System Identification, Lecture 1

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Lecture 1

- System Identification.
- System.
- Model.
- Identification.
- Course Outline.

Course Material

- Book: "System Identification", T. Söderström, P. Stoica, Prentice-Hall, 1989 [1]
- Slides: available at lectures

Course:

- Lectures.
- Exercise sessions.
- MATLAB sessions.
- Laboratory session.
- Exam.

[1] see http://www.it.uu.se/research/syscon/Ident, ...

News:

- Open:
  `http://www.it.uu.se/edu/course/homepage/systemid/vt10`

- "Studentportalen"
  `http://www.it.uu.se/edu` → 'system identification'

System Identification (SI)

Def. System Identification is the study of *Modeling* dynamic *Systems* from *experimental data*.

- Statistics, Systems Theory, Numerical Algebra.
- System Identification is art as much as science.
- Software available (MATLAB)
- – Estimation (Gauss (1809)),
  – Modern System Identification (Åström and Bohlin (1965), Ho and Kalman (1966)),
  – Recent System Identification (L. Ljung, 1977-1978)
  – Textbooks (L.Ljung 1987, Söderström and Stoica, 1989).

System

System ($\mathcal{S}$): A defined part of the real world. Interaction with the environment are described by input signals, output signals and disturbances.

Dynamical System: A system with a memory, i.e. the input value at time t will influence the output signal at the future, i.e. $t' > t$.

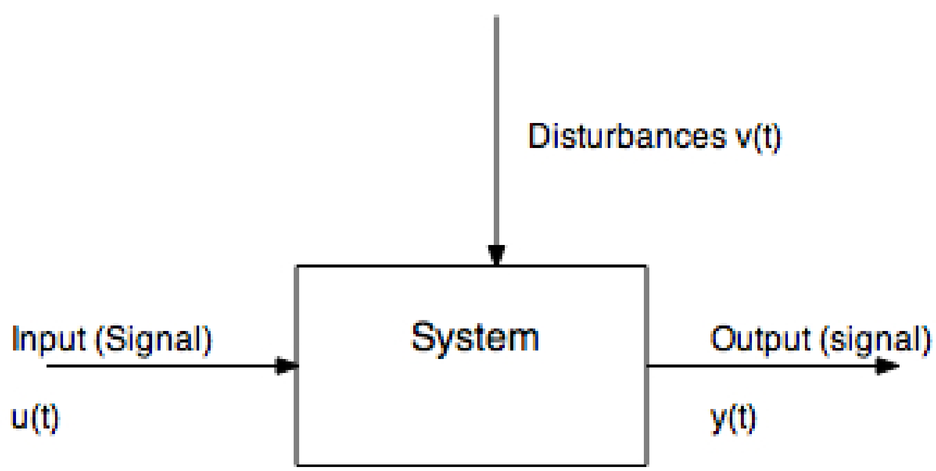


Figure 1: Schematic picture of a system

Ex.: A Stirred Tank

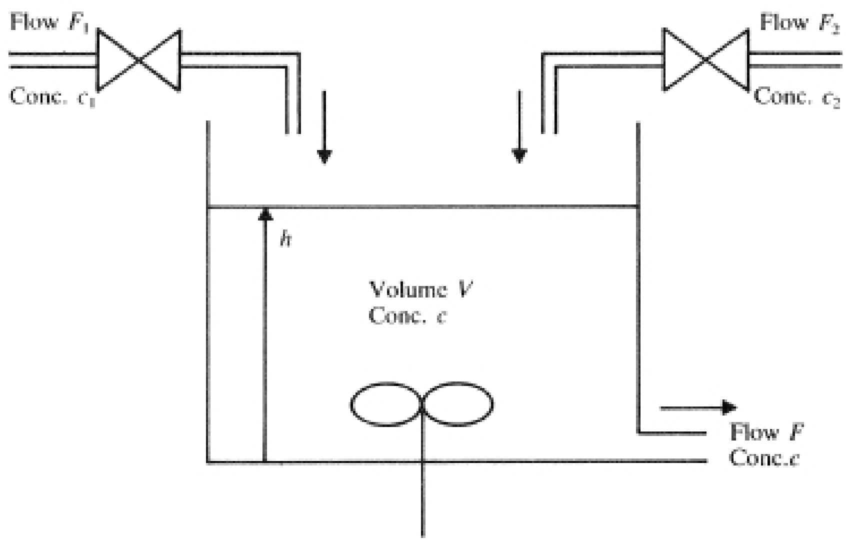


Figure 2: A Stirred Tank

Ex.: Speech

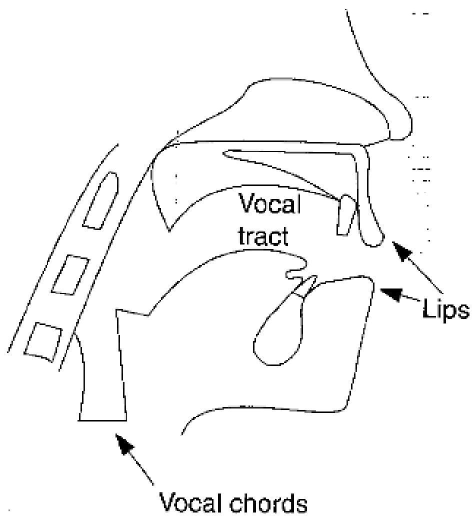


Figure 1.7 Speech generation.

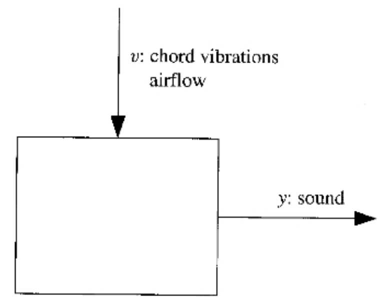


Figure 1.8 The speech system: y: output; v: unmeasured disturbance.

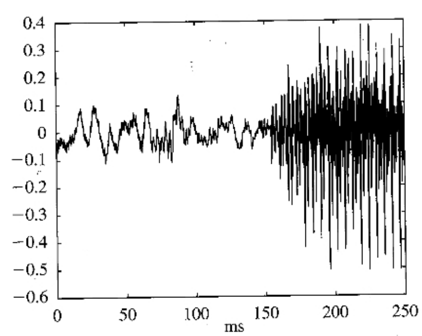


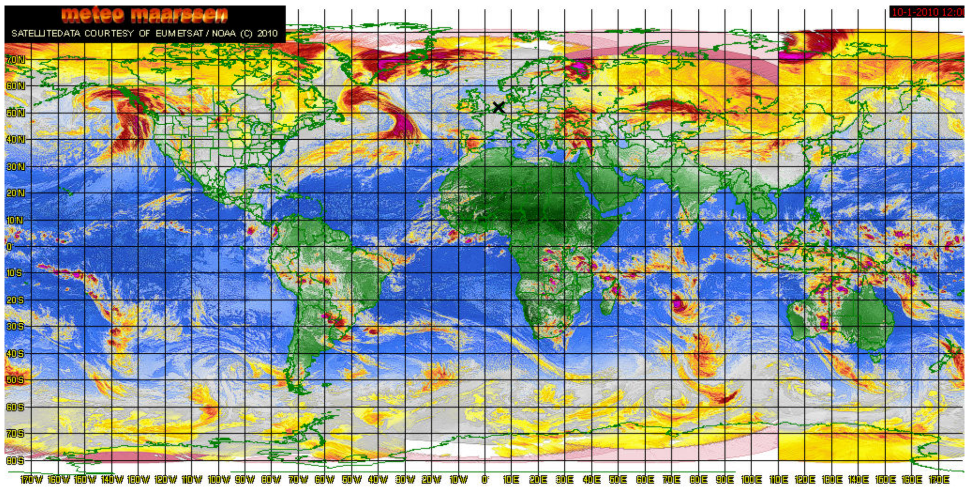
Figure 1.9 The speech signal (air pressure). Data sampled every 0.125 ms. (8 kHz sampling rate).

Ex. and...

- Stock (Shock) Market

- Acoustic Noise Cancellation Headset (Adaptive filtering)

- Evolution of the Temperature in the world

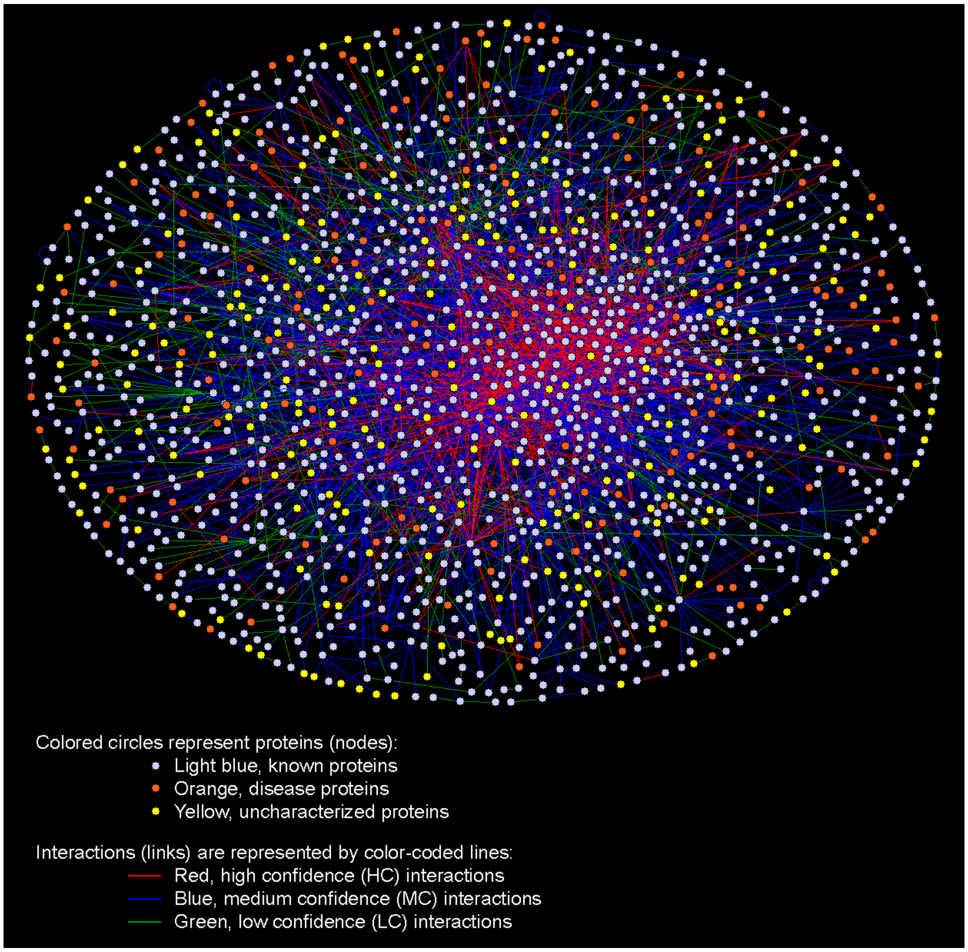


- Construction (Strength)

- Robots (Mechanical, Operational, Intellectual)

- Social Behavior of Crowd (gossip)

- A human protein-protein interaction network



... Engineering view

Models

Model ($\mathcal{M}$): A description of a system. The model should capture the essential behavior of the system.

Systems	Models
Complex	Approximative (Idealization)
Examine real system is costly	Models can answer many questions.

Applications

- Process Design. Ex. Designing new cars, planes, ...
- Control Design.
  1. Simple regulators
  2. Simple models, optimal regulators,
  3. sophisticated models.
- Prediction. Ex. Forecast the weather, Predict the Stock market.
- Signal Processing. Ex. Acoustic Echo Cancellation.
- Simulation. Ex. Train new nuclear plant operators, try new operating strategies.
- Fault Detection. Ex. VISA.

Type of Models

- Mental, intuitive or verbal. Ex. Driving a car.
- Graphs and Tables. Ex. Bode plots and step responses.
- Math. models. Ex. Differential and Difference equations.

Mathematical Models

- **Analytical Models** Basic laws from physics (...) are used to describe the behavior of a phenomenon (system).
  - Know the physics.
  - Yields physical Interpretation
  - Quite general models. Often Nonlinear
- **System Identification**
  - *Black-Box models* (Konfektionsmodeller) "Choose a standard model and tune the parameters (...) to the data".
    - Easy to construct and use.
    - Less general. Linear (-ized)
  - *Grey-Box models* (Skräddarsydda Modellerer) "Derrive the model from laws and tune 'some' parameters to data".
    - Combines Analytical models and black-box identification.

Examples of Models

- Nonlinear vs. Linear (superposition principle):

  "The net response at a given place and time caused by two or more stimuli is the sum of the responses which would have been caused by each stimulus individually." (Wiki)

- Time-continuous versus Time-discrete

- Deterministic versus Stochastic

The System Identification Procedure

1. Collect Data. If possible choose the input signal such that the data has maximally informative.

2. Choose Model Structure. Use application knowledge and engineering intuition. Most important and most difficult step (don't estimate what you know already)

3. Choose Identification Approach. How would a good model look like?

4. Do. Choose *best* model in model structure (Optimization or estimation)

5. Model Validation. Is the model good enough for our purpose?

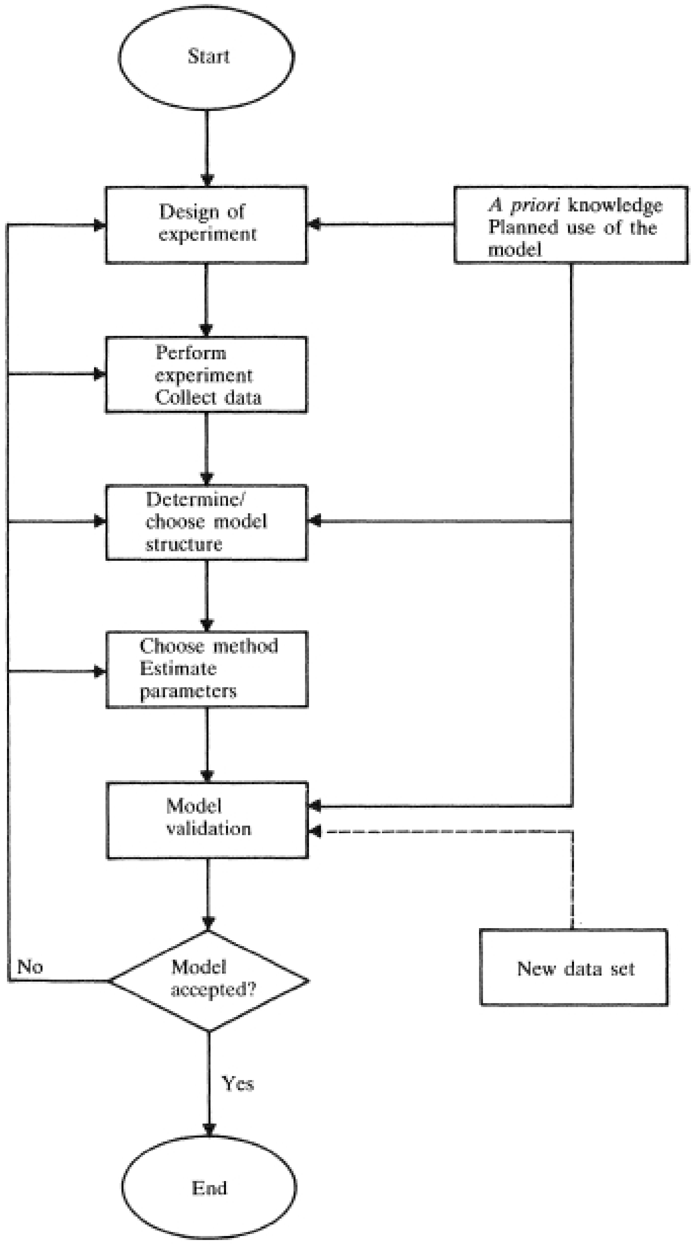


FIGURE 1.3 Schematic flowchart of system identification.

Typical Problems to Answer

- How to design the experiment. How much data samples to collect?
- How to choose the model structure?
- How to deal with noise?
- How to measure the quality of a model?
- What is the purpose of the model?
- How do we handle nonlinear and time-varying effects?

System Identification Methods

- **Non-parametric Methods (SI)**. The results are (only) curves, tables, etc. These methods are simple to apply. They give basic information about e.g. time delay, and time constants of the system.

- **Parametric Methods (SI)** The results are values of the parameters in the model. These may provide better accuracy (more information), but are often computationally more demanding.

Course Outline

1. Introduction (Ch.1,2).
2. Linear Regression (Ch.4).
3. Nonparametric Identification, Input Signals, Model Parametrizations (Ch. 3,5,6).
4. Prediction Error Methods (Ch. 7).
5. Instrumental Variable Methods (Ch.8).
6. Model Structure Determination and Model Validation (Ch.11).
7. Recursive Identification Methods (Ch.9).
8. Identification of Closed Loop Systems (Ch.10).
9. Summary and Practical Aspects (Ch. 12).

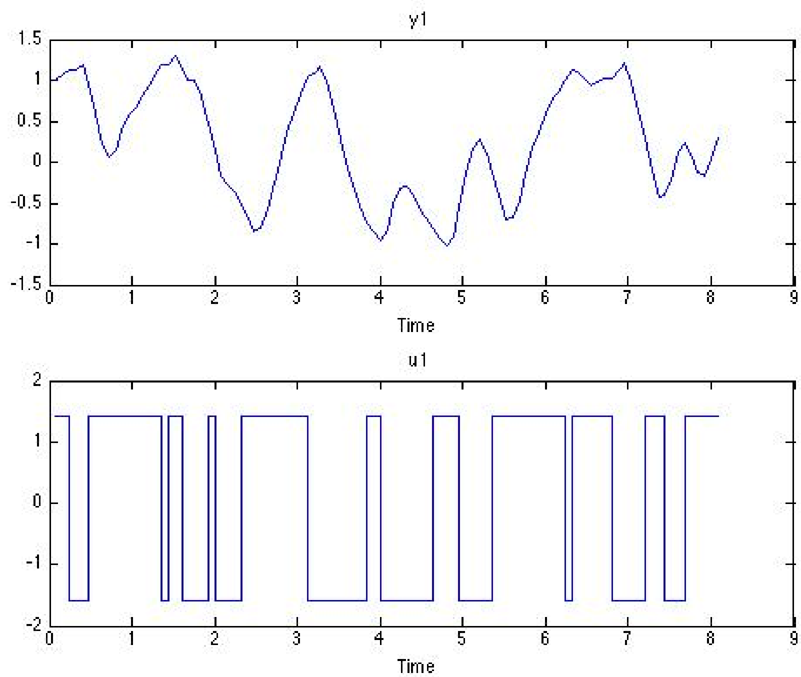
Conclusion

- *System identification is the art of building mathematical models of dynamical systems using experimental data.* It is an iterative procedure.
  - A real system is often very complex. A model is merely a good *approximation*.
  - Data contain often noise, individual measurements are unreliable.
- Analytical methods versus system identification (white-, black-, grey box)
- Non-parametric versus Parametric Methods
- Procedure: (a) Collect data, (b) Choose Model Structure, (c) Determine the best model within a structure, (d) Model validation.

An example

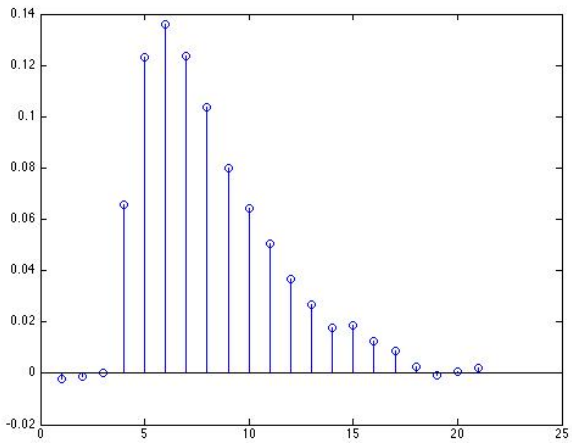
Identify a hairdryer: air is fanned through a tube and heated at the inlet. Input $u(t)$: power of the heating device. Output $y(t)$: air temperature.

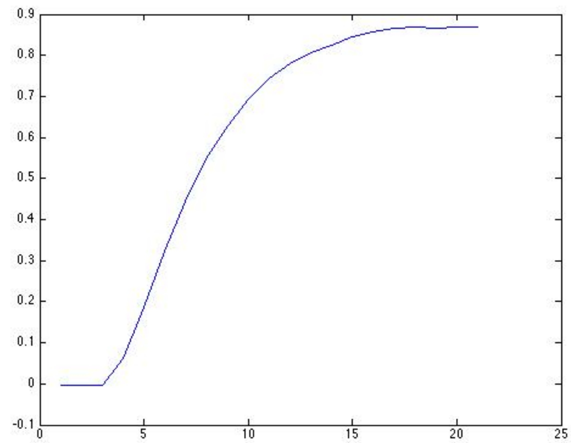
```
>> load dryer2
>> z2 = [y2(1:300) u2(1:300)];
>> idplot(z2, 200:300, 0.08)
```



Nonparametric Modeling

```
>> z2 = dtrend(z2);
>> ir = cra(z2);
>> stepr = cumsum(ir);
>> plot(stepr)
```

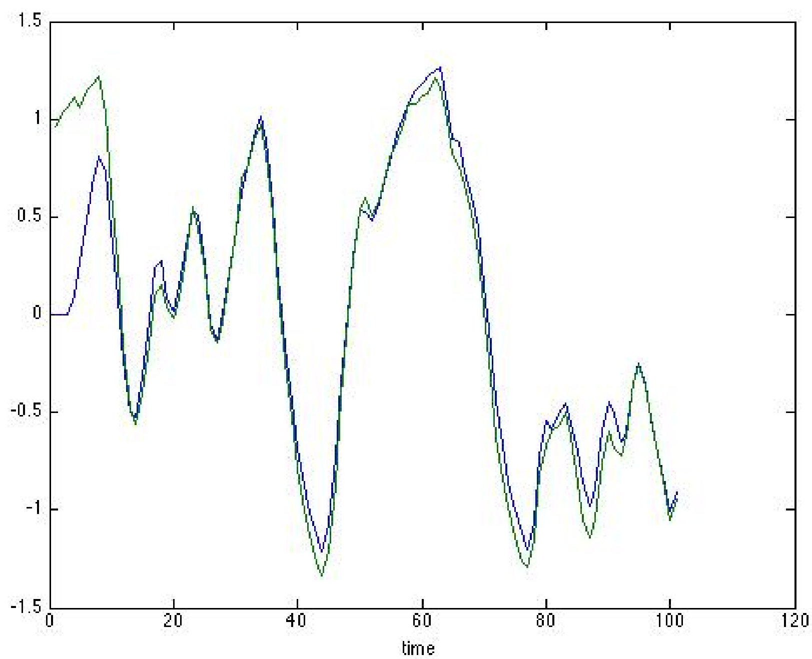




Parametric modeling:

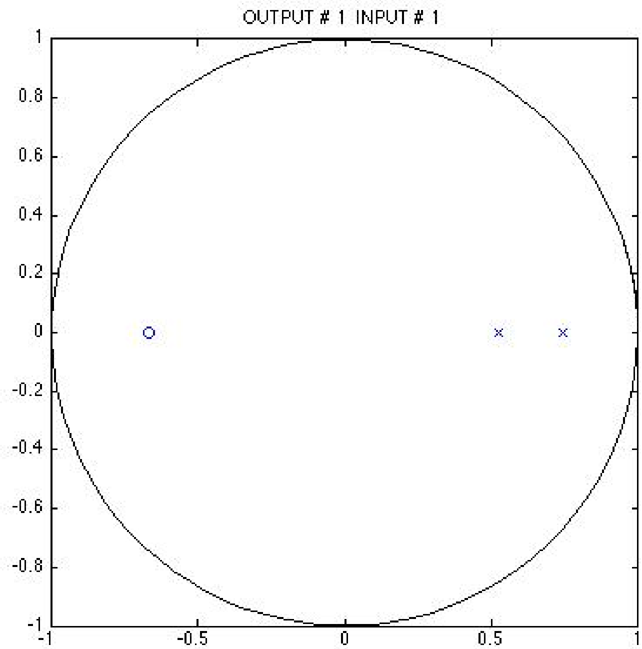
$$y(t) + a_1 y(t-1) + a_2 y(t-2) = b_1 u(t-3) + b_2 u(t-4)$$

```
>> model = arx(z2, [2 2 3]);
>> model = sett(model,0.08);
>> u = dtrend(u2(800:900));
>> y = dtrend(y2(800:900));
>> yh = idsim(u,model);
>> plot([yh y]);
```



Pole-zero plot of the model:

```
>> zpth = th2zp(model);
>> zpplot(zpth);
```



Compare the transfer functions obtained from from non- and parametric methods:

```
>> gth = th2ff(model);
>> gs = spa(z2); gs = sett(gs,0.08);
>> bodeplot([gs gth]);
```