Impedance:

- Traditional electrical sense - as generalized resistance: Simple & Complex!!
- In the mechanical sense, or in a general sense with regard to other domains (e.g., fluid, thermal) as well depending on the type of signals involved.
    1. A voltmeter can modify the currents (and voltages) in a circuit, and this concerns electrical resistance of a dc circuit or more generally, electrical impedance, when ac circuits are considered.
    2. A heavy accelerometer will introduce an additional dynamic (mechanical) load, which will modify the actual acceleration at the monitoring location. This concerns mechanical impedance.
    3. A thermocouple junction can modify the temperature that is measured as a result of the heat transfer into the junction. This concerns thermal impedance.

Similarly we can define impedance for fluid systems, magnetic systems (reluctance), and so on. In general, impedance is defined as:

$$Impedance = \frac{Across\,Variable}{Through\,Variable}$$

The ***across variable*** is measured across the two ends (ports) of a component, and the ***through variable*** transmits through the component unaltered.

- Examples of across variables are voltage, velocity, temperature, and pressure.
- Examples of through variables are current, force, heat transfer rate, and fluid flow rate.
- Even though electrical impedance is defined as voltage/current, which is consistent with the definition.

Mechanical ***impedance***, historically, has been defined as force/velocity, which is the inverse of the definition above. It is the ***mobility*** that is defined as velocity/force, and it should be interpreted as impedance in the general sense (i.e., generalized impedance), in our analysis.

Cascade Connection of Devices:

The output impedance: $Z_0 = \frac{\text{open−circuit (i.e.,no−load) voltage at the output port}}{\text{the short−circuit current at the output port}}$

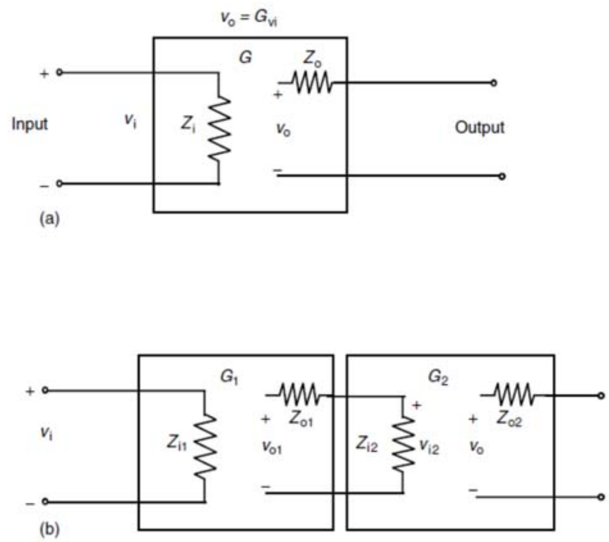
- O/C voltage at output is the output voltage present when there is no current flowing at the output port. This is the case if the output port is not connected to a load (impedance). *As soon as a load is connected at the output of the device, a current flows through it, and the output voltage drops to a value less than that of the open-circuit voltage.*
- To measure the open-circuit voltage, the rated input voltage is applied at the input port and maintained constant, and the output voltage is measured using a voltmeter that has a high (input) impedance.
- To measure the short-circuit current, a very low-impedance ammeter is connected at the output port.

The output impedance: $Z_i = \frac{Rated\ input\ Volatge}{corresponding\ current\ through\ the\ input\ terminals}$

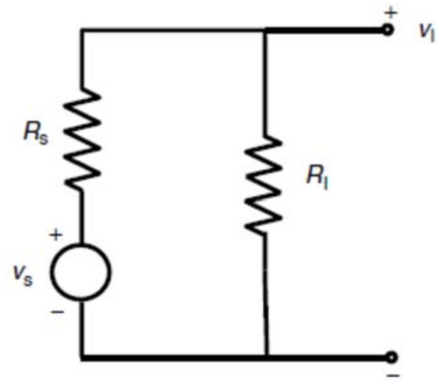
While Output terminals are maintained in O/C.

Z_0 and Z_i can be represented as shown in the diagram.

- Note that v_0 is the open-circuit output voltage.
- When a load is connected at the output port, the voltage across the load will be different from v_0 because this is caused by the presence of a current through Z_0



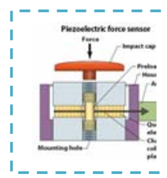
Loading Effect and Impedance Matching:



- When two electrical components are interconnected, current (and energy) flows between the two components and changes the original (unconnected) conditions. *This is known as the (electrical) loading effect, and it has to be minimized.*
- At the same time, adequate power and current would be needed for signal communication, conditioning, display, and so on.
- Both situations can be accommodated through proper *matching of impedances* when the two components are connected. Usually, an impedance-matching amplifier (i.e., an impedance transformer) would be needed between the two components.

From the analysis given in the preceding section:

- The signal-conditioning circuitry should have a considerably large input impedance in comparison with the output impedance of the sensor–transducer unit to reduce loading errors.



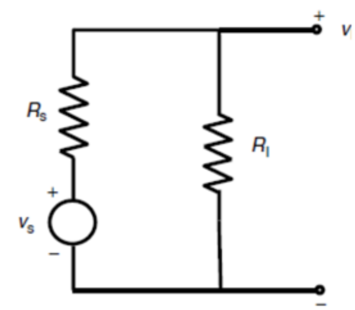
Example: Problem is quite serious in measuring devices such as piezoelectric sensors, which have very high output impedances. A **piezoelectric** sensor is a device that uses the **piezoelectric** effect, to measure changes in pressure, acceleration, temperature, strain, or force by converting them to an electrical charge.

- *In such cases, the input impedance of the signal-conditioning unit might be inadequate to reduce loading effects;*
- *Also, the output signal level of these high impedance sensors is quite low for signal transmission, processing, actuation, and control.*
- *The solution for this problem is to introduce several stages of amplifier circuitry between the output of the first hardware unit (e.g., sensor) and the input of the second hardware unit (e.g., data acquisition unit).*
- *The first stage of such an interfacing device is typically an impedance-matching amplifier that has high input impedance, low output impedance, and almost unity gain.*
- *The last stage is typically a stable high-gain amplifier stage to step up the signal level. Impedance-matching amplifiers are, in fact, op-amps with feedback.*

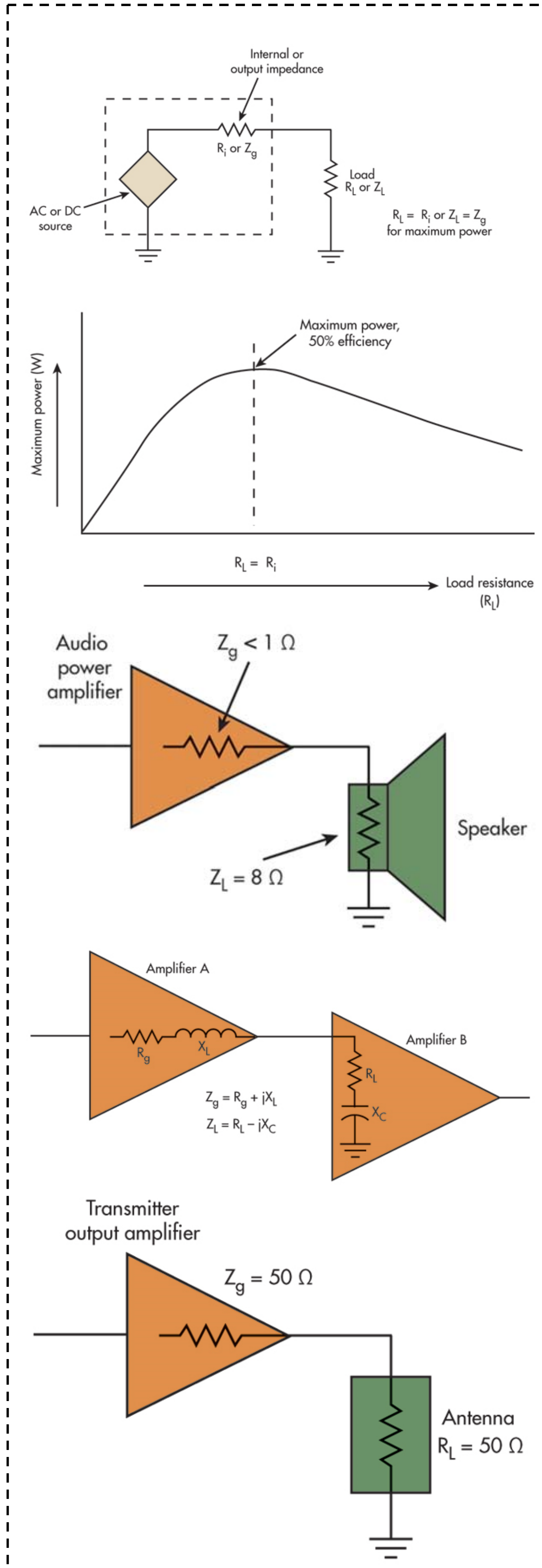
When connecting a device to a signal source, loading problems can be reduced by making sure that the device has a high input impedance.

Unfortunately, this will also reduce the level (amplitude, power) of the signal received by the device. In fact, a high impedance device may reflect back some harmonics of the source signal. A termination resistance might be connected in parallel with the device to reduce this problem.

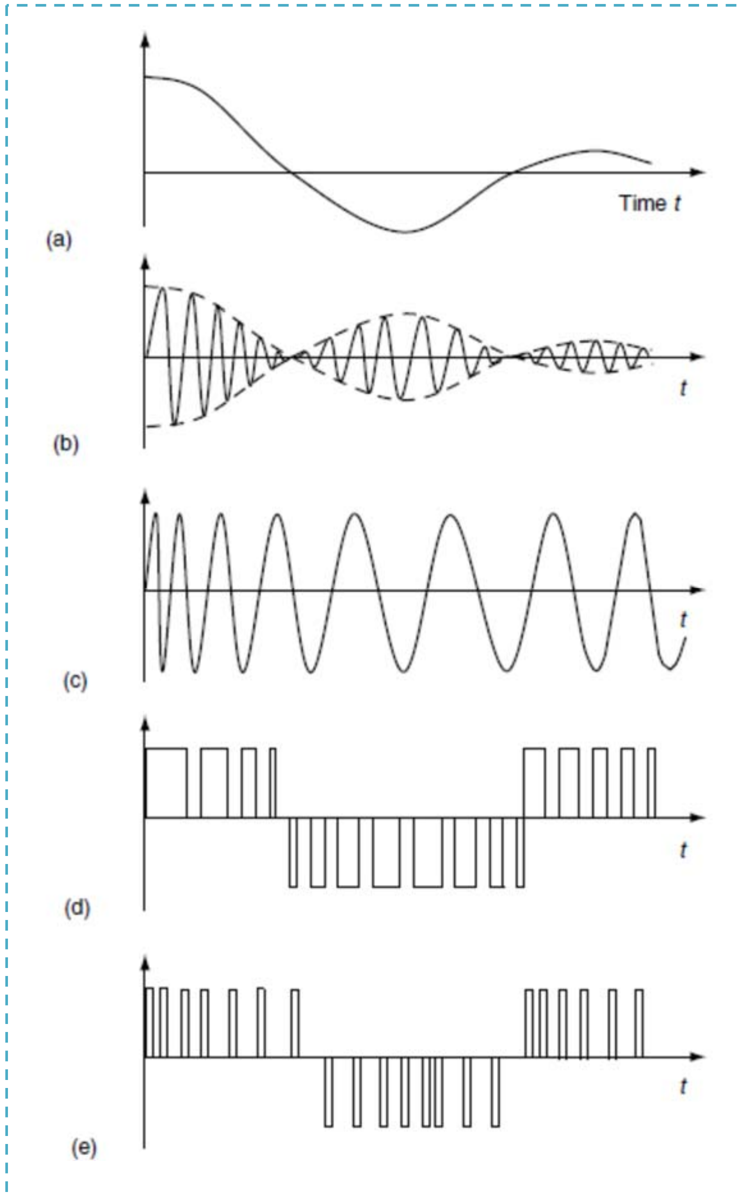
In many data acquisition systems, output impedance of the output amplifier is made equal to the transmission line impedance. When maximum power amplification is desired, conjugate matching is recommended. In this case, input and output impedances of the matching amplifier are made equal to the complex conjugates of the source and load impedances, respectively.



Using Complex Impedance:



Modulation:



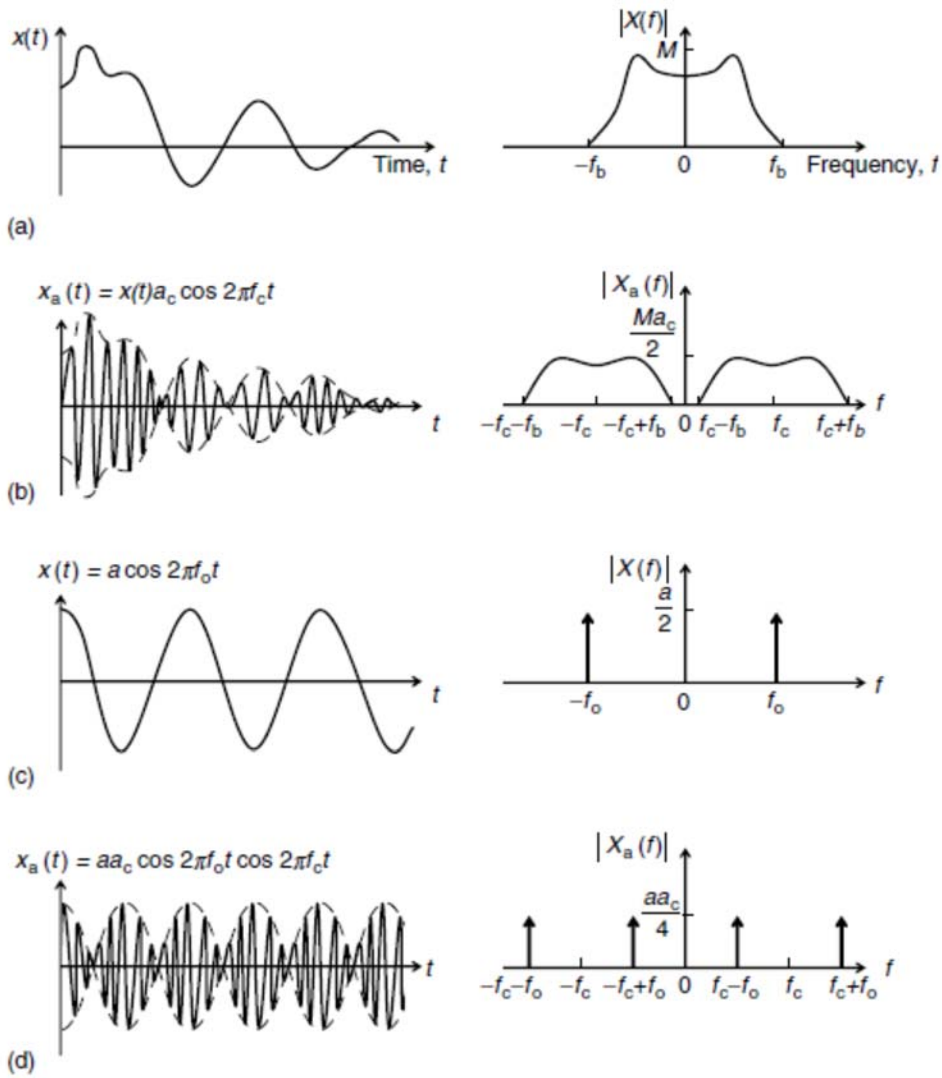
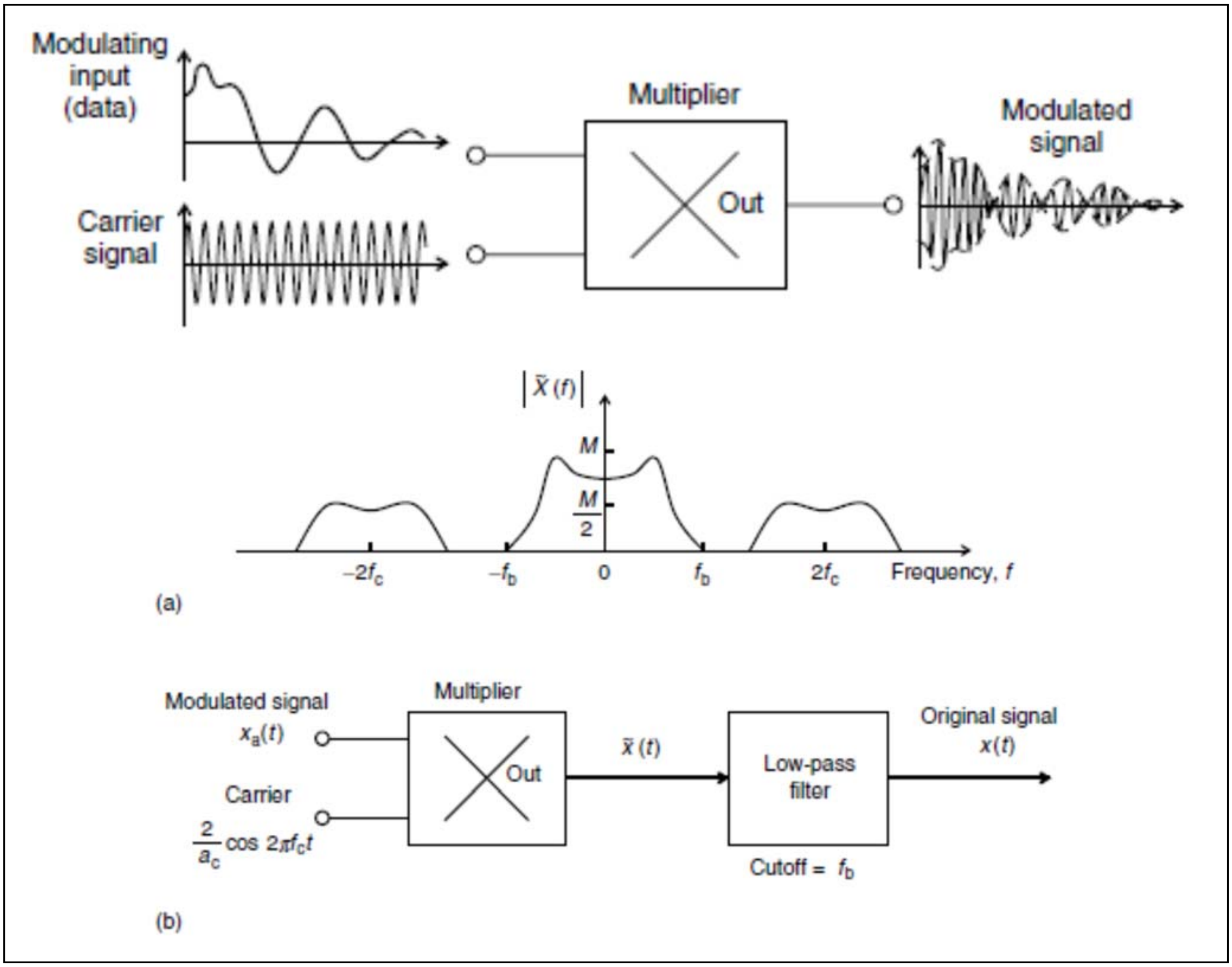


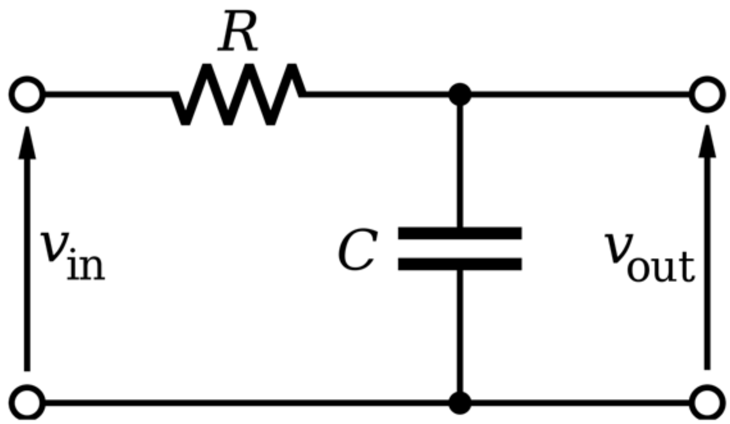
FIGURE 2.22
Illustration of the modulation theorem. (a) A transient data signal and its Fourier spectrum magnitude. (b) Amplitude-modulated signal and its Fourier spectrum magnitude. (c) A sinusoidal data signal. (d) Amplitude modulation by a sinusoidal signal.

Modulation and De-Modulation:



Consider the modulated signal above:

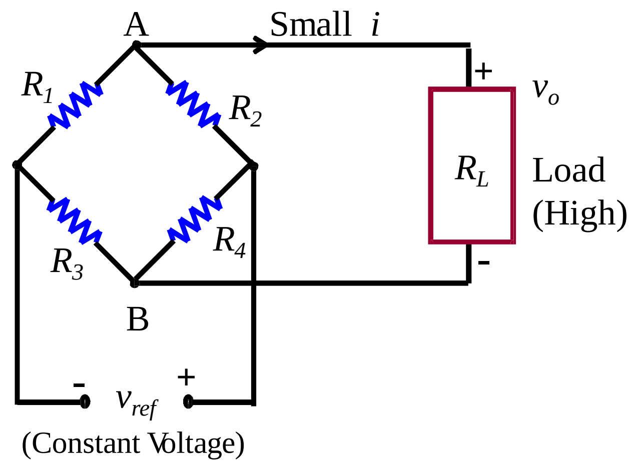
Low Pass Filter with a cut-off:

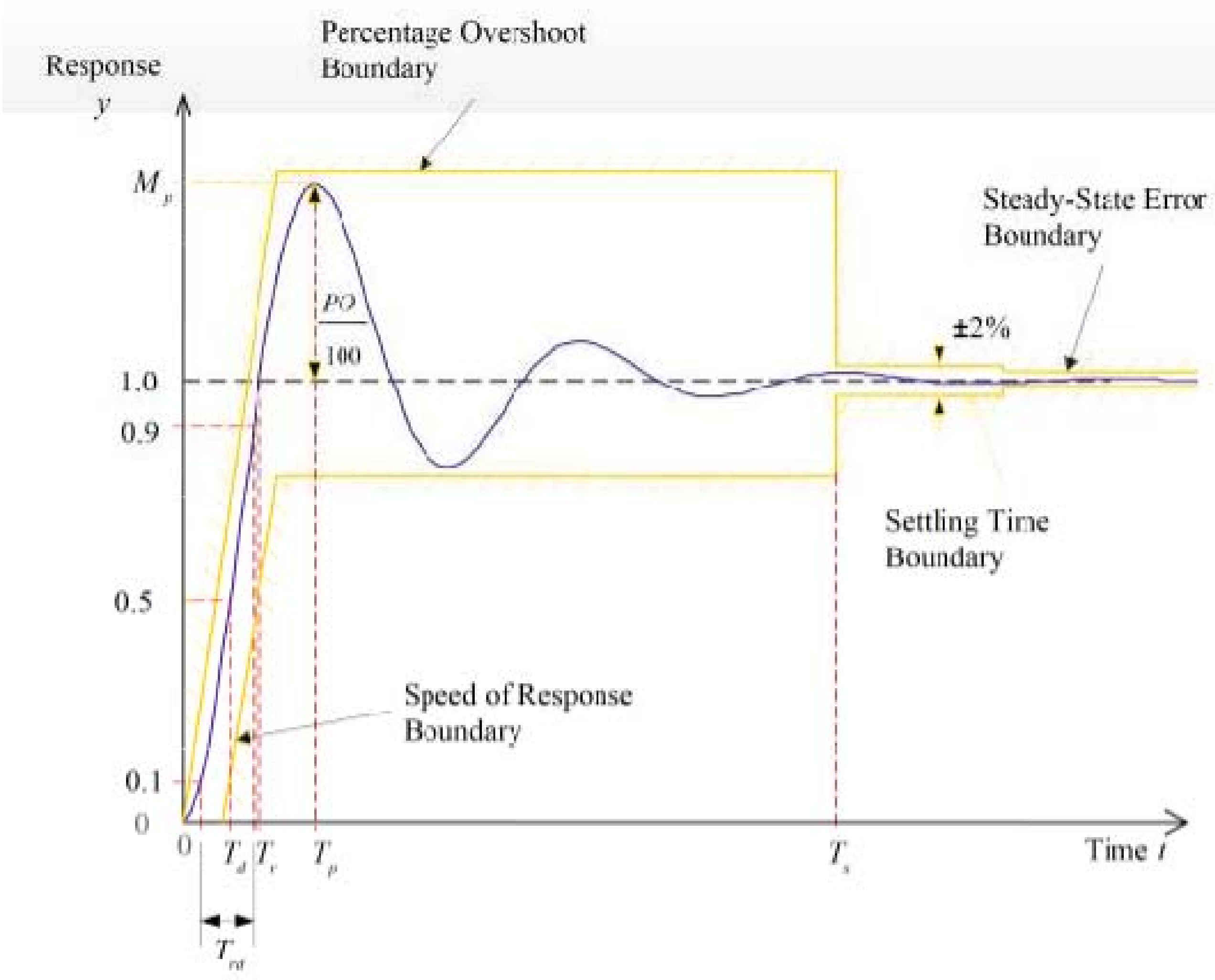


Bridge Circuits:

Bridge circuits are used to make a form of measurement:

- Change in resistance
- Change in inductance
- Change in capacitance
- Oscillating frequency




Percentage Overshoot
Boundary
Response
y
M_p
Steady-State Error
Boundary
$\frac{PO}{100}$
±2%
1.0
0.9
0.5
Settling Time
Boundary
Speed of Response
Boundary
0.1
0
0
T_d
T_r
T_p
T_s
Time t
T_{rd}