Engineering 1620: Small Signals and Algebraic Notation

Nodes at which the potential is the sum of a DC term plus a much smaller time-dependent part are ubiquitous in systems that do linear amplification and filtering. Such signals are like foam on the ocean or bubbles on a river. While most of the water is still, the interesting view is the result of the motion of waves on the surface. For example, if you want to know if a powerboat went by recently, you look for its wake and not anything deeper. Yet the wake and the powerboat would not be there without all the water to support them. In electrical systems, the DC (still water) conditions are needed to supply power to amplify the signal but the information is in the time-dependent (waves) part. Frequently in electronic systems, we rely on the time-dependent "wiggle" in the signal to be "small" enough that the system can be treated as a linear one. We will have to treat the criterion for "small" as an empirical matter to be estimated for each new system.

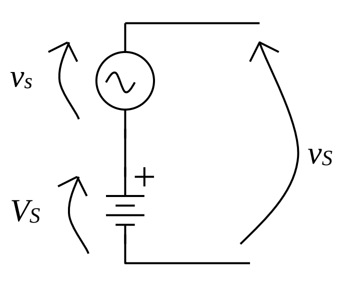
I have found that students frequently miss the idea behind the notation that is used to describe such situations. There are several variants on the standard notation and the idea is something easy to miss in Razavi. Here is a working summary of the customary mathematical notation! I will attempt to be careful to follow it.

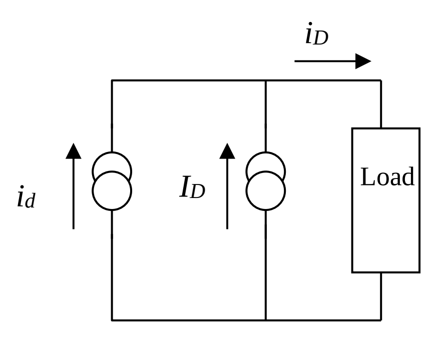
Variable	Subscript	Example	Meaning
Lowercase	Lowercase	v_s or i_s	A "small" time-dependent voltage or current. Linear circuit models that only simulate operations with these voltages are said to be "small-signal" models.
Uppercase	Uppercase	V_S	A DC (steady) voltage or current of any size. May drift with time but that change does not convey any information.
Lowercase	Uppercase	v_{OUT}	A total signal that is the sum of a DC and a time-dependent part.
Uppercase	Repeated Uppercase	V_{DD} or I_{CC}	A power supply voltage or current; the subscript denotes what the power is for (D for drains of MOSFETS, C for collectors, etc.).

Algebraically, these rules take on such forms as:

$$v_S = V_S + v_s \text{ and } i_D = I_D + i_d \ .$$

In graphical forms, these rules look like:





Note that my current source symbols do not do a good job of distinguishing between the two source types (time dependent and time independent). Only the mathematical symbols do.

In the same vein, it is customary to use uppercase letters to assign reference designators (physical names) to components, *e.g.*, R1 or C3 for a resistor or capacitor. If the name has a subscript, it too is uppercase. However, active devices are often assigned resistances or capacitances between model nodes that are not distinct physical objects but represent differential changes to small voltage changes. These customarily are written with lowercase characters and lowercase subscripts. For example, the differential forward bias resistance for a diode might be written as r_d. It is a model parameter and relates to the DC current through the diode, I_D, as $r_d = \frac{nkT}{qI_D}$.