

- Small-Gain Theorem
- Passivity - definitions
- Passivity and Lyapunov Stability

Input/output stability formalisms are well suited for studying the stability of feedback connections. Consider the system shown in figure 1, where $G_1 : \mathcal{L}_e \rightarrow \mathcal{L}_e$ and $G_2 : \mathcal{L}_e \rightarrow \mathcal{L}_e$. We suppose that both systems are finite gain stable so that

$$\begin{aligned} \|y_1\| &\leq \gamma_1 \|e_1\| + \beta_1 \\ \|y_2\| &\leq \gamma_2 \|e_2\| + \beta_2 \end{aligned}$$

for all $e_1, e_2 \in \mathcal{L}_e$.

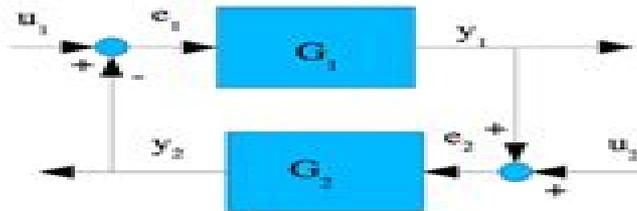


Fig. 1. Small Gain Theorem

We say this feedback loop is well-posed if for every pair of inputs, $u_1, u_2 \in \mathcal{L}_e$ there exists a unique output $e_1, y_2, e_2, y_1 \in \mathcal{L}_e$. The question raised here (as earlier) is whether the feedback connection from $u \rightarrow e$ and $u \rightarrow y$ is finite gain \mathcal{L} -stable.

Small Gain Theorem: The preceding feedback connection is finite gain \mathcal{L} -stable if $\gamma_1 \gamma_2 < 1$.

Proof: Define the system

$$Se_{2\tau} = u_{2\tau} + P_\tau(G_1(u_{1\tau} + P_\tau(G_2e_{2\tau})))$$

where

$$P_\tau(u) = \begin{cases} u(t) & t \leq \tau \\ 0 & \tau < t \end{cases}$$

Now consider two signals $e_{2\tau}$ and $\hat{e}_{2\tau}$ in \mathcal{L}_e such that

$$\begin{aligned} &\|Se_{2\tau} - S\hat{e}_{2\tau}\| \\ &= \|G_1(u_{1\tau} + P_\tau(G_2e_{2\tau})) - G_1(u_{1\tau} + P_\tau(G_2\hat{e}_{2\tau}))\| \\ &\leq \gamma_1 \|G_2e_{2\tau} - G_2\hat{e}_{2\tau}\| + \beta_1 \\ &\leq \gamma_1 \gamma_2 \|e_{2\tau} - \hat{e}_{2\tau}\| + \beta_1 + \beta_2 \end{aligned}$$

This is a contraction mapping under the assumption so we can use the contraction mapping principle to infer the

existence of a fixed point such that $e_{2\tau}^* = Se_{2\tau}^*$ where

$$\begin{aligned} e_{2\tau}^* &= u_{2\tau} + P_\tau(G_1(u_{1\tau} + P_\tau(G_2e_{2\tau}^*))) \\ &\leq P_\tau(u_2 + G_1(u_1 + G_2e_{2\tau}^*)) \\ &= P_\tau e_{2\tau}^* \in \mathcal{L}_e \end{aligned}$$

A similar argument shows there exists $e_{1\tau}^* \in \mathcal{L}_e$ that satisfies the loop equation.

So we can now see that

$$\begin{aligned} \|e_{1\tau}\| &\leq \|u_{1\tau}\| + \|(G_2e_{2\tau})_+\| \\ &\leq \|u_{1\tau}\| + \gamma_2 \|e_{2\tau}\| + \beta_2 \\ &\leq \|u_{1\tau}\| + \gamma_2 (\|u_{2\tau}\| + \gamma_1 \|e_{1\tau}\| + \beta_1) + \beta_2 \\ &= \gamma_1 \gamma_2 \|e_{1\tau}\| + (\|u_{1\tau}\| + \gamma_2 \|u_{2\tau}\| + \beta_2 + \gamma_2 \beta_1) \end{aligned}$$

This implies that

$$\|e_{1\tau}\| \leq \frac{1}{1 - \gamma_1 \gamma_2} (\|u_{1\tau}\| + \gamma_2 \|u_{2\tau}\| + \beta_2 + \gamma_2 \beta_1)$$

A similar argument shows that

$$\|e_{2\tau}\| \leq \frac{1}{1 - \gamma_1 \gamma_2} (\|u_{2\tau}\| + \gamma_1 \|u_{1\tau}\| + \beta_1 + \gamma_1 \beta_2)$$

which satisfies our definition for \mathcal{L} stability.

Passivity is an important tool in the analysis and design of nonlinear control systems. The idea originates in traditional circuit theory. Consider the two-terminal circuit element shown below in figure 2.



Fig. 2. Two-Terminal Circuit Element

The current through this device is y and the voltage across the device is u . We assume that u and y are related through the impedance function Z such that $u = Zy$. Note that if $uy \geq 0$ then we know that energy is absorbed by the circuit element and we say that element is **passive**. If $uy < 0$ then energy is delivered by the device and we say this device is **active**.

We now extend this concept to dynamical systems of the form

$$\begin{aligned} \dot{x} &= f(x, u) \\ y &= h(x, u) \end{aligned}$$

where $f : \mathbb{R}^n \times \mathbb{R}^p \rightarrow \mathbb{R}^n$ is locally Lipschitz with $f(0, 0) = 0$ and $h : \mathbb{R}^n \times \mathbb{R}^p \rightarrow \mathbb{R}^p$ is continuous with $h(0, 0) = 0$.

The RLC circuit in figure 3 motivates our following discussion. In this system we take the current through the inductor as state x_1 and we take the voltage across the capacity as



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6 use the table of ions in model 1 to answer the following questions a in the compound zinc phosphide what is the charge on the zinc ion b in the compound zinc phosphide what is the charge on the phosphide ion 7 explain why a 3 to 2 ratio of ions is necessary for the compound zinc phosphide 8

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description the pogil project and flinn scientific have collaborated to publish this series of student centered learning activities for high school chemistry create an interactive learning environment with 36 specially designed guided inquiry learning activities in 13 major topic areas