ELECTRONICS LAB I EE321

INTRODUCTION

Voltage Gain:

$A_v = \frac{v_O}{v_I}$ $A_{v(dB)} = 20\log\lvert A_v \rvert$	v_O = output voltage v_I = input voltage

Power Gain:

$A_p = \frac{P_L}{P_I} = \frac{v_O\, i_O}{v_I\, i_I} = A_v A_i$ $A_{p(dB)} = 20\log A_p$	P_L = load power P_I = input power

Current Gain:

$A_i = \frac{i_O}{i_I}$ $A_{i(dB)} = 20\log\lvert A_i \rvert$	i_O = output current i_I = input current

Transistor Bias: difference in potential between base and emitter.

***Q*-Point:** (also quiescent point, dc bias point, operating point) is the center of the **transfer characteristic** (operating voltage range) at which it is desirable to **bias** the transistor.

The **mean** is the average value.

% ERROR in measurement.

$$\frac{\text{value of one division}}{\text{value of measurement}} \times 100 = \text{percent error}$$

$$\frac{1}{\text{quantity counted}} \times 100 = \text{percent error}$$

RMS error is the average error (in engineering units), also called the **standard deviation**. $e_{rms} = \sqrt{\left(\frac{1}{N}\right)^2 \sum_{i-1}^{N} (m_i - \overline{m})^2}$	ε_{rms} = rms error [eng. units] N = number of samples m_i = sample [eng. units] $\overline{m}$ = mean value (avg. value) [eng. units]

RESISTOR COLOR CODE					
FIRST 2 BANDS		THIRD BAND		FOURTH BAND	
COLOR	VALUE	COLOR	MAGNITUDE	COLOR	TOLERANCE
black	0	silver	0.XX Ω	none	±20%
brown	1	gold	X.X Ω	silver	±10%
red	2	black	XX Ω	gold	±5%
orange	3	brown	XX0 Ω		
yellow	4	red	X.X Ω		
green	5	orange	XX kΩ		
blue	6	yellow	XX0 kΩ		
purple	7	green	X.X MΩ		
gray	8	blue	XX MΩ		
white	9				

Capacitor Code: 3-digit code. The first two digits are the significant digits. The third digit specifies the number of zeros to follow the result, giving the value in picofarads. For example:

103 = 10 & 000 = 10000 pF = 10 nF = .01 mF.

DIGITAL SIGNAL ANALYZER (DSA)

The **sample rate** must be at least two times the frequency. The sample rate is the number of samples taken per second or **frame size / total sample time**.

The **frame size** is required by the software to be some power of two. This is the number of segments that the sample is broken into.

The **total sample time** must be some multiple of the period (no fractions of a period).

$$\text{total sample time} = \frac{\text{frame size}}{\text{sample rate}}$$

$$\text{total sample time} = \frac{1}{\text{frequency}} \times \text{number of periods}$$

$$\boxed{\frac{\text{frame size}}{\text{sample rate}} = \frac{\text{number of periods}}{\text{frequency}}}$$

Fourier Series: Any periodic function of period T can be expressed as a sum of sinusoids. The Fourier Series is only valid for functions that are truly periodic--that never end.

$$v(t) = A_o + \sum_{m=1}^{\infty}\left[A_m \sin\left(\frac{2\pi m}{T}\right) + \phi_m\right]$$

where $A_o = \frac{1}{T}\int_0^T v(t)\,dt$ = the DC level or average value of the function. A_0 is the DC level. A_m is the amplitude of the m^{th} harmonic. ϕ_m is the phase of the m^{th} harmonic.

$$A_m = \sqrt{\left(\frac{1}{T}\int_0^T v(t)\sin(2m\pi t/T)\,dt\right)^2 + \left(\frac{1}{T}\int_0^T v(t)\cos(2m\pi t/T)\,dt\right)^2}$$

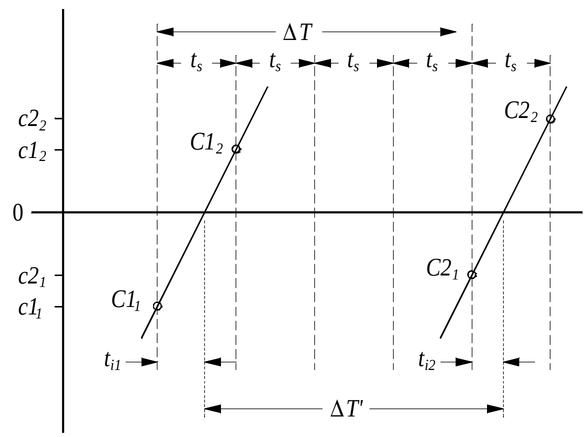
$$\phi = \arctan\frac{\left(\frac{1}{T}\int_0^T v(t)\cos(2m\pi t/T)\,dt\right)}{\left(\frac{1}{T}\int_0^T v(t)\sin(2m\pi t/T)\,dt\right)}$$

THE OSCILLOSCOPE

MEASURING PHASE SHIFT:

Finding the **phase shift** on the scope: $$\phi = \frac{\Delta t}{T} \times 360 \text{ degrees}$$	ϕ = phase shift [degrees] Δt = difference in time of the zero-crossings of two waveforms [seconds] T = period [seconds]

Finding **phase shift** by **interpolation**:



where:

- t_s = the sample period of the scope [seconds]
- t_{i1} = the horizontal distance from cursor position $C1_1$ to the zero crossing of the first wave [seconds]
- t_{i2} = the horizontal distance from cursor position $C2_1$ to the zero crossing of the second wave [seconds]
- $\Delta T'$ = the actual offset of the two waves [seconds]
- ΔT = the offset of the two waves as measured by the first-selected cursor positions [seconds]
- $C1_1$ = the first-selected position of Cursor 1
- $C2_1$ = the first-selected position of Cursor 2
- $C1_2$ = the second-selected position of Cursor 1
- $C2_2$ = the second-selected position of Cursor 2
- $c1_1$ = the vertical dimension of the first-selected position of Cursor 1 [volts]
- $c2_1$ = the vertical dimension of the first-selected position of Cursor 2 [volts]
- $c1_2$ = the vertical dimension of the second-selected position of Cursor 1 [volts]
- $c2_2$ = the vertical dimension of the second-selected position of Cursor 2 [volts]

$$t_{i1} = \frac{|c1_1|}{|c1_1| + |c2_1|} t_s \qquad t_{i2} = \frac{|c2_1|}{|c2_1| + |c2_2|} t_s$$

$$dT' = dT - t_{i1} + t_{i2}$$

DETERMINING THE TIME CONSTANT τ:

Method 1: Where the voltage can be observed reaching the steady state value:

1) Place cursor C2 where the voltage appears to have reached the steady state. It remains here.
2) Place cursor C1 at another point on the curve.
3) Record ΔV_1 and ΔT_1.
4) Move C1 to another position along the curve.
5) Record ΔV_2 and ΔT_2.
6) Solve for τ

$$\ln \frac{\Delta V_2}{\Delta V_1} = \frac{-|\Delta T_1 - \Delta T_2|}{\tau}$$

Method 2: This method can be used even when the steady state voltage value is not visible:

1) Place cursor C2 on the curve near its midpoint relative to the *x*-axis. It remains here.
2) Choose a value for ΔT such that cursor C1 may be placed this distance from C2 on either side.
3) Using C1, determine values ΔV_1 and ΔV_2 found by placing C1 ΔT from the left and ΔT from the right of C2.
4) ΔV_1 and ΔV_2 are interchangeable, affecting only the sign of the result. Use the formula to find τ:

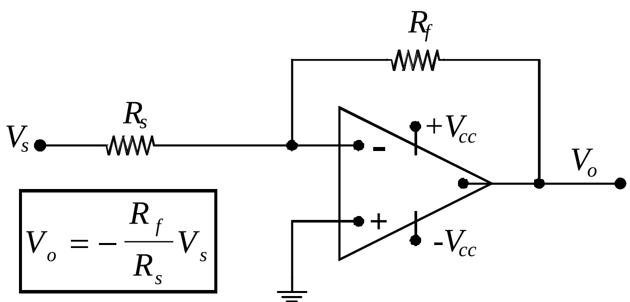
$$\ln \frac{\Delta V_2}{\Delta V_1} = \frac{-\Delta T}{\tau}$$

OP AMPS

CHARACTERISTICS OF THE IDEAL OP AMP

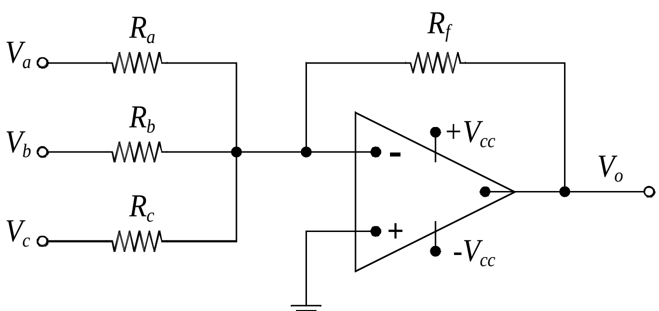
- The difference between the voltages at the inputs (v_2 - v_1) multiplied by the open-loop gain *A* yields the op amp output $A(v_2 - v_1)$.
- The input impedance is infinite.
- The input current is zero.
- The output impedance is zero.
- The output current is whatever is required to maintain the output voltage.
- The output is in phase with the signal at the positive input.
- Infinite **common-mode rejection**, the rejection of identical signals at the + and - inputs.
- The open-loop gain *A* is equal for all frequencies.
- The open-loop gain *A* is infinite.

INVERTING AMPLIFIER



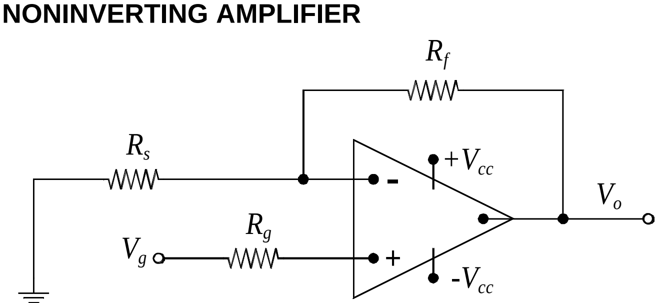
$$V_o = -\frac{R_f}{R_s} V_s$$

INVERTING SUMMING AMPLIFIER



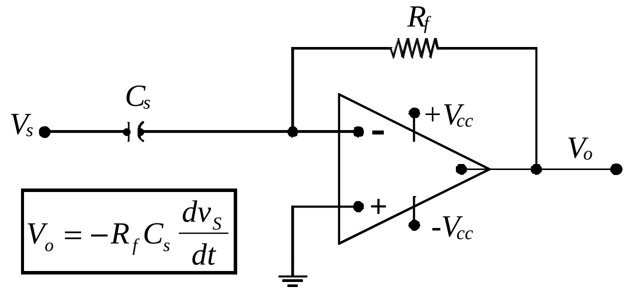
$$V_o = -\left(\frac{R_f}{R_a} V_a + \frac{R_f}{R_b} V_b + \frac{R_f}{R_c} V_c\right)$$

NONINVERTING AMPLIFIER



$$V_o = \frac{R_s + R_f}{R_s} V_g$$

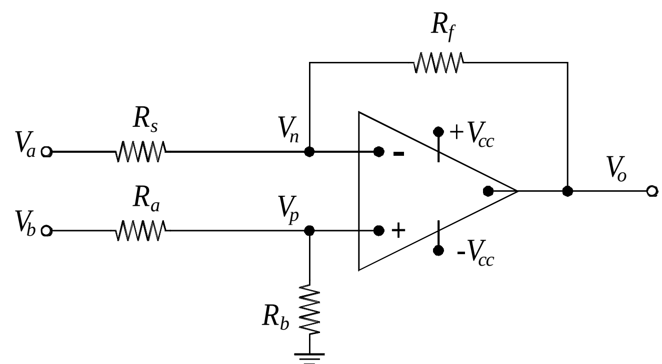
DIFFERENTIATING AMPLIFIER



$$V_o = -R_f C_s \frac{dv_S}{dt}$$

$$\phi = +90°$$

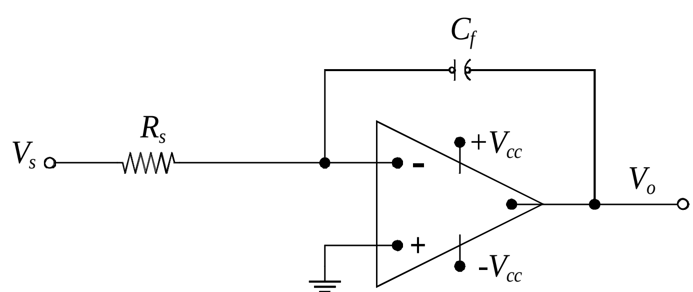
DIFFERENCE AMPLIFIER



$$V_n = V_p = V_b \frac{R_b}{R_a + R_b}$$

$$\frac{V_n - V_a}{R_s} + \frac{V_n - V_o}{R_f} = 0$$

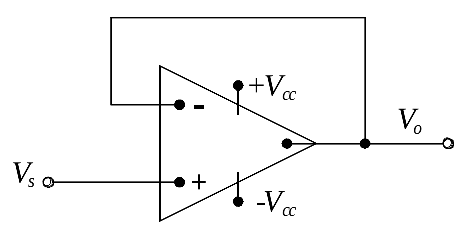
INTEGRATING AMPLIFIER



$$V_o = -\frac{1}{R_s C_f} \int_{t_o}^{t} V_s \tau d\tau + V_o(t_o)$$

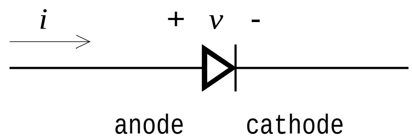
$$\phi = +90°$$

FOLLOWER OR UNITY GAIN AMPLIFIER



DIODES

FORWARD-BIASED DIODE



CHARACTERISTICS OF THE IDEAL DIODE

- If v is negative, the diode is *reversed biased* and acts as an open circuit.
- If a positive current is applied in the direction shown, the diode is *forward biased* and acts like a closed switch with $v = 0$.

CHARACTERISTICS OF A REAL DIODE

- If v is negative, the diode is *reversed biased*. If the magnitude of v is small, the diode conducts little until the magnitude of v reaches the *breakdown voltage* at which point the diode conducts.
- If a positive current is applied in the direction shown, the diode is *forward biased*. There is not a significant amount of conduction until the voltage reaches about 0.7V. For higher voltages, the diode conducts with a small voltage drop.

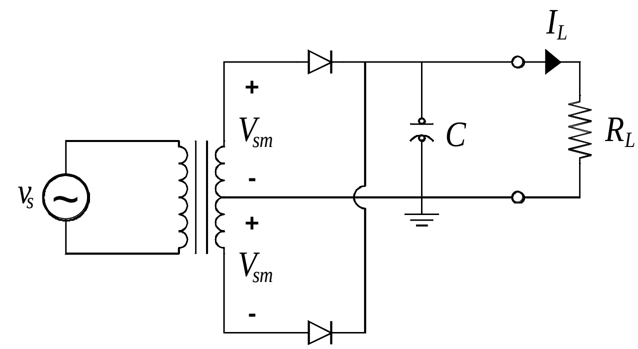
THE I:V RELATIONSHIP (EE338 version) IN THE FORWARD-BIAS REGION $I_D = I_S\, e^{V_D / nV_T}$ $\ln I_D / I_S = V_D / nV_T$	I_D = diode current I_S = saturation current e = natural number V_D = voltage across diode n = 1 generally V_T = thermal voltage, ≈ 25 mV

THE I:V RELATIONSHIP (version from previous class) IN THE FORWARD-BIAS REGION $I_D = I_S (e^{V_D / nV_T} - 1)$	I_D = diode current I_S = saturation current e = natural number V_D = voltage across diode n = 1 generally V_T = thermal voltage, ≈ 25 mV

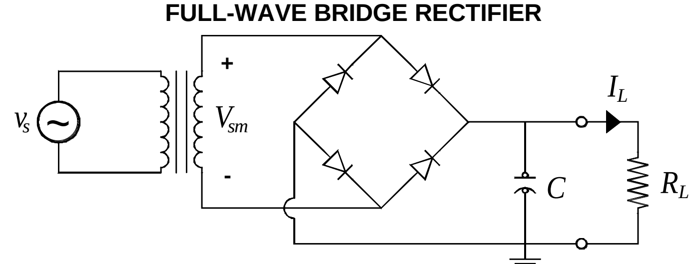
THERMAL VOLTAGE $V_T = \frac{kT}{q}$	V_T = thermal voltage, ≈ 25 mV k = Boltzmann's constant, 1.38×10^{-23} joules/kelvin T = absolute temperature (kelvins), 273 + temp. in °C q = magnitude of electronic charge, 1.60×10^{-19} coulomb

RECTIFIER CIRCUITS

2-DIODE FULL-WAVE RECTIFIER

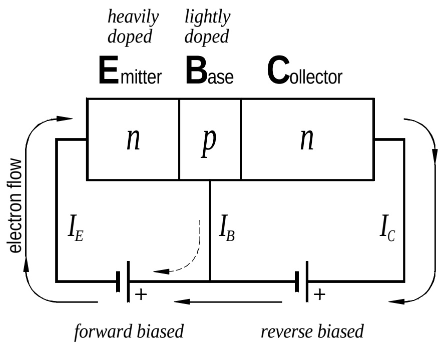


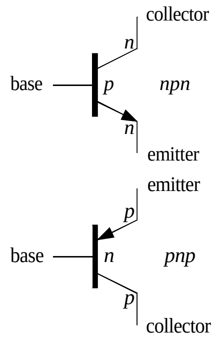
FULL-WAVE BRIDGE RECTIFIER



Formulas apply for small ripple voltages: $V_{ripple} = \frac{V_{sm}}{2\, fR_L C}$ $V_L = V_{sm} - \frac{V_{ripple}}{2}$	V_{ripple} = ripple voltage, peak to peak V_{sm} = transformer voltage, peak f = frequency [Hz] R_L = load resistance [Ω] C = capacitance [F]

BIPOLAR JUNCTION TRANSISTORS - DC ANALYSIS





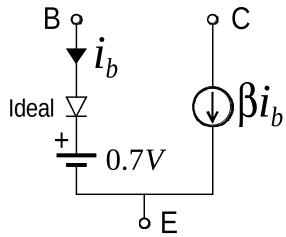
(Current flows in the direction of the arrow)

Bias: the difference in DC potential between base and emitter.

SMALL SIGNAL MODEL (NPN)

Use for DC analysis.

For PNP, reverse the polarities of the diode and voltage supply; reverse the direction of flow in the current supply.



***Q*-POINT:**

The *Q*-Point (also quiescent point, dc bias point, or operating point) is the center of the **transfer characteristic** (operating voltage range) at which it is desirable to **bias** the transistor. It is adjusted by setting the DC voltage level of the base terminal.

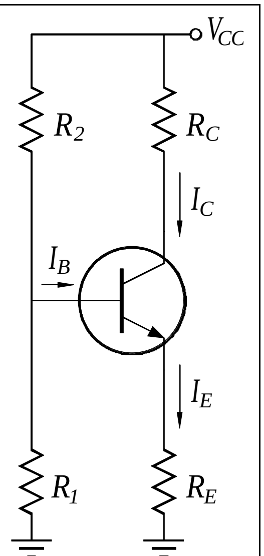
Rule of Thumb: To set the Q-Point, let

$$V_B = R_C I_C = \frac{1}{3} V_{CC}$$

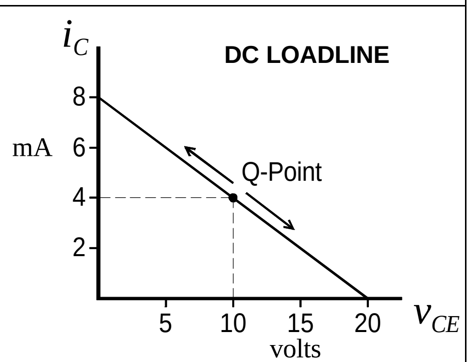
and

$$I_1 = 10 I_B = 10 \frac{I_E}{\beta + 1}$$

where I_1 is the current through the base-to-ground resistor.



A transistor amplifier is biased so that the ***Q*-Point** is located near the center of the **DC Loadline**. When an AC signal is applied, the *Q*-Point oscillates along the loadline.



BASE CURRENT:

The relationships among the emitter, base, and collector currents are functions of β. The relationships apply to signal current as well as DC current.

$$I_C = \beta I_B \qquad I_E = (\beta + 1) I_B$$

I_B = DC base current
I_C = DC collector current
I_E = DC emitter current
β = the **beta** value of the transistor

α AND β:

$$\alpha = \frac{I_C}{I_E} \qquad \beta = \frac{I_C}{I_B}$$

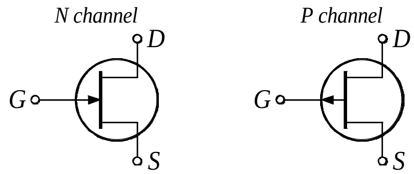
$$\alpha = \frac{\beta}{\beta + 1} \qquad \beta = \frac{\alpha}{1 - \alpha}$$

α is constant for a particular transistor. It's value is less than but close to 1, normally 0.98-0.9995. **α** is the gain of a Common-Base amplifier.

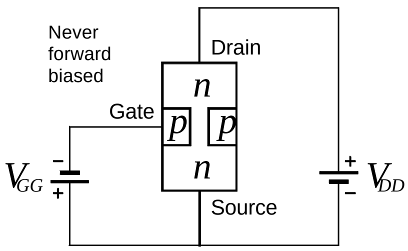
β is constant for a particular transistor, typically in the range of 100 to 200 but may be 50-2000. Since the value of **β** may vary significantly among transistors of the same type, a **β**-tolerant circuit design is desirable. **β** is the Common-Emitter current gain.

FIELD-EFFECT TRANSISTORS

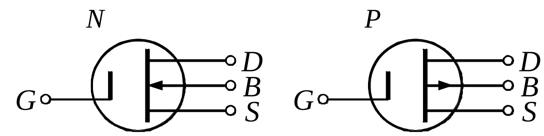
Junction Field Effect Transistor JFET



Creating a depletion region by reverse biasing the gate reduces (*pinches*) current between the drain and the source.

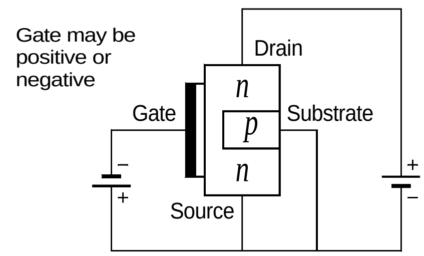


Depletion-type



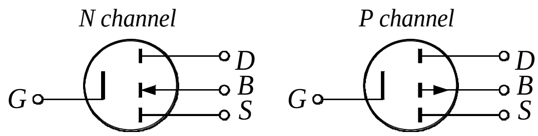
Depletion-type MOSFET

MOSFET's do not have thermal runaway.



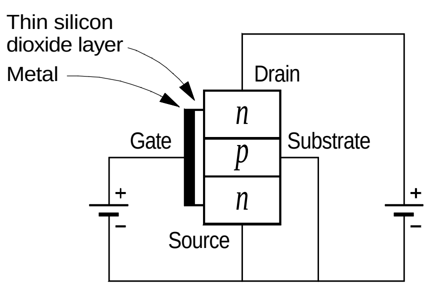
Metal Oxide Silicon Field Effect Transistors

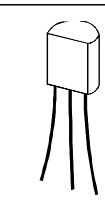
Enhancement-type MOSFET



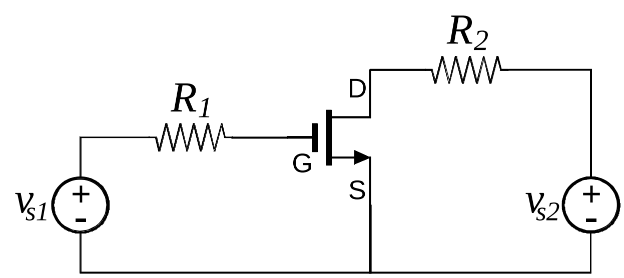
G Gate
D Drain
B Substrate*
S Source

*usually connected internally to the source



FET 2N3819	

SETUP FOR PLOTTING CHARACTERISTIC CURVES



In Pspice, select Analysis / Setup / DC Sweep / Linear / Nested / Voltage Source / Values. Set values for V_{s1} such as 0,-1,-2,-3,-4. Sweep V_{s2} over a range of voltages. Plot drain current versus drain-to-source voltage.

GENERAL

GRAPHING TERMINOLOGY

With x being the horizontal axis and y the vertical, we have a graph of y **versus** x or y **as a function of** x. The x-axis represents the **independent variable** and the y-axis represents the **dependent variable**, so that when a graph is used to illustrate data, the data of regular interval (often this is time) is plotted on the x-axis and the corresponding data is dependent on those values and is plotted on the y-axis.

PSPICE ABBREVIATIONS

AC voltage used for AC sweep simulation
DF (large value) from e^(-DF(T)/2)
TD Time Delay before start
TR Time to Rise
TRAN the source voltage for a transient analysis
TF Time to Fall
PW Pulse Width
PER Period
T1, T2, T3, etc. elapsed time from zero
V1 bottom voltage level (must be less than V2)
V2 top or next voltage level
VAMPL voltage amplitude
VOFF voltage offset

PARAMETERS IN PSPICE

Let's say we are setting up parameters for a resistor **RL**. We choose a parameter name **RLpar**. In the resistor RL attributes dialog we enter **VALUE={RLpar}**. Add a new part PARAM. In its attributes dialog set **NAME1=RLpar**. Give it a default value like **VALUE1=10k**. Close the dialog and drag the part PARAMETERS to one side to be sure that there isn't another one hidden under it.

Select Analysis, Settings, Parametric. Under Swept Variable Type, select **Global Parameter**. Under Name, put **RLpar**. Under Sweep Type, fill in as appropriate.