A New Analysis and Design Method of a PI-Like Fuzzy Logic Controller Used in Power Converters

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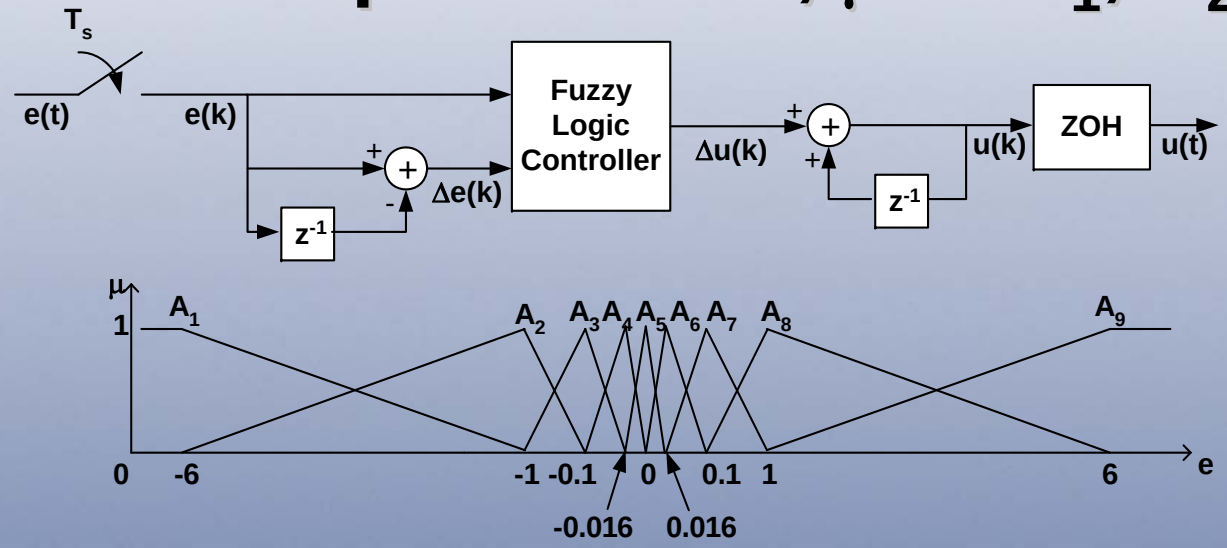
Presentation Overview

1. ***Introduction***
2. **Relationship Between the Proposed Fuzzy Logic Controller and Linear PI Control**
3. **Design Methodology of the Proposed Fuzzy Logic Controller**
4. **Simulation and Experimental Results**
5. **Conclusions**

Fuzzy Logic Control

Fuzzification process for inputs:

- Inputs are: error e[k] and change in error $\Delta e[k]$
- Membership functions, μ to A_1, A_2, etc



Defuzzification for the outputs:

- $\Delta u[k]$

Advantages of Fuzzy Logic

1. Reduced development costs
2. Good performance
3. Digital implementation
4. Ability to deal with complexity, non-linearity, and imprecise systems

Disadvantages of Fuzzy Logic

1. Controllers traditionally designed by trial and error
2. Difficult to get stability and performance analysis
3. Difficult to get transfer functions and small signal analysis

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Proposed Idea

Use linear control techniques and small signal models for the fuzzy controller design!

i.e. initialize the design with a traditional small signal design

Motivation

Exploit the advantages of liner control techniques:

- Stability and performance can be assessed
- Transfer function can be predetermined
- Easy to design a fuzzy logic controller with known dynamic performance

While exploiting the advantages of fuzzy logic control:

- Better large signal dynamic performance can be achieved

Controller Comparison

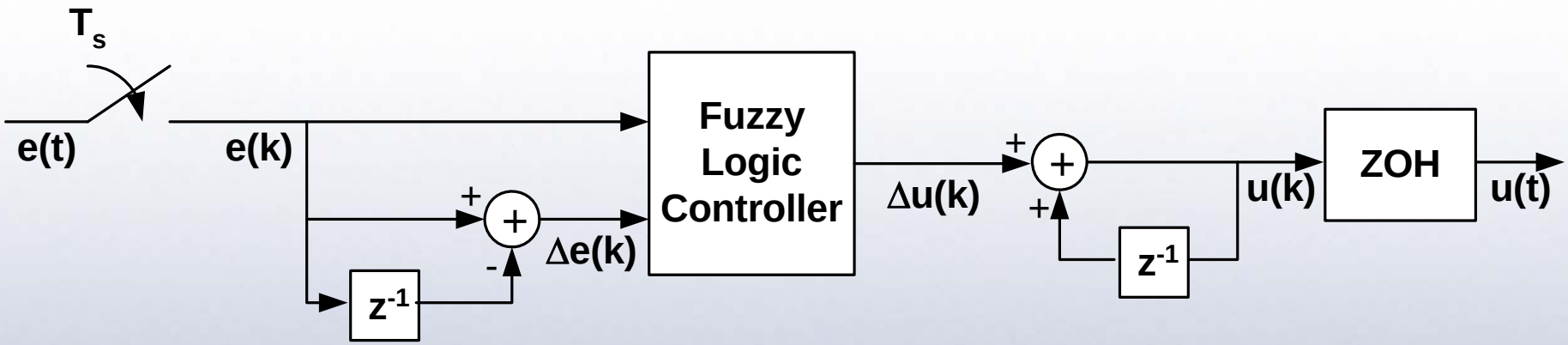

Fig. 1 Digital PI-like fuzzy logic controller

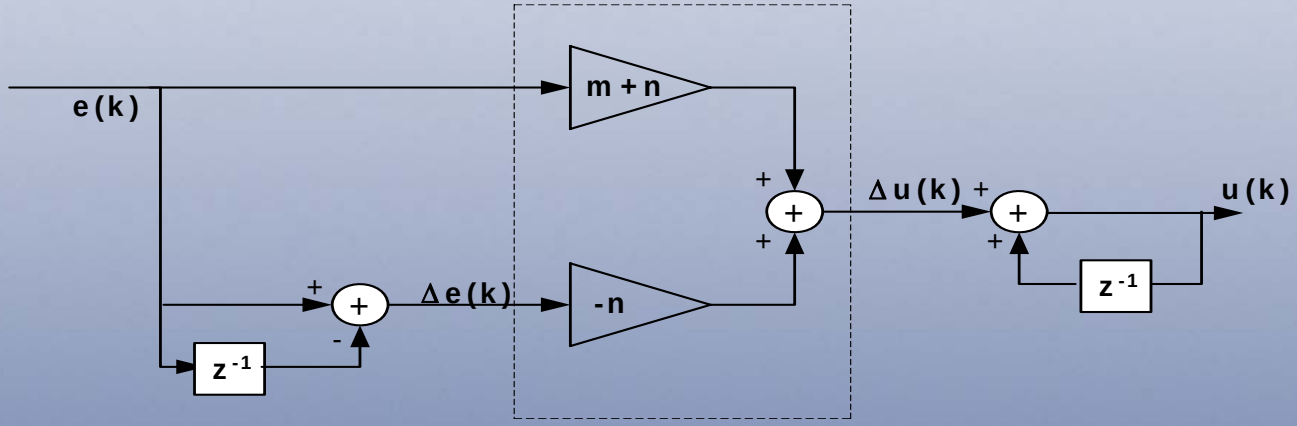

Fig. 2 Digital PI Controller

PI chosen for simplicity – other controllers can also be used

Relationship between PI-Like FLC and linear PI Controller

The discrete form of digital PI controller:

$$\Delta u(k) = (m + n)e(k) - n \cdot \Delta e(k)$$

If a Sugeno-type Fuzzy Logic Controller is used:

The initial value of the FLC control rules is chosen as:

$$\Delta u_{A_k B_k} = e_k(m + n) + \Delta e_k(-n)$$

Equations are the same, therefore:

The FLC can be made to give the same control output as the digital PI controller!

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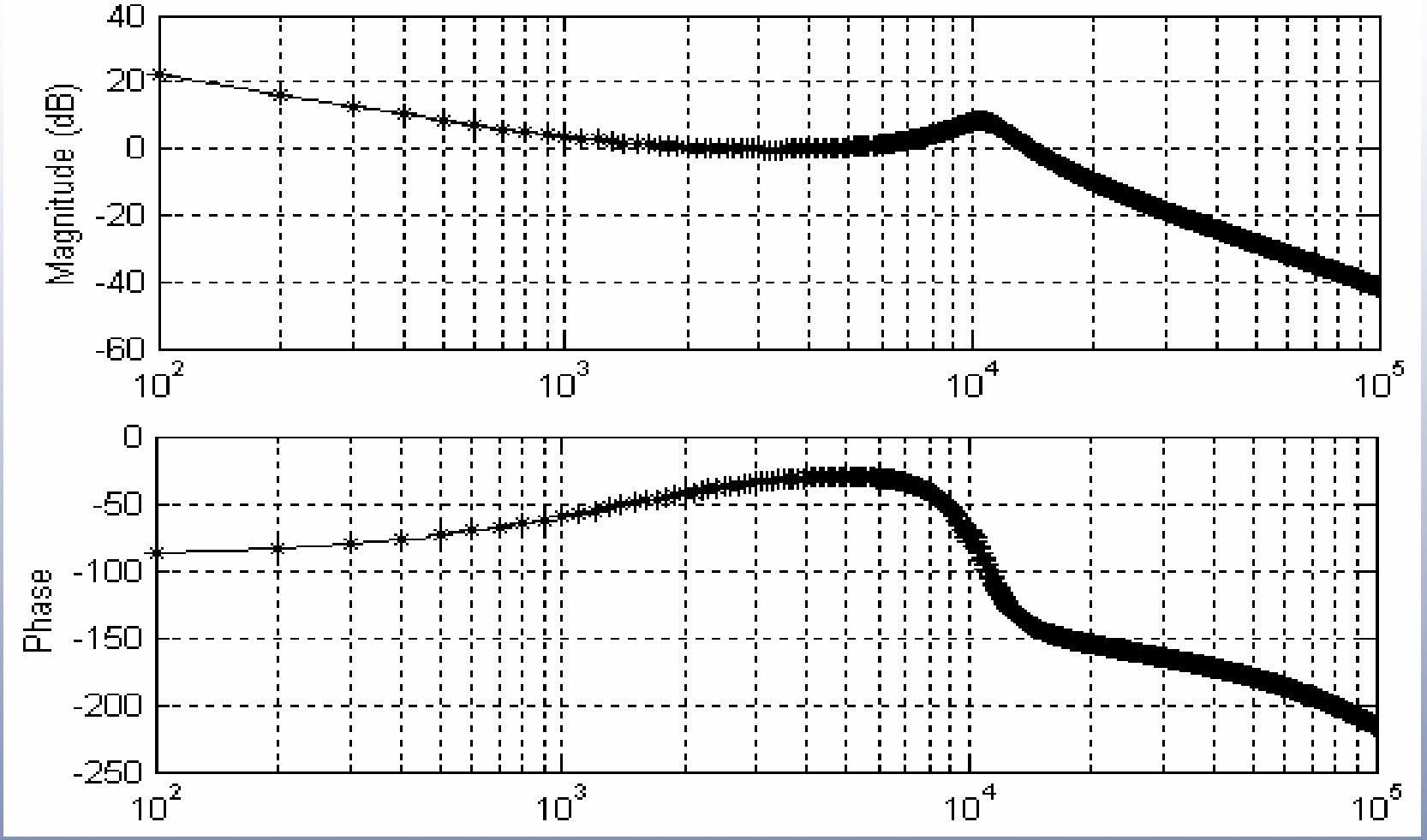
4. Simulation and Experimental Results

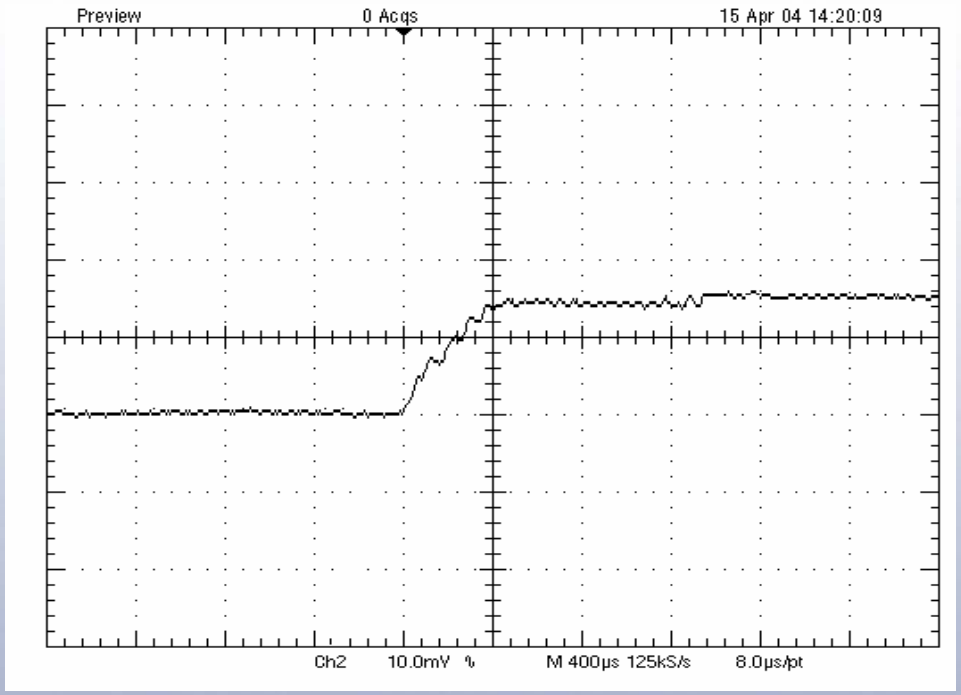
- **FPGA was used to implement the proposed fuzzy logic control algorithm with a synchronous buck converter**
- **Buck Parameters:**
  - ***Vin=5V***
  - ***Vo=2.5V***
  - **load power=25 W**
  - ***L=1μH*,**
  - ***C=235μF***
  - **ESR=1mΩ**
  - **R_L=2mΩ**
  - ***fs*=400khz**

Frequency Domain Analysis Simulation Results

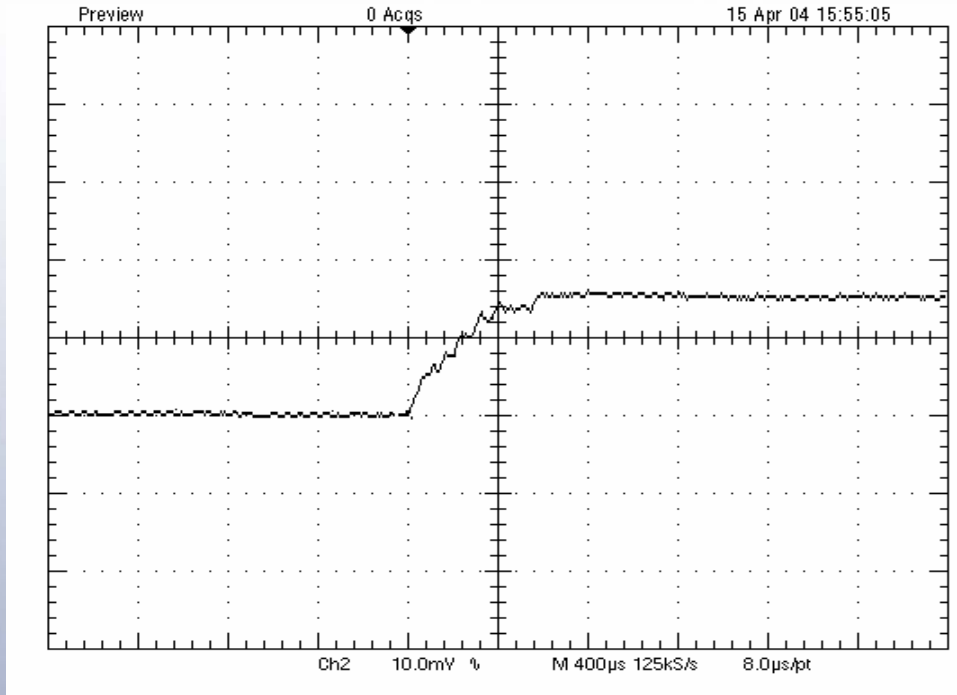


Solid Line: fuzzy logic controller,
Stars: digital PI controller

Output Voltage Response to 16 mV Small Step Reference Change



(a) Digital PI controller

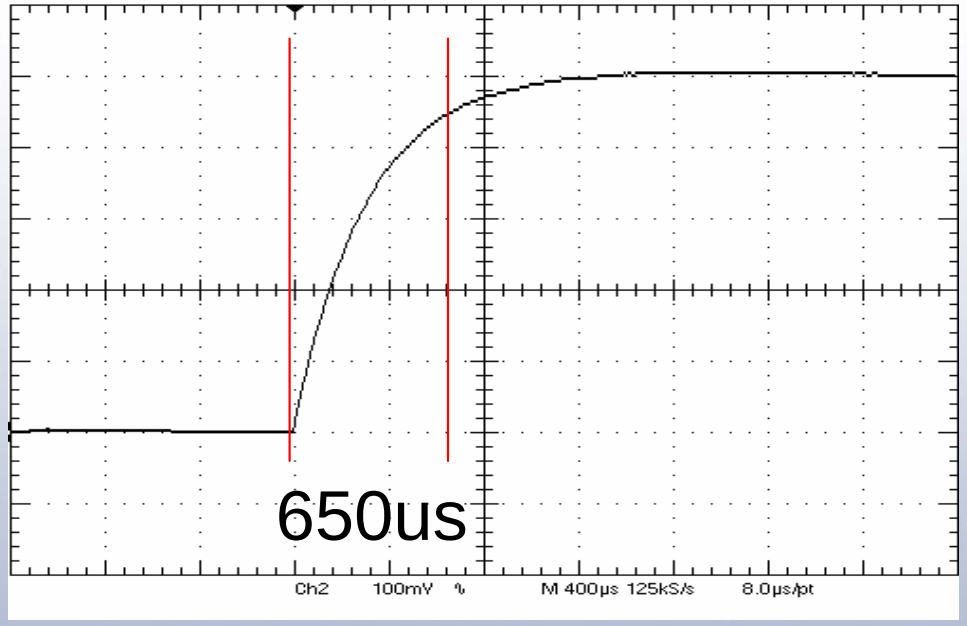


(b) Fuzzy logic controller

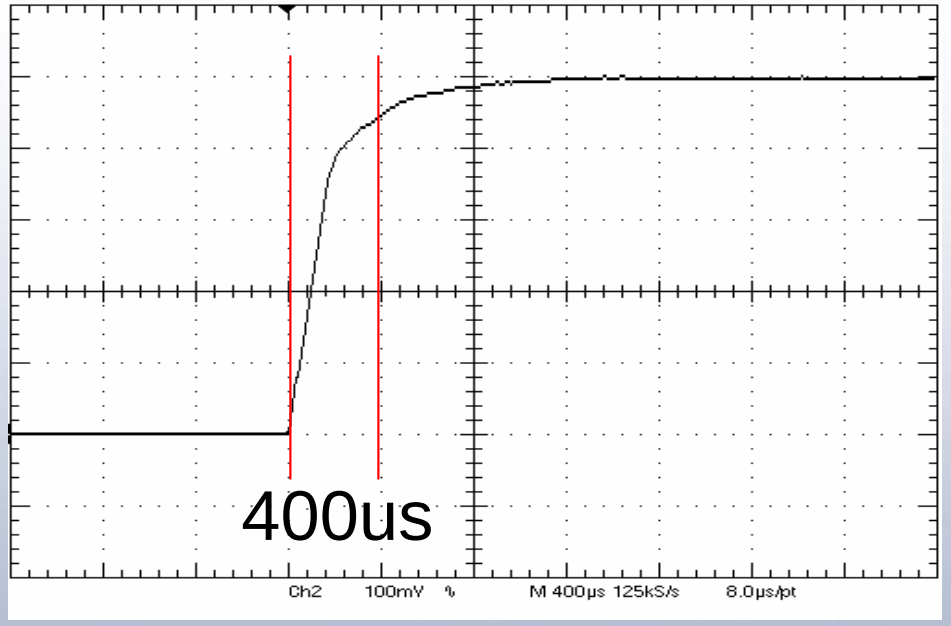
(X axis: 400us/div, Y axis: 10mv/div)

Nearly identical small signal behaviour!

Output Voltage Response to 0.5V Large Step Reference Change



(a) Digital PI controller

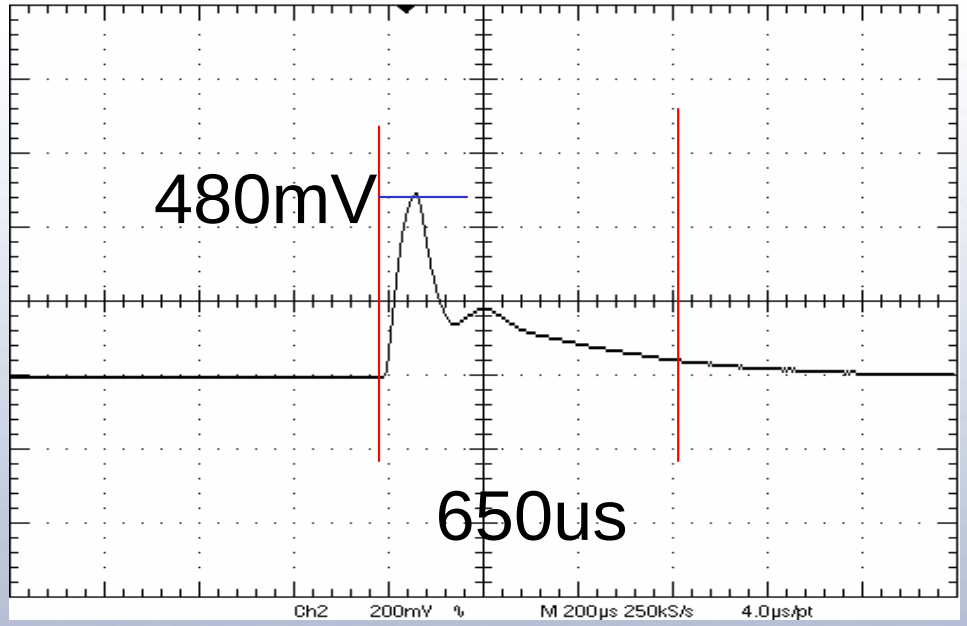


(b) Fuzzy logic controller

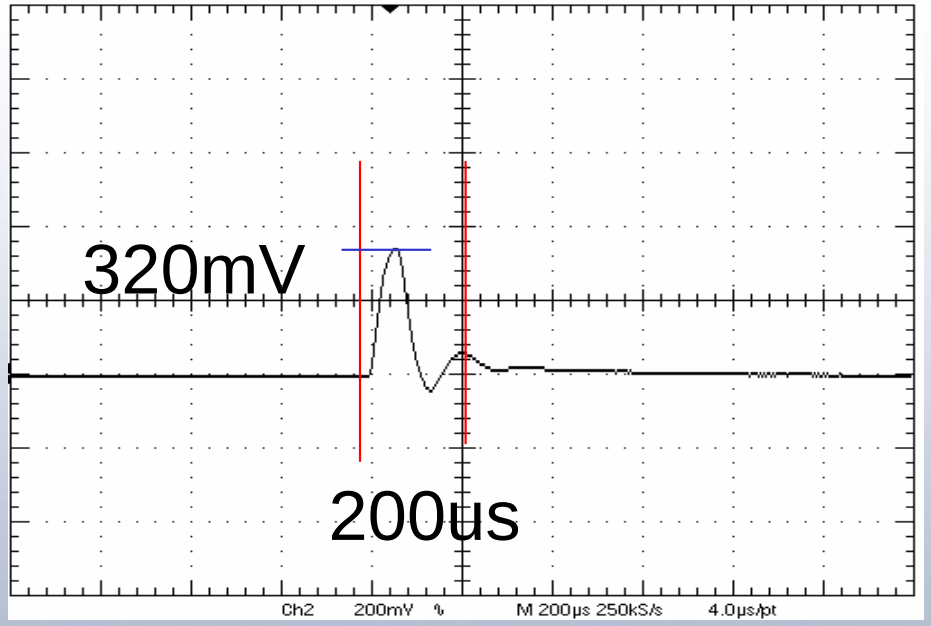
(X axis: 400us/div, Y axis: 100mv/div)

Improved large signal behaviour with FLC

Output Voltage Response to Input Voltage Change from 5V to 6V



(a) Digital PI controller

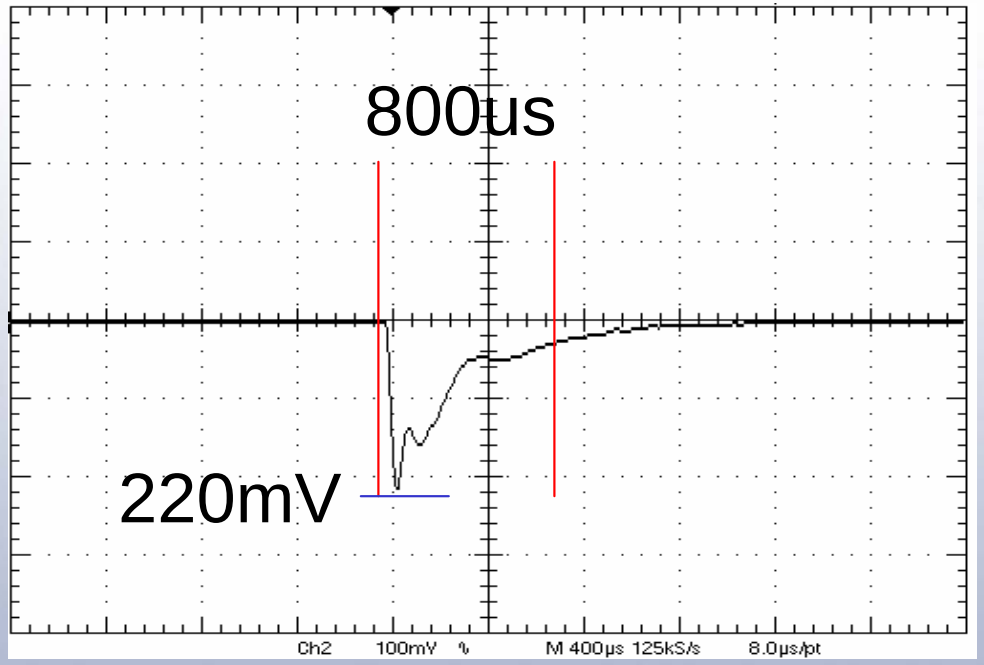


(b) Fuzzy logic controller

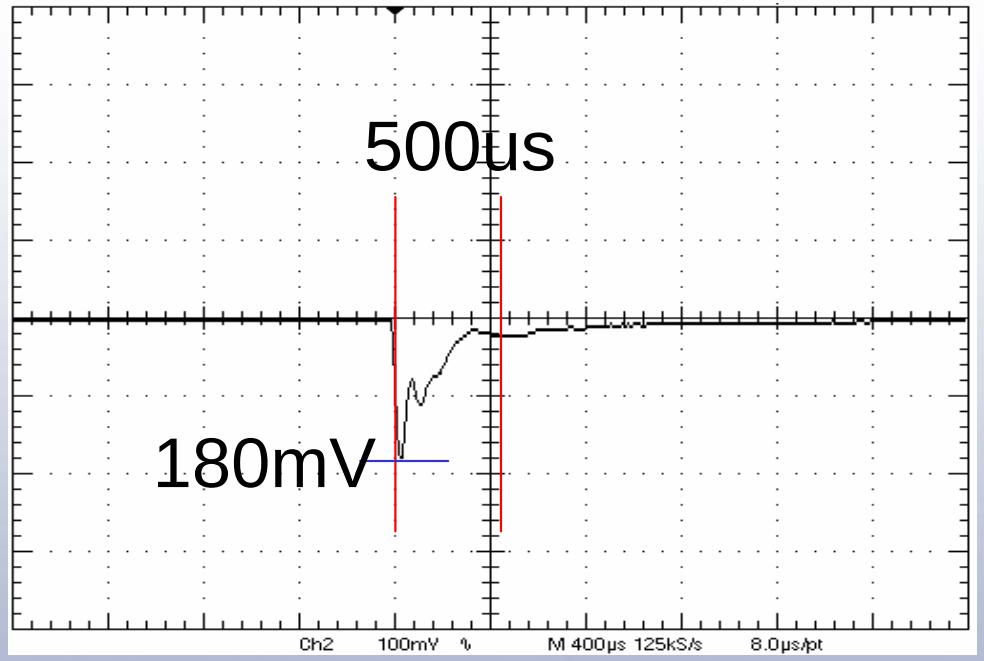
(X axis: 200us/div, Y axis: 200mv/div)

Improved large signal behaviour with FLC

Output Voltage Response
Load Step from 5A to 10A



(a) Digital PI controller



(b) Fuzzy logic controller

(X axis: 400us/div, Y axis: 100mv/div)

Improved large signal behaviour with FLC

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5. Conclusions

A method has been proposed to simplify FLC design using traditional linear controller design techniques - advantages:

1. **The small signal model of the converter and linear control techniques are initially used**
2. **Trial and error is unnecessary**
3. **Assessment of the performance and stability of fuzzy logic controller is easy**
4. **Improved large signal performance can be achieved by applying heuristic knowledge**

Thank you for attending,

Questions?