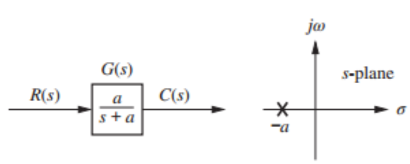
- The next step following block reduction — **analysis and design**
- **Make analysis** to see if the response specification and performance requirements can be met by simple adjustment of system parameters
  - **If not** — design additional hardware controllers
  - one of the most important analysis technique is **time-domain analysis**
- Test signals
  - Engineer usually selects **standard test inputs**
    - Impulse
    - Step
    - Ramp
    - Parabolic
    - Sinusoid
  - Which one of these typical input signals to use?
    - determined by the form of the input that the system will be subjected
  - Gradually changing functions of time — **ramp**
  - sudden disturbances — **Step**
  - shock inputs — **Impulse**
- Step input
  - Represent constant command such as position, velocity, or acceleration

    - if the system's output is position, the step input represents a desired position
    - If the system's output is velocity, the step input represents a constant desired speed
- Ramp input
    - Represents a linearly increasing command
    - if the system's output is position, the input ramp represents a linearly increasing position, such as that found when tracking a satellite moving across the sky at constant speed
- Once a control system is **designed on the basis of test signals**, the **performance** of the system in response to **actual inputs is generally satisfactory**
    - **enables one to compare the performance of many systems** on the same basis
- Control system behavior is altered by **fluctuations** in component values or system parameters — caused by **temperature**, **pressure**, or other **environmental changes**
- the designer is concerned about **transient response**, **steady-state error**, **stability**, and **sensitivity**
- Transient response of 1^{st}-order system
    - relationship between the input and the output **involves the rate at which the output changes**

- contains storage element cannot respond instantaneously to change an input
    - **mercury in glass** thermometer
    - **Velocity of a true falling mass**
    - Air pressure build-up in **bellow**
- thermometer at temperature $\boldsymbol{T_0}$ inserted into a liquid at a temperature
- how the output, i.e. the reading of the thermometer T, varies with time $\boldsymbol{T(t) = T_1 + (T_0 - T_1)e^{-t/\tau}}$
- **Time constant**
    - time the system takes to reach 63.2% of its final value
    - $\boldsymbol{1\,\tau:\ 63\%}$
    - $\boldsymbol{2\,\tau:\ 86\%}$
    - $\boldsymbol{2\,\tau:\ 95\%}$
- The system response is called a "**first-order lag**" because the **output lags behind the input**
- The dynamic shape of 1st-order response to a step input is a function of time constant



- Location of pole — time constant

- farther the pole from the imaginary axis, the faster the transient response
- Rise time
  - The time for the waveform to go from 0.1 to 0.9 of its final value
  - $T_r = \frac{2.2}{a}$
- Settling time
  - time for the response to reach, and stay within, 2% of its final value
  - $T_s = \frac{4}{a}$
- 1st-order transfer function via testing

$$\boldsymbol{C(s) = \frac{K}{s(s+a)} = \frac{K/a}{s} - \frac{K/a}{s+a}}$$

  - identify $\boldsymbol{K}$ and $\boldsymbol{a}$ from laboratory testing, we can obtain the transfer function of the system
  - **has the first-order characteristics** — **no overshoot** and **nonzero initial slope**

- Response of 1st-order system to ramp input

$$C(s) = \frac{1}{s^2} * \frac{1}{\tau s + 1}$$

$$c(t) = t - \tau + \tau e^{-t/\tau}$$

$$e(\infty) = \tau$$

  - The smaller the time constant τ, the smaller the steady-state error in following the ramp input