Work-Ready Electronics

Synchronizing Curriculum to the Rapidly Changing Workplace

Module: Metal Oxide Semiconductor Field Effect Transistors (MOSFETs) and Common Electronic Circuits

WORKREADY ELECTRONICS

Metal Oxide Semiconductor Field Effect Transistors (MOSFETs)

MOSFETs are not new. In fact, production devices were first available in the mid-1960s. Today they are the most widely used transistor type in electronic circuits.

While MOSFETs are covered in all electronic technology textbooks and solid state courses in community colleges, they are not given the emphasis their leadership in the industry represents. Most texts and courses continue to stress coverage of bipolar junction transistors (BJTs). While BJTs are still used, their application has declined in favor of MOSFETs.

Textbooks today provide only an introduction to MOSFET operation and very little about the actual circuits in which they are used. This module is designed to supplement and update course and textbook coverage to provide the student with a contemporary look at modern MOSFET circuits and applications.

What Technicians Should Know

- Operation of the most commonly used type of MOSFET
- MOSFET biasing
- Basic MOSFET linear circuits including current sources and differential amplifiers
- Basic MOSFET switching circuits with an emphasis on complementary MOS (CMOS)
- How to handle MOSFETs

Prerequisites

To successfully complete this module, the student should have knowledge and skills in the following areas:

- Semiconductor fundamentals including PN junctions and materials
- BJT transistor biasing and operation
- Basic BJT amplifier circuits
- Basic BJT switching circuits

Rationale for MOSFET Dominance

MOSFETs in Perspective

The Semiconductor Industry Association (SIA) statistics say that well over 90% of all electronic circuits in use today are made with MOSFETs. This includes both integrated circuits (ICs) and discrete component devices. The majority of MOSFETs are inside ICs; however, there are also many discrete devices that are used in power amplification and switching.

BJTs are also still used in older equipment and ICs but their overall percentage of all transistors has declined over the years in favor of MOSFETs. But the greatest usage of BJTs is now very high frequency and high speed switching applications. Heterojunction bipolar transistors (HBTs) made from compound semiconductor materials like silicon-germanium (SIGe), gallium-arsenide (GaAs), and indium-phosphide (InP) are the fastest devices made. They are used in radio frequency, microwave, and fiber optic applications as well as very high speed computer logic.

Why MOSFETs Dominate

The primary reason MOSFETs have become the most widely used type of transistor is that their very simple construction and extremely small size allow them to be more easily made in IC form. In addition, because they are so small, more of them can be packaged in a smaller area of silicon for a given circuit or function than with BJTs. Over 100 MOSFETs can be made in the same area as a single BJT. Their smaller size results in smaller circuits which are also far more economical to produce.

In addition, smaller circuits allow more circuits to be packaged on a single silicon chip. This has lead to large scale integration where thousands and even millions of transistors can be made simultaneously on a single chip. Modern personal computers use microprocessors with over 40 million MOSFETs. Memory chips contain over 100 million transistors each. Such high numbers are impossible to achieve with BJTs.

Smaller Circuits

Because MOSFETs are so small, they permit complete systems to be packaged in a small single package. The embedded controller or single chip microcomputer is a good example. Other examples of complete systems on a chip are modems and cell phones. Such circuits make their end products smaller, simpler, and less expensive.

Smaller circuits also operate at much higher frequencies. They can be used for radio or wireless applications well into the microwave (>1 GHz) region. They also implement faster switching and logic circuits. Modern microprocessors can run at speeds exceeding 3 GHz switching speeds.

Smaller MOSFET circuits also consume much less power than BJT circuits. Lower power conserves energy and makes battery and portable operation practical. We would not have cell phones, laptop computers, PDAs, MP3 players, or other battery powered portable device without MOSFETs.

MOSFET Biasing

MOSFETs are easier to use because their biasing is simpler and consumes less power.

The input impedance to a MOSFET gate is essentially an open circuit. While not infinite, its resistive impedance is hundreds of megohms. This means that it essentially draws no current from the driving circuit. It does not “load” the driving circuit.

For digital MOSFET applications, biasing circuits are not required.

Input Impedance

Bipolar transistors must have their emitter-base junction forward biased to function. This causes current to flow in the junction (a diode) and current to be drawn from the driving circuit. This causes more power to be drawn and results in much lower input impedance.

The input impedance to a MOSFET is a capacitor. The gate and the substrate, or base on which it is built, form a capacitor with the silicon dioxide between them forming the dielectric. Applying an input voltage to the gate charges the input capacitance.

MOSFET circuits can be constructed with no resistors thereby further decreasing the size of the overall circuit compared to bipolar circuits.

MOSFETs – The Downside

The primary disadvantage of MOSFETs has been their lower switching speed when compared to BJTs. Charging the capacitance of the gate takes more time than forward biasing on emitter-base junction of a BJT.

However, as MOSFETs have gotten smaller, their gate capacitance has decreased significantly. As a result, MOSFETs are almost as fast as BJTs in most applications. BJTs will only outperform MOSFETs at the very highest of frequencies (beyond 10 GHz).

MOSFETs are also very sensitive to static electric charges. Even a small static voltage on the gate can destroy the transistor. Care must be taken when handling MOSFETs to prevent this problem. Many MOSFETs and ICs are protected internally with clamping diodes to mitigate this problem. This will be discussed in a later section of this module.

MOSFET and BJT Applications

Virtually all modern electronic products are made with MOSFETs in IC form. As semiconductor process technology improves, MOSFET sizes continue to decrease making even higher density and faster chips possible. More circuitry can be put on a chip thereby making complete products on a single chip easier to make.

MOSFET sizes are usually designated by gate width or feature size by IC designers. Currently, MOSFET sizes range from one micron (1 μm) in the older chips down to 0.13 μm. A micron is one millionth of a meter or 1000 nanometers (nm). New semiconductor processes are now available to make MOSFETs with feature sizes of 90 and 65 nm (0.090 and 0.065 μm).

Discrete MOSFETs are also used in RF power amplifiers and power switching applications such as motors, DC-DC converters, regulators, and inverters.

BJTs are found primarily in older equipment and in some RF/microwave amplifier circuits and switching circuits used in fiber optic systems.

Test your knowledge

Metal Oxide Semiconductor Field Effect Transistors (MOSFETs) and Common Electronic Circuits
Knowledge Probe 1
Rationale for MOSFET Dominance

Click on Course Materials at the top of the page.

Then choose **Knowledge Probe 1**.

Review of MOSFETs