10.4 RF Transistor Characteristics

Reading Assignment: *pp. 522-526*

The most important and useful circuit element ever devised is the transistor.

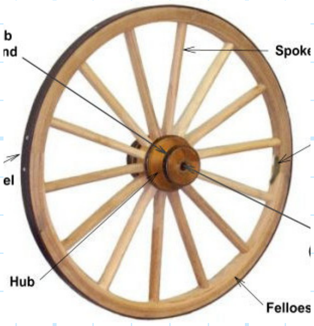
HO: RF TRANSISTORS

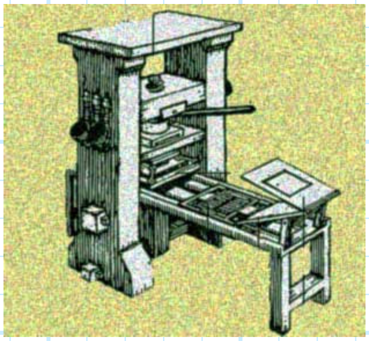
Among its other applications, transistors can be used to make gain stages for microwave amplifiers and oscillators.

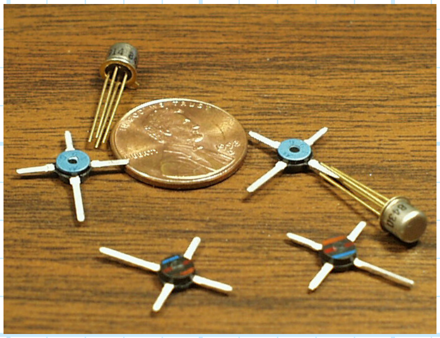
HO: TRANSISTORS AS GAIN ELEMENTS

RF Transistors

The transistor—this three terminal device has turned out to be one the most significant inventions in **human history**!





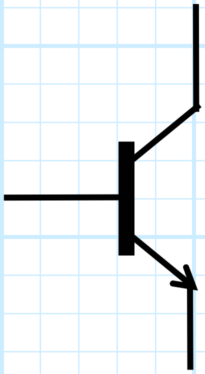


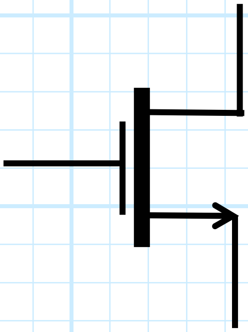
Its application to **digital** devices and machines get all the press, but they are of course equally invaluable for **analog** applications, including RF and microwave.

Specifically, a transistor allows for us to generate **signal gain**—to transfer energy from a DC source and apply it to an RF signal, without otherwise distorting that signal.

Because of this, we can build two crucial items for most microwave systems: a microwave **amplifier** and its **unstable** cousin, the microwave **oscillator**.

This microwave devices are made from the usual suspects: Bipolar Junction Transistors (**BJTs**) and Field Effect Transistors (**FETs**).





However, we find in microwave applications that these transistors are often (but not always) formed from a different semiconductor **material** than the usual **Silicon** (Si).

Instead, we find that microwave transistors are often made using the semiconductor material **Gallium Arsenide** (GaAs).

Gallium Arsenide has many practical problems associated with it, but it simply has higher carrier mobility than does Silicon. In other words GaAs is ***faster*** than Si.

Thus, if we wish to build amplifiers and oscillators at the **highest** microwave frequencies (e.g., >18 GHz), we must use **GaAs**!

Among the problems with GaAs is that we **cannot** construct Metal **Oxide** Semiconductor FETs (MOSFETs), devices which are the most prevalent technology used in digital applications.

As a result, GaAs FETs come in a variety of designs and types, with perhaps the most prevalent being the MEtal Semiconductor FET (MESFET). A full description of micro wave transistor types is found on page 522 of your book.

Transistors as Gain Elements

A **quiz**!

1. To construct a small-signal amplifier, a **BJT** must be **DC biased** to which **mode**:

A. Active B. Triode

C. Cutoff D. Saturation

2. To construct a small-signal amplifier, a **FET** must be DC biased to which mode:

A. Active B. Triode

C. Cutoff D. Saturation

3. The **BJT** amplifier **configuration** that typically provides the highest open-circuit **voltage gain** is the:

A. common emitter B. common source

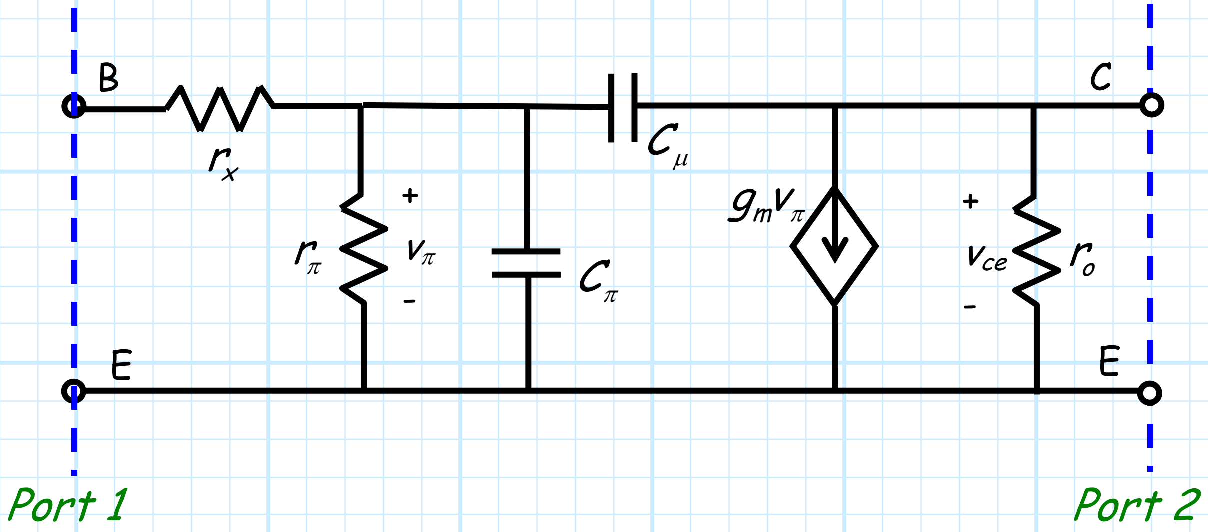
C. common base D. common collector

E. common drain F. common gate

4. The **FET** amplifier configuration that typically provides the highest open-circuit voltage gain is the:

A. common emitter	B. common source
C. common base	D. common collector
E. common drain	F. common gate

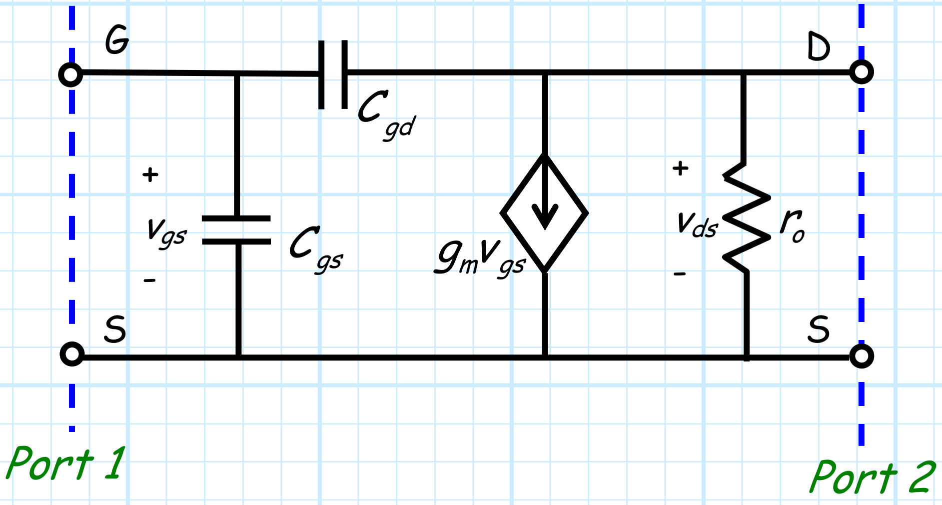
The high-frequency small-signal (hybrid-pi) **model** for a **BJT** in the **common emitter** configuration is:



Here the values g_m, r_π, r_o are all **small-signal parameters**—values determined in part by the **DC bias** of the transistor.

The values r_x, C_π, C_μ are **parasitic elements**. Generally too small to consider for low-frequency operation, these value make a great difference at microwave frequencies!

Likewise, the high-frequency small-signal **model** for a **MOSFET** device in a **common-source** configuration is:

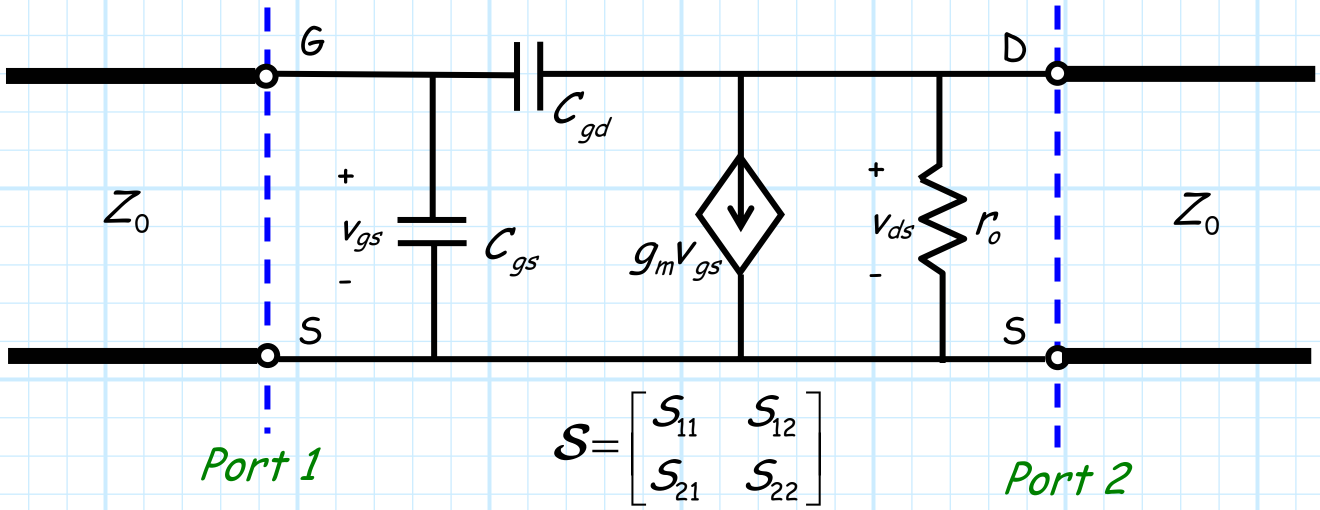


where again g_m, r_o are small-signal parameters and C_{gs}, C_{gd} are parasitic elements.

Note that each of these circuits form a **two-port network!**

This network we will define as a **gain stage**, where port 1 is the **input** port and port 2 the **output** port.

Since they are two-port networks, we can describe them with a **scattering matrix**:



$$\mathcal{S} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix}$$

We can determine this scattering matrix either by direct **measurement** (using a network analyzer) or by **analysis** of the small-signal circuit.

Either way, we will find that this two-port network has some **interesting** characteristics!

1. We will typically find that both $|S_{11}|$ and $|S_{22}|$ are relatively large (e.g. $0.6 < |S_{11}| < 1.0$).

2. We will typically find that $|S_{12}|$ is relatively small (e.g, $|S_{12}| = 0.01$.

3. We will typically find that $|S_{21}|$ is much greater than one (e.g, $|S_{12}| = 3.5$)!

As a result, it is evident that this **gain stage** is:

a. **not** matched (just look at $|S_{11}|$ and $|S_{22}|$)

b. **not** reciprocal (just look at $|S_{12}|$ and $|S_{21}|$)

c. **not** lossless—but neither is it lossy ($|S_{11}|^2 + |S_{21}|^2 > 1$)!

This gain stage is an **active** device—the DC bias supplies energy that is converted into RF signal power at the output port. In other words, **more** RF power flows **out** than flows **in**!

Q: *So, is this gain stage a* ***microwave amplifier****?*

A: It **could** be used as such, but generally we start with this **gain stage** and then carefully design **two** additional networks—one for the **input** and one for the **output**. These three networks together form a typical (low-power) microwave amplifier!