Lecture 5A – Graphical Analysis

The static characteristic. The dynamic characteristic. The transfer characteristic. Graphical analysis. The small signal diode model. The large signal diode model.

The Static Characteristic

Any linear resistive circuit can be reduced to an equivalent circuit containing one source and one resistor. When the source is a voltage, the reduction is obtained using Thévenin's theorem.

Use Thévenin's Theorem to simplify the *linear* parts of a circuit

Consider the following circuit:

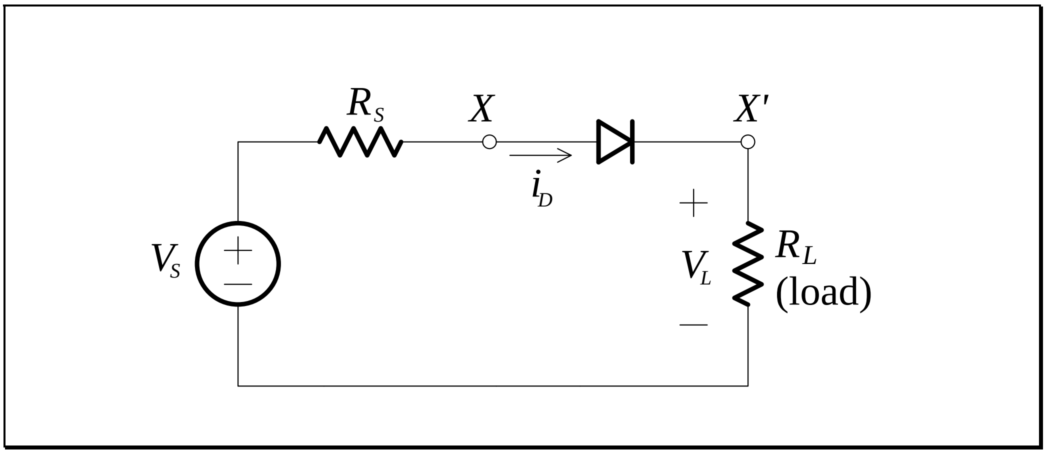

Figure 5A.1

The equivalent circuit (as far as the diode is concerned) can be found using Thévenin's theorem. *(Look into the circuit from the diode terminals. What do you see?)* The Thévenin equivalent circuit for the diode is:

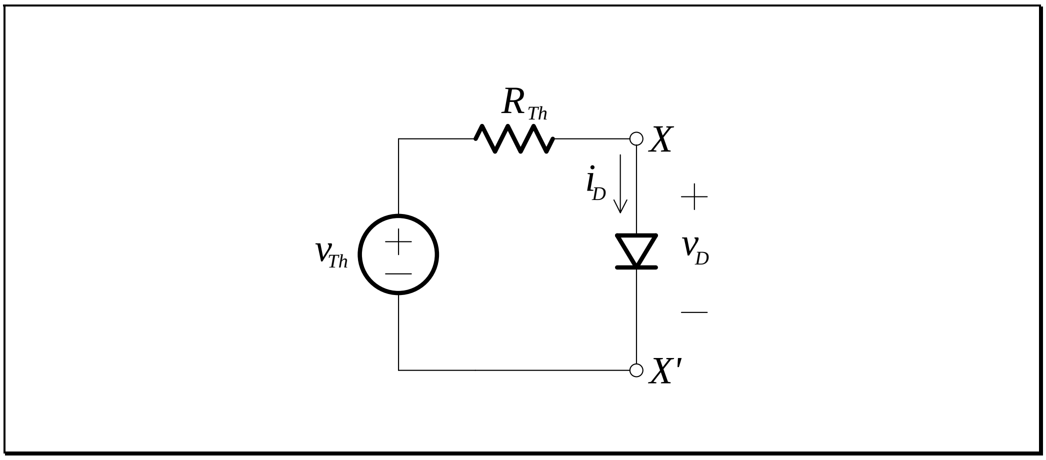

Figure 5A.2

Verify that the Thévenin voltage and Thévenin resistance in this case are given by:

$$V_{Th} = V_s \tag{5A.1a}$$

$$R_{Th} = R_S + R_L \tag{5A.1b}$$

KVL around the loop gives:

$$v_D = V_{Th} - R_{Th} i_D \tag{5A.2}$$

which, when rearranged to make i_D the subject, gives:

$$\boxed{i_D = -\frac{1}{R_{Th}}\left(v_D - V_{Th}\right)} \tag{5A.3}$$

The "load line" is derived using linear circuit theory

When graphed, we call it the load line. It was derived from KVL, and so it is always valid. *(Compare with the load line in magnetics which was obtained from Ampère's Law)*.

The load line gives a relationship between i_D and v_D that is determined purely by the external circuit. The diode's characteristic gives a relationship between i_D and v_D that is determined purely by the geometry and physics of the diode.

The “load line” and device characteristic intersect at the Q point

Since both the load line and the characteristic are to be satisfied, the only place this is possible is the point at which they meet. This point is called the quiescent point, or Q point for short. It is only valid for DC conditions (*Why?*):

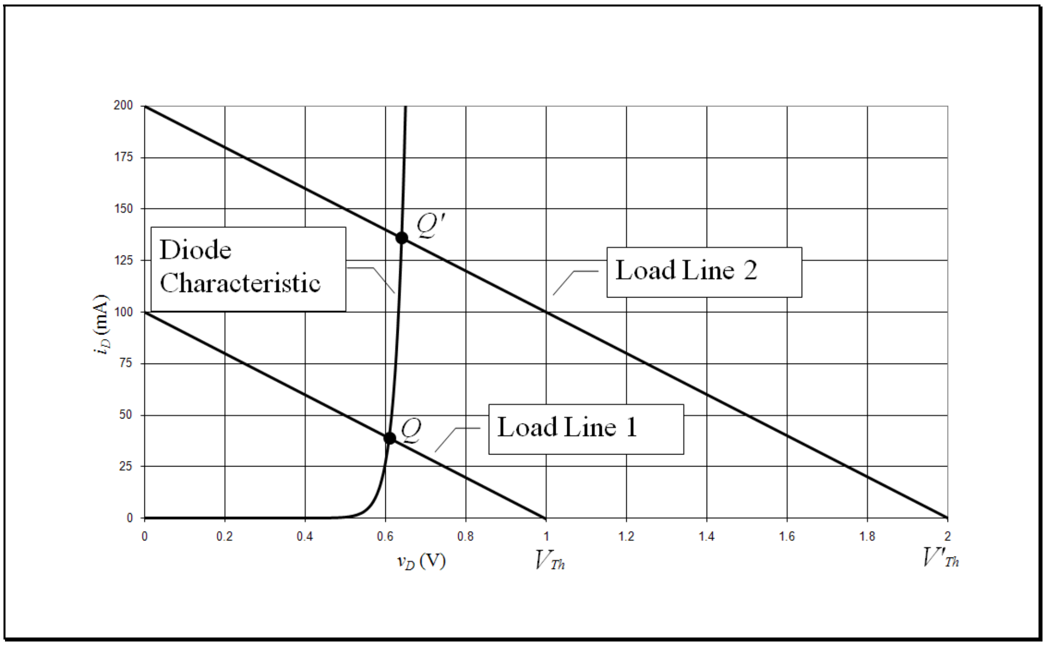

Figure 5A.3 – Graphical Analysis Using a Load Line

If the source voltage is increased, the Thévenin voltage changes to V'_{Th} and the operating point to Q' (the DC load line is shifted to the right).

The Dynamic Characteristic

The dynamic characteristic gives directly the relationship between the diode current and the Thévenin voltage ($i_D \sim V_{Th}$):

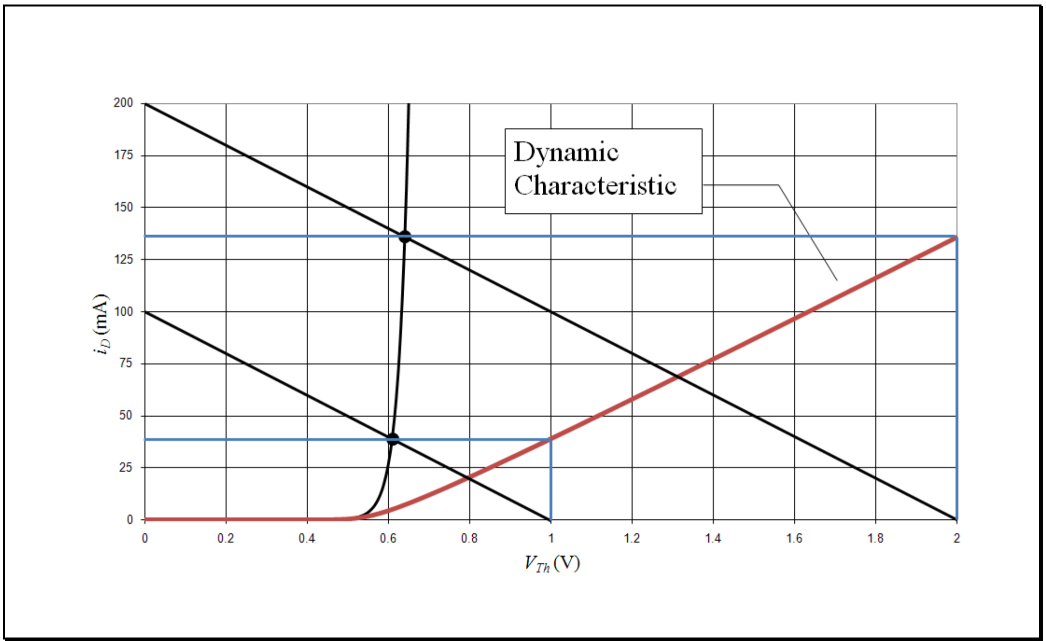

Figure 5A.4 – Graphical Analysis Using the Dynamic Characteristic

The Transfer Characteristic

A transfer characteristic ($v_L \sim v$) is obtained by graphing the output voltage versus the input voltage (it shows how the input is transferred to the output). It is obtained directly from the dynamic characteristic since $v_L = R_L i_D$.

Graphical Analysis

To analyse the effect of applying a voltage that contains a DC and AC component, we generally have to use a graphical technique:

We can use graphical analysis on non-linear systems where time is a variable

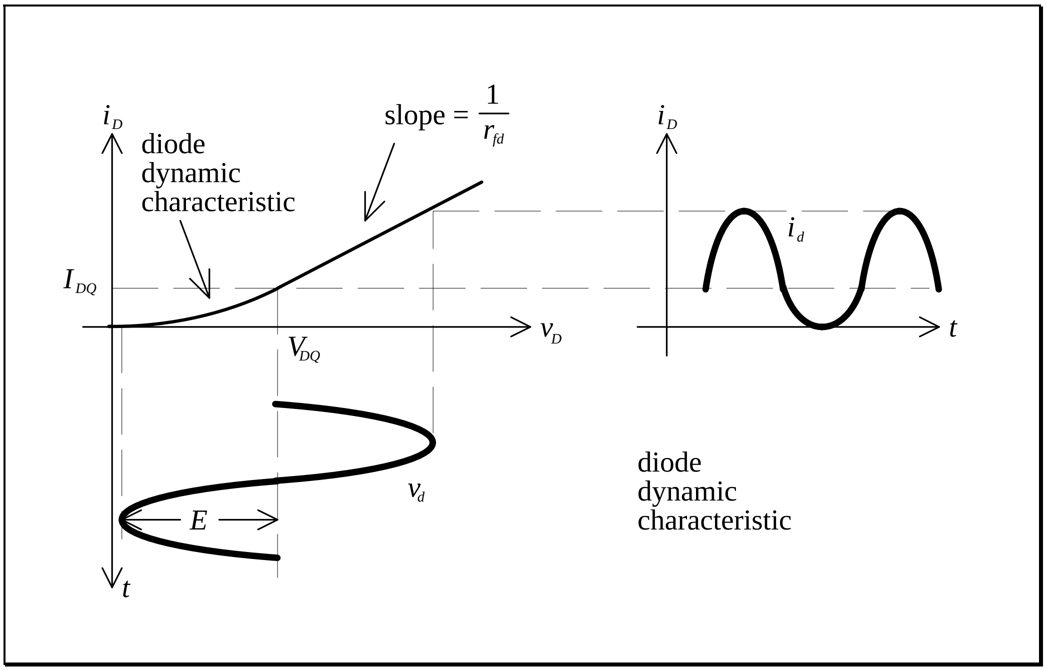

Figure 5A.5

From this, we can determine the total current in the circuit, as well as the voltage across the diode:

$$v_D = V_{DQ} + r_{fd} i_d \tag{5A.4}$$

Note that $V_{DQ} \neq E$ in Figure 5A.5.

The Small Signal Diode Model

With "small signals", we can linearise a non-linear element and then use superposition

If the voltage contains an alternating component that is very small relative to the DC voltage, then the circuit can be analysed using the principle of superposition. The AC component is termed "a small signal". Superposition can only be performed when the system is linear. For the small signal, a linear diode model is used. For a source of:

$$v_s = E_s + \hat{v}_s \sin \omega t \tag{5A.5}$$

the Thévenin equivalent circuit can be split into two separate circuits:

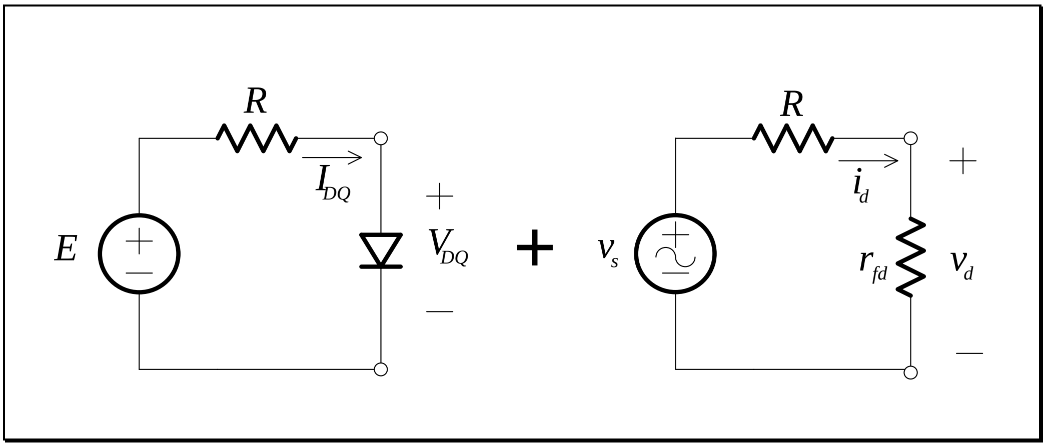

Figure 5A.6

The AC equivalent circuit contains small signal parameters of the diode equivalent circuit. The resistance is the inverse of the slope at the *Q* point, the voltage is the voltage axis intercept of the tangent at the *Q* point.

For the model to be valid, the AC signal must be small, so that the tangent to the curve approximates the curve. This is the small signal approximation. You can see the effects of having a large signal using the dynamic or transfer characteristic.

We determine the voltage across the load and the current through it by:

$$i_L = I_{DQ} + i_d \tag{5A.6a}$$

$$v_L = R_L i_L \tag{5A.6b}$$

The Large Signal Diode Model

With an alternating source only, we can analyse effects such as cut-in angle using a large signal equivalent circuit of the diode:

A suitable linear model of the diode can be used for AC sources

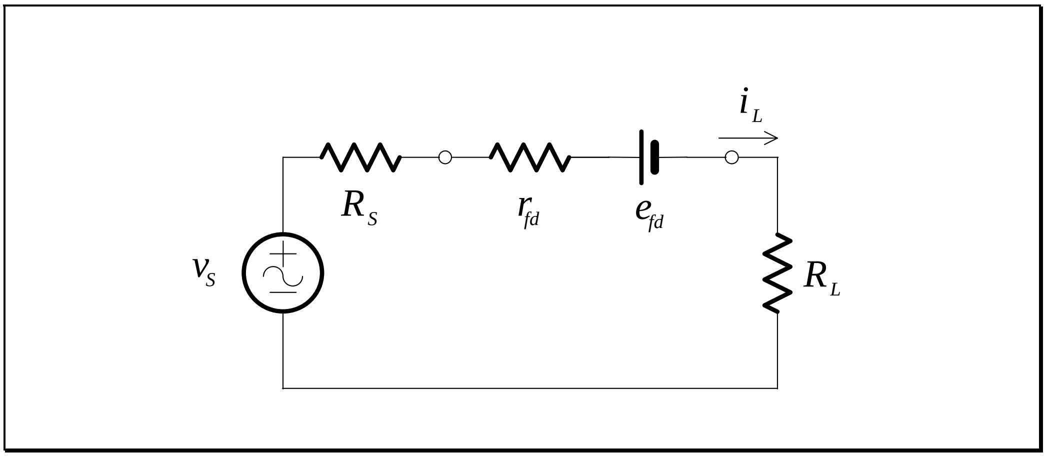

Figure 5A.7

Our model is valid only when the diode is conducting, so we will examine the circuit when the diode just reaches the threshold of conduction (but is still zero).

At this point:

$$i_L = \frac{\hat{v}_S \sin \omega t - e_{fd}}{R_S + R_L + r_{fd}} = 0 \tag{5A.7}$$

which means that:

$$\hat{v}_S \sin \omega t = e_{fd}$$

$$\omega t = \gamma = \sin^{-1}\left(\frac{e_{fd}}{\hat{v}_S}\right) \tag{5A.8}$$

For example, if $\hat{v}_S = 5\text{ V}$ and $e_{fd} = 0.6\text{ V}$, then $\gamma = \sin^{-1}(0.6/5) = 6.9°$. This is a small angle, but it is still noticeable on a DSO. The angle gets bigger for a smaller amplitude voltage source.

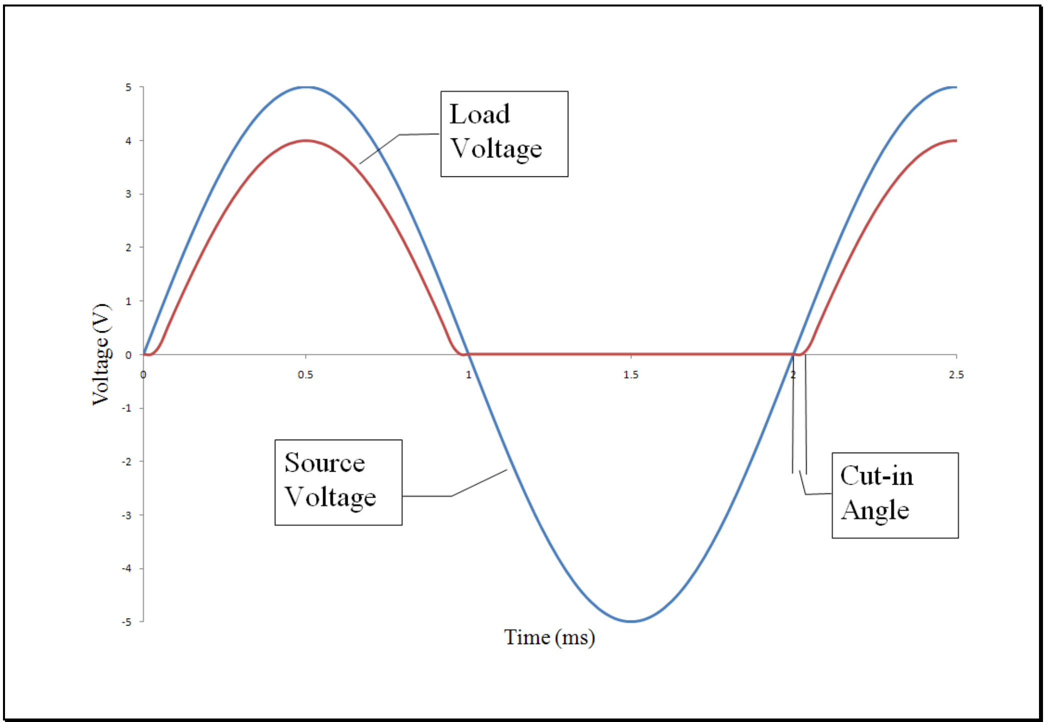

Figure 5A.8

Summary

- We can use Thévenin's theorem to simplify the linear parts of a circuit. Analysis of the linear circuit leads to the load line, which can then be graphed on a nonlinear circuit element's characteristic to obtain the operating point (also called the *Q*-point).

- We can create dynamic characteristics and transfer characteristics of circuits with nonlinear elements using graphical techniques.

- We can conduct separate DC and AC analyses of a circuit if the circuit is linear, using the principle of superposition. For nonlinear circuit elements, we first find the DC operating point, then linearise the nonlinear element's characteristic to obtain a "small signal" model. We can then conduct AC circuit analysis. The analysis will only be valid for small deviations about the DC operating point.

References

Sedra, A. and Smith, K.: *Microelectronic Circuits*, Saunders College Publishing, New York, 1991.