC circuit Q and loading by the follower.

In the circuit shown in Figure 13.24 a carefully constructed and tunable LC circuit is used to set the frequency of an oscillator. This is known as a VFO (variable-frequency oscillator); it is used as the tunable element in some transmitters and receivers, as well as **variable-frequency** RF signal sources. In this circuit

a JFET provides the necessary power gain, with positive feedback from the source coupled into a “link” on L_1 . The link has fewer turns than the inductor, providing voltage gain and therefore oscillation. By adding a varactor diode, which acts as a voltage-variable capacitor (see Fig. 5.44), you can make such an oscillator voltage-tunable. Note the use of a feed-through capacitor and decoupling RF chokes on the power-supply leads; this is nearly universal practice in radiofrequency circuits.

The circuit in Figure 13.25 is a 200MHz common-emitter transistor amplifier stage. This circuit illustrates neutralization, the technique of canceling out capacitively coupled signal from output to input by adding a current of the opposite phase. C_N is the neutralizing capacitor, driven from the bottom of the collector “tank” circuit where the phase is opposite to that at the collector. This circuit matches the output impedance to the line by tapping down on the “tank” (the collector LC circuit), a simple but inflexible method.

This last circuit (Fig. 13.26) is a 25kW RF amplifier, using a zero-bias **grounded-grid** triode. Vacuum tubes are still used in high-power frequency amplifiers, because no solid-state device can match their performance (for example, the 8973 power triode delivers 1.5MW at 50MHz!). The grounded-grid configuration requires no neutralization. The output circuit is the popular pi network, driven by blocking capacitor C_8 . C_9 , L_4 , and C_{10} form the actual network, with their values determined by the desired resonant frequency, impedance transformation, and loaded Q (Q, or quality factor, is a measure of the sharpness of resonance, see Section 1.22). The RF choke at the output prevents dc voltage appearing there, and the plate RF choke is used to apply plate voltage while allowing signal swing at the operating frequency.