Analog electronics

Third lecture

Characteristic Curves, Hybrid Parameters, Equivalent Circuit

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Third stage

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2022- 2023

Outline

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3.1 Characteristic curves

The I-V Characteristic Curves, which is short for Current-Voltage Characteristic Curves or simply I-V curves of an electrical device or component, are a set of graphical curves which are used to define its operation within an electrical circuit. As its name suggests, I-V characteristic curves show the relationship between the current flowing through an electronic device and the applied voltage across its terminals. I-V characteristic curves are generally used as a tool to determine and understand the basic parameters of a component or device and which can also be used to mathematically model its behavior within an electronic circuit. But as with most electronic devices, there are an infinite number of I-V characteristic curves representing the various inputs or parameters and as such we can display a family or group of curves on the same graph to represent the various values. Figure below show characteristic curves of an ideal resistor.

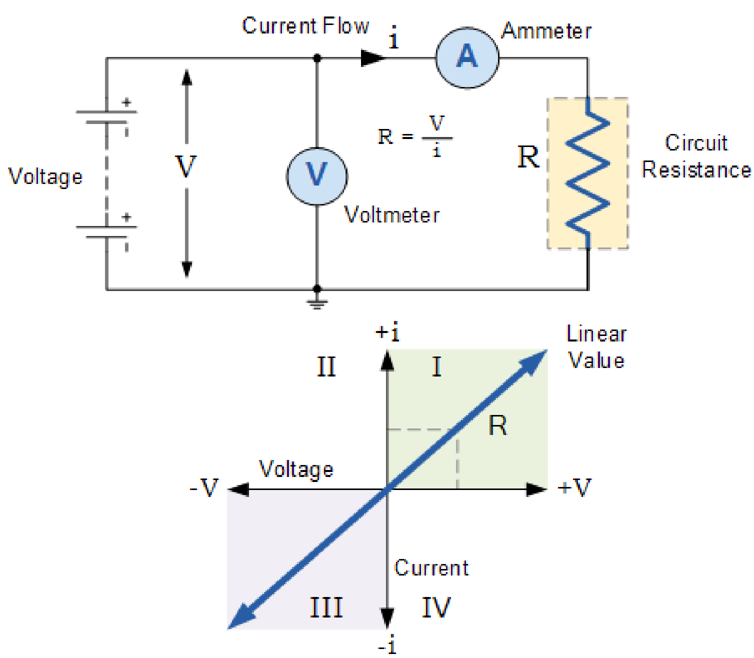

Figure 1: Characteristic curves of an ideal resistor circuit.

Figure below show Characteristic Curve of a Diode.

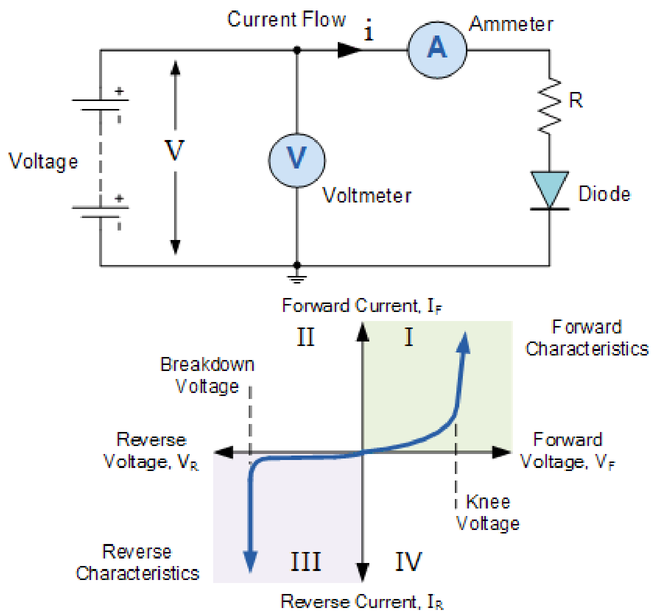

Figure 2: Characteristic curves of an diode circuit..

Characteristic Curves of Transistor

Figure 3 below shows a simple circuit of a transistor, in which the 1.5 V battery and the resistance RB determine the base current IB, and the 24 V battery together with RC define the collector current IC. We are interested in determining the variation of the collector current IC. This current can be varied either by changing the base current IB or the collector-emitter voltage VCE (the voltage between the collector C and the emitter E). The base current can be varied by the variable resistor RB.

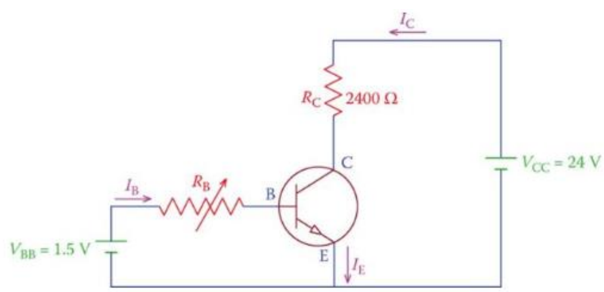

Figure 3: Simple circuit for a transistor operation.

The characteristic curves of a transistor provide the relationship between collector-emitter voltage and collector current for different values of the base current. Because there are two parameters that affect IC, a set of individual curves shown together denote various operating conditions.

A typical curve is shown in Figure 4a, and a set of these curves are depicted in Figure 4b. Each individual curve depicts the variation of IC versus the value of collector-emitter voltage (VCE) for a fixed value of base current IB.

Cut Off Region: When **IB is zero**, a transistor is **cut off**, and it does not conduct no matter how much voltage is applied to the collector; any collector current is due to leaks, is very small, and is negligible. In both Figure 4a and b, the curve corresponding to IB = 0 is exaggerated for clarity. The area under the curve corresponding to IB = 0, shaded in Figure 4a, represents the region where a transistor is cut off and is not conducting.

Saturation Region: For each nonzero value of IB, the collector current starts from zero when the collector-emitter voltage is zero. A transistor starts conducting and the collector current increases rapidly when VCE > 0. The area around this abrupt change in IC also shaded in Figure 4a, corresponds to when a transistor is in saturation.

Saturation implies that the collector current has reached its maximum value for that collector-emitter voltage and cannot increase further by increasing the base current IB. For example, consider point M corresponding to VCE = VM in Figure 4b. For this point, IC has reached its maximum and cannot be increased by increasing IB. In contrast, an increase in IB can move point N to N′, both corresponding to a collector-emitter voltage VN.

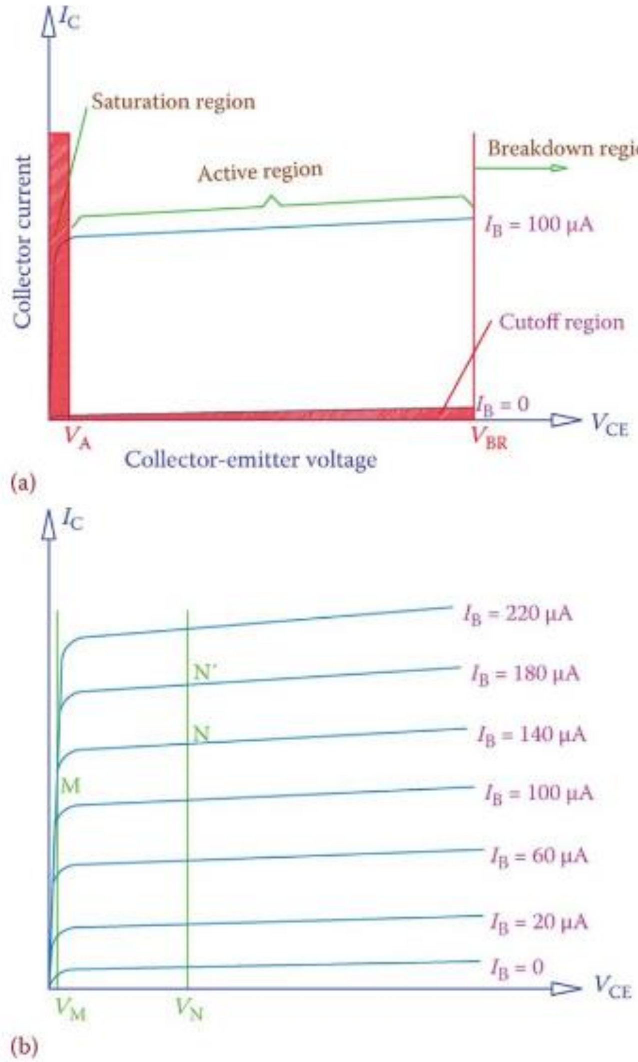

Figure 4: Collector current versus collector voltage characteristic curve of a transistor. (a) For one value of base current. (b) For multiple values of base current.

Saturation (in a transistor): The state of a transistor at which the collector current has reached its maximum value for the present collector-emitter voltage, and cannot increase further by only increasing the base current IB.

Active Region: When saturated, a transistor cannot operate as expected. In normal operation, transistors function in the active region, the area that the characteristic curve is a segment of an almost horizontal straight line. In this region increasing collector-emitter voltage has little effect on the collector current. In other words, the transistor exhibits a large resistance in this region, so that increasing voltage has little effect on the current through it. This resistance is variable because it depends on the value of IB (for each value of IB the ratio VCE/IC is different).

Active region: An area in the characteristic curve of a transistor, in terms of collector-emitter voltage and collector current values that the transistor can function. If any of these values falls outside of its range a transistor falls in the saturation region or cutoff region and cannot function (see Figure 4a).

Breakdown voltage: Voltage at which a semiconductor device changes behavior or gets damaged.

3.2 hybrid parameters

For analyzing circuits containing active devices such as transistors, it is more convenient to think of the input terminals of a four-terminal coupling network as an equivalent voltage source and the output terminals as a Norton-equivalent current source. We then describe the coupling network in terms of four hybrid parameters (h-parameters).

To find the open-circuit voltage of the equivalent source at input terminals (port 1) in Figure 5(a), we feed V2 into the output terminals (port 2). In this circuit, we consider the equivalent source to be a voltage-controlled voltage source. The parameter that represents the fraction of the output voltage appearing at the input terminals is V1/V2, which is a ratio without units. This parameter is the open-circuit reverse- voltage ratio, h12.

Since we are treating the dependent source as a voltage-controlled voltage source, we short-circuit the output terminals while we measure the input voltage and current, as shown in Figure 5(b). The parameter h11 is V1/I1, which is expressed in ohms and represents the short-circuit input impedance of the network. Since h12V2 is a voltage source, the equivalent input circuit for the coupling network shows the dependent voltage source and input impedance in series, as in Figure 5(c).

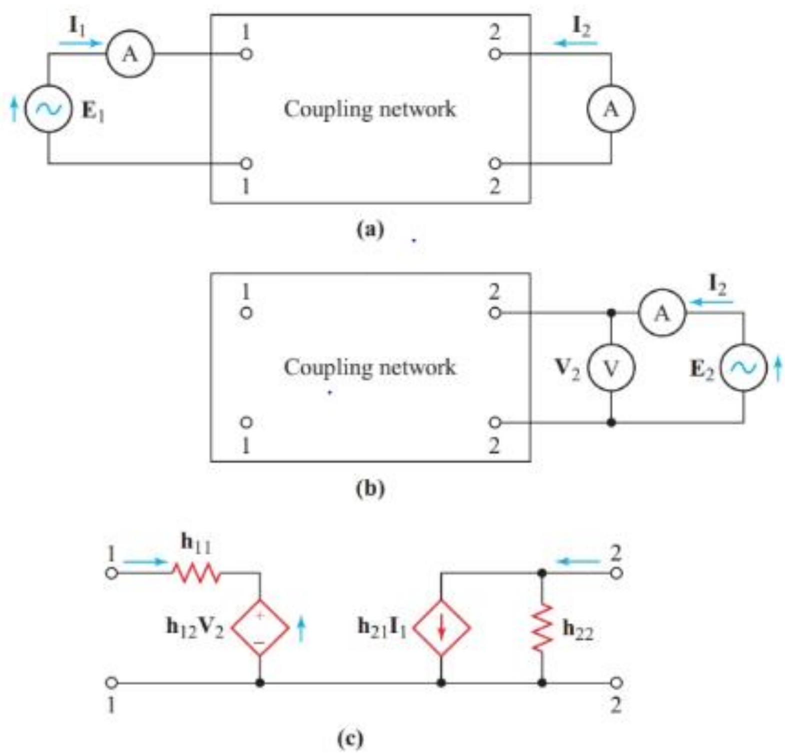

Figure 5: Figure 2 Finding the Norton-equivalent output circuit of a four-terminal network: (a) short-circuit forward current; (b) output admittance; (c) complete hybrid parameters.

To determine the short-circuit current of the Norton-equivalent source at the output terminals (port 2) in Figure 5(a), we feed I1 into the input terminals and short-circuit the output terminals through the ammeter measuring I2. As long as the network impedances are linear (independent of voltage and current), I2 will be a constant fraction of the input current I1. The ratio I2/I1 is the short-circuit forward-current ratio, h21.

Short-circuit input impedance:

$$h_{11} = \frac{V_1}{I_1} \text{(with } V_2 = 0\text{)} \qquad (1)$$

Open-circuit reverse-voltage ratio:

$$h_{12} = \frac{V_1}{V_2} \text{(with } I_1 = 0\text{)}\, Open - Circuit \qquad (2)$$

Short-circuit forward-current ratio:

$$h_{21} = \frac{I_2}{I_1} \text{(with } V_2 = 0\text{)}\, Short - Circuit \qquad (3)$$

Open-circuit output admittance:

$$h_{22} = \frac{I_2}{V_2} \text{(with } I_1 = 0\text{)} \qquad (4)$$

The two unknowns in these equations are I1 and V2.

$$h_{11} I_1 + h_{12} V_2 = E_1 \qquad (5)$$
$$h_{21} I_1 + h_{22} V_2 = I_2 \qquad (6)$$

The transistor amplifier equivalent circuit of Figure 6 is a typical example of hybrid parameters.

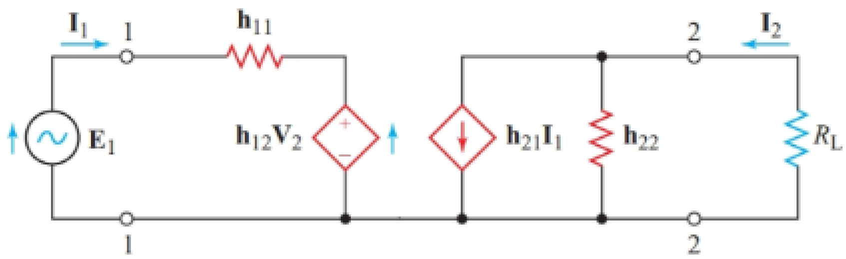

Figure 6: Hybrid parameters of a simple transistor amplifier.

3.3 Equivalent Circuit

Equivalent Circuit of transistor: An electric circuit made up of the basic elements resistance, inductance, and capacitance in a simple arrangement such that its performance would duplicate that of a more complicated circuit or network

A network of voltage sources, current sources, and resistors can be replaced by an equivalent circuit which has identical terminal properties (I-V characteristics) without affecting the operation of the rest of the circuit.

Let us identify a pair of nodes, say node a and b, such that the circuit can be partitioned into two parts as shown in figure 7.

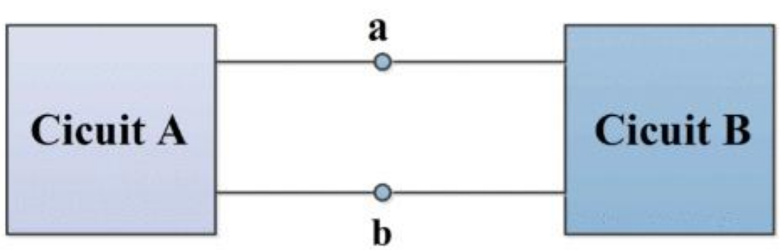

Figure.7: Circuit partitioned into two parts

Furthermore, suppose that circuit A contains no dependent source that is dependent on a variable in circuit B and vice versa. Then, we can model circuit A by an appropriate independent voltage source, call it Voc that is connected in series with an appropriate resistance, call it RTH. This series combination of a voltage source and a resistance is called the equivalent of circuit A. in other words, circuit A in figure 7 and the circuit in the shaded box in figure 8 have the same effect on circuit B. Circuit B (which is often called a load) may consist of many circuit elements, a single element (a load resistor), or no element.

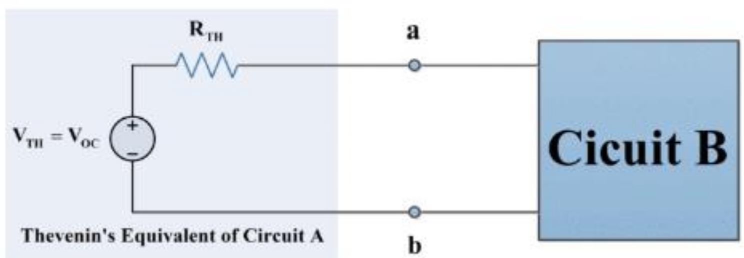

Figure.8: Equivalent Circuit

3.4 References

Electronics principles (fourth edition) by Malvino.