(13)

Date | Page

Dealing with nuisances

1. Time delays

⇒ Time delays are ubiquitous in control systems:

→ Delays are incurred when the controller is implemented on a computer.

→ In some system, delays may also be part of the physical plant.

★ Transfer function of a time delay

⇒ A time delay is an operator that transforms an input signal $t \to u(t)$ into a delayed output signal $t \to y(t)$, with $y(t) = u(t-T)$, where $T \geq 0$ is the amount of delay.

⇒ Clearly this is a linear operator: the delayed version of a linear combination of a signal is equal to the linear combination of the delayed signals.

⇒ In order to compute the transfer function of this linear operator, consider an input of the form $u(t) = e^{st}$.

⇒ The output will be:

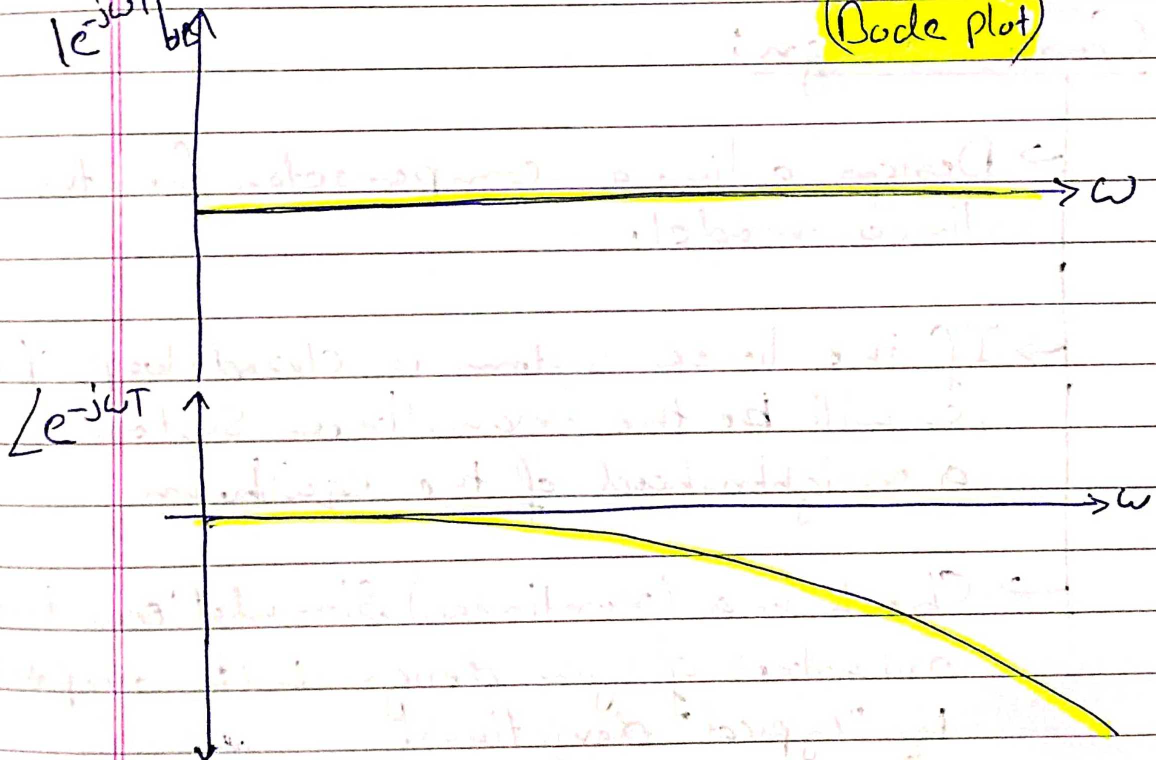
$$\boxed{y(t) = e^{s(t-T)} = e^{-sT}u(t)}$$

⇒ and hence the transfer function of a delay of T seconds is e^{-sT}.

★ **The frequency response of a time delay**

$$|e^{-j\omega T}| = 1 \qquad \angle e^{-j\omega T} = -\omega T$$

(Bode plot)



⇒ The main effect of a time delay is a reduction of the phase margin.

↳ The phase margin reduces as crossover frequency increases.

Date

Page

(2) Control of nonlinear systems

⇒ Jacobian Linearization

→ Find the desired equilibrium condition (state & control)

→ Linearize the non-linear model around the equilibrium

⇒ Control design:

→ Design a linear compensator for the linear model.

→ If the linear system is closed-loop stable, so will be the non-linear system in a neighbourhood of the equilibrium

→ Check in a (nonlinear) simulation the robustness of your design with respect to "typical" deviations.

(3) Integrator wind-up

⇒ Once the input saturates, the integral of the error keeps increasing.

⇒ When the error decreases, the large integral prevents the controller from resuming "normal operations" quickly.

(The integral error must decrease first)

⇒ ==Idea==: Once the input saturates, stops integrating the error.