Loop Shaping in the 21st Century

A proposal for a 1-day pre-conference workshop at the 2016 American Controls Conference

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Abstract—We propose to reprise our highly successful workshop on loop shaping from the 2011 ACC. Loop shaping remains popular for designing SISO controllers, and several tools developed over the last fifteen years or so make it even more useful. These tools include new compensator structures (e.g., lead and lag compensators with complex poles and zeros, the complex proportional integral lead compensator, and phase-adjustable resonant filter), new visualization methods such as the Robust Bode (RBode) plot for designing for robust performance, and new techniques for phase stabilization. This one-day workshop will teach the features of these tools and how to use them effectively. We envision this workshop will be particularly valuable to the large portion of the industrial controls community in the Greater Boston area and beyond that uses loop shaping and to educators.

I. THE NEED FOR THIS WORKSHOP

Loop shaping remains a popular method for controller design for SISO systems because it is powerful and intuitive. In spite of its long history, a number of developments over the last fifteen years or so have led to new tools for making loop shaping even more useful (e.g., [1], [2], [3], [4], [5], [6], [7], [8], [9], [10]). This one-day workshop will teach the features of these tools and how to use them effectively.

This workshop will be particularly valuable to the large portion of the industrial controls community that uses loop shaping and to educators.

II. TOPICS

The advances in loop shaping of the past 15 years fall primarily in two areas. The first area is using complex zeros and complex poles for decoupling the phase contribution of a compensator from its shape at a particular frequency. (See Fig. 1.) Among other advantages, these new compensator structures more readily provide the capability of designing phase stabilized systems.

The second area is new visualization tools. The visualization tools are enhancements of the Bode plot that depict closed-loop specifications on the open-loop Bode plot. (See Fig. 2.) These tools provide the capability for designing low order controllers for robust performance from frequency response data alone. That is, realizable transfer functions are not need for the plant model, nor for the performance weighting function, nor for the uncertainty weighting function.

Fig. 1. Comparison of lead compensators with complex poles and zeros

Fig. 2. Example of an RBode plot showing the frequency response of the controller avoiding forbidden regions. The closed-loop system exhibits robust performance if and only if there are no intersections.

Our workshop with cover topics in Advanced Compensator Structures and in Advanced Techniques as follows:

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1. Advanced Compensator Structures (e.g. Fig. 1)
   a. Lead and lag compensators with complex poles and zeros [4]
   b. Phase adjustable resonance and notch filters [6]
   c. Complex proportional integral lead compensators [6]
   d. Placement of complex poles and zeros for specific angle contributions at points in the complex plane [8]

2. Advanced Techniques
   a. Phase stabilization.
      i. resonance stabilization [2]
      ii. narrow band high gain [5]
   b. Controller Design with the RBode Plot (e.g. Fig. 2)
      i. unstructured uncertainty [9]
      ii. structured uncertainty [10]

III. STRUCTURE

This 1-day workshop will consist of a series of modules of approximately 30-45 minutes. Each module will have 10-20 minutes of instruction followed by the participants using their laptops to perform loop shaping exercises using MATLAB™. We will distribute MATLAB™ code for the various compensator structures and visualization techniques for participants to use at the workshop. They may then take the software with them afterwards. We will provide copies of appropriate references.

We plan to use the head-positioning control system in hard disk drives as an example problem (Figure 3).

![Disk drive components](image)

**Figure 3. A disk drive with various components labeled.**

REFERENCES


