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NSTX-U PCS Neutral Beam, Global Parameter Control, and rtEFIT Post-Processing Categories

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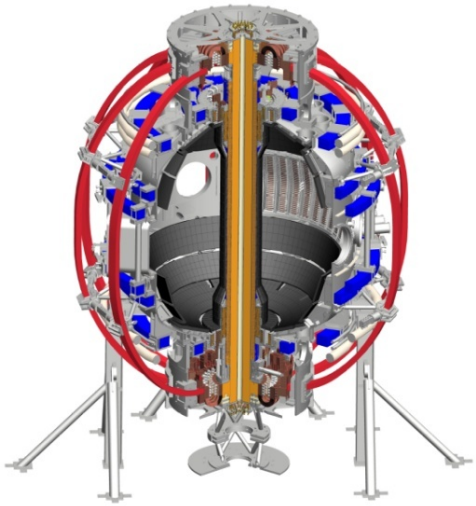
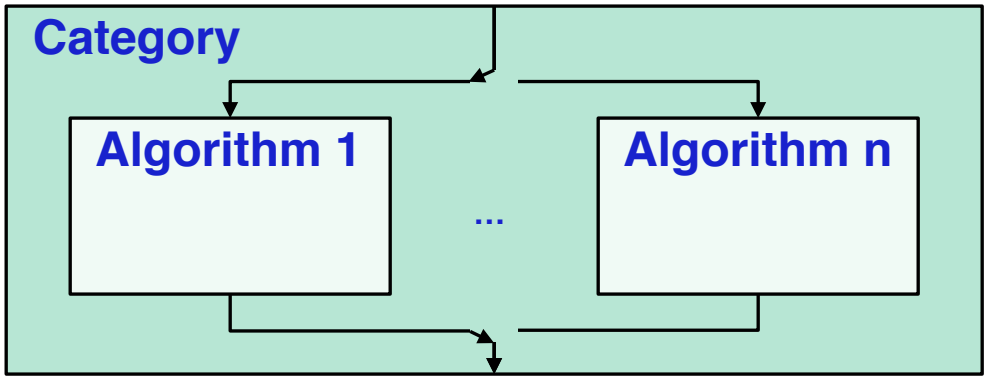


Reminder of the PCS Structure

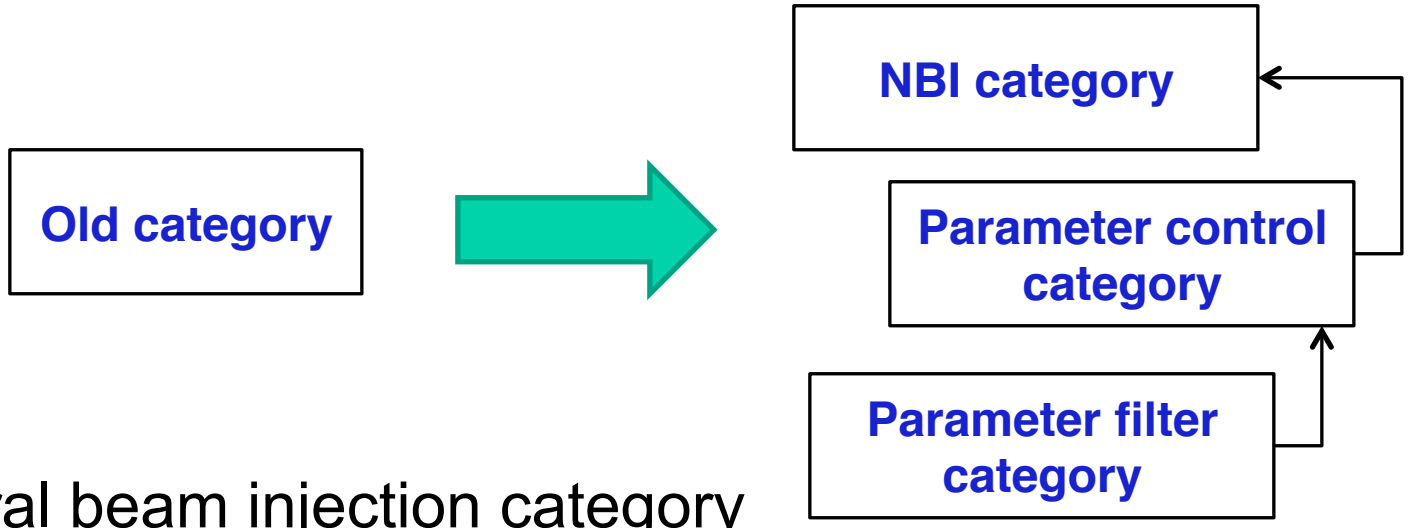
- *Category:* a place in PCS controlling a single piece of hardware or executing a specific function
- *Algorithm:* the code that does the calculations/control
- Relationship:
  - Algorithms live in categories
  - Only one algorithm from each category can run at a given time
  - All algorithms within a given category should produce the same number and function of outputs



Status when NSTX Stopped Running

- **Single algorithm** included filtering of rtEFIT outputs, β_N control loop, and code to determine beam modulations
- Algorithm:
  - Was configured for **only three beams**
  - Did not have any **mechanism for other control algorithms to command the beams**
  - Was very long, **inflexible**, not easy to follow or debug

Overview of Proposed System



- Neutral beam injection category
  - 3 algorithms for controlling the beams with different types of input requests
  - Flexible to allow different control algorithms to command the beams
- Equilibrium scalar parameter control category
  - Control algorithms for quantities like q_{min}, β_N,…
- Equilibrium parameter filter category
  - Provides filtering of the rtEFIT output, through either simple digital filters or a Kalman filter

Neutral Beam Injection Category (NBI) Overview

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- **Desired powers** (either from user input or feedback control categories) translated to **duty cycles** based on (GUI editable) beam powers
- **Output** will be a set of 6 binary signals that control **whether each beam is 'blocked' or not**
- **Minimum on and off times** for each beam (GUI editable) are enforced
- **Maximum number of blocks** (GUI editable) is enforced

NBI Algorithm #1: Individual Power Control (IPC)

- Desired power of each beam specified from **waveforms** or **other category**
- Power is converted to duty cycles
- **Modulation status** of each beam determined from duty cycle needed to achieve desired power and minimum on/off times
- Each source has a **default behavior** that is used **if its maximum number of blocks is reached**

NBI Algorithm #2: Total Power Control (TPC)

- A **total power** request is input from **waveform** or **another category**
- Only **one source is modulated** at any given time
  - Which source is modulated depends on a "batting order", editable in a GUI
  - Once the source reaches its **max # of blocks**, another source is used

For a 5MW request:

Batting Order	2	3	4	6	5	1
Max power (MW)	2	2	2	2	2	2
Duty Cycle	100%	100%	50%	0%	0%	0%

- Operator can specify **certain beams** to be **removed** from modulation algorithm
- Total power request is ultimately converted to duty cycles for each source
  - And duty cycles converted to modulations as in the previous algorithm

NBI Algorithm #3: Ramp down

- This algorithm is provided in order to provide **a smooth but rapid ramp-down of the injected power**, for either planned or unplanned discharge terminations
- It shall be specified at some point in the future

Global Parameter Control Category (GPC) Overview

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- Algorithms for **controlling scalar quantities** related to the plasma equilibrium
- 5 target quantities chosen from:

Symbol	Definition	Units	
W_{MHD}	Stored kinetic energy	kJ	
β_T	Beta toroidal	—	***Choose 1***
β_N	Normalized Beta	—	
β_P	Beta poloidal	—	
W_B	Stored magnetic energy	kJ	***Choose 1***
l_i	Normalized internal inductance	—	
q_0	Safety factor on-axis	—	
q_{min}	Minimum safety factor	—	
q_{95}	Safety factor at 95% flux surface	—	***Choose 3***
q^*	Cylindrical safety factor	—	
$\hat{\rho}\left(q_{min}\right)$	Radius of the minimum safety factor	—	
I_{meas}	Total plasma current	MA	

Global Parameter Control Category (GPC): Outputs

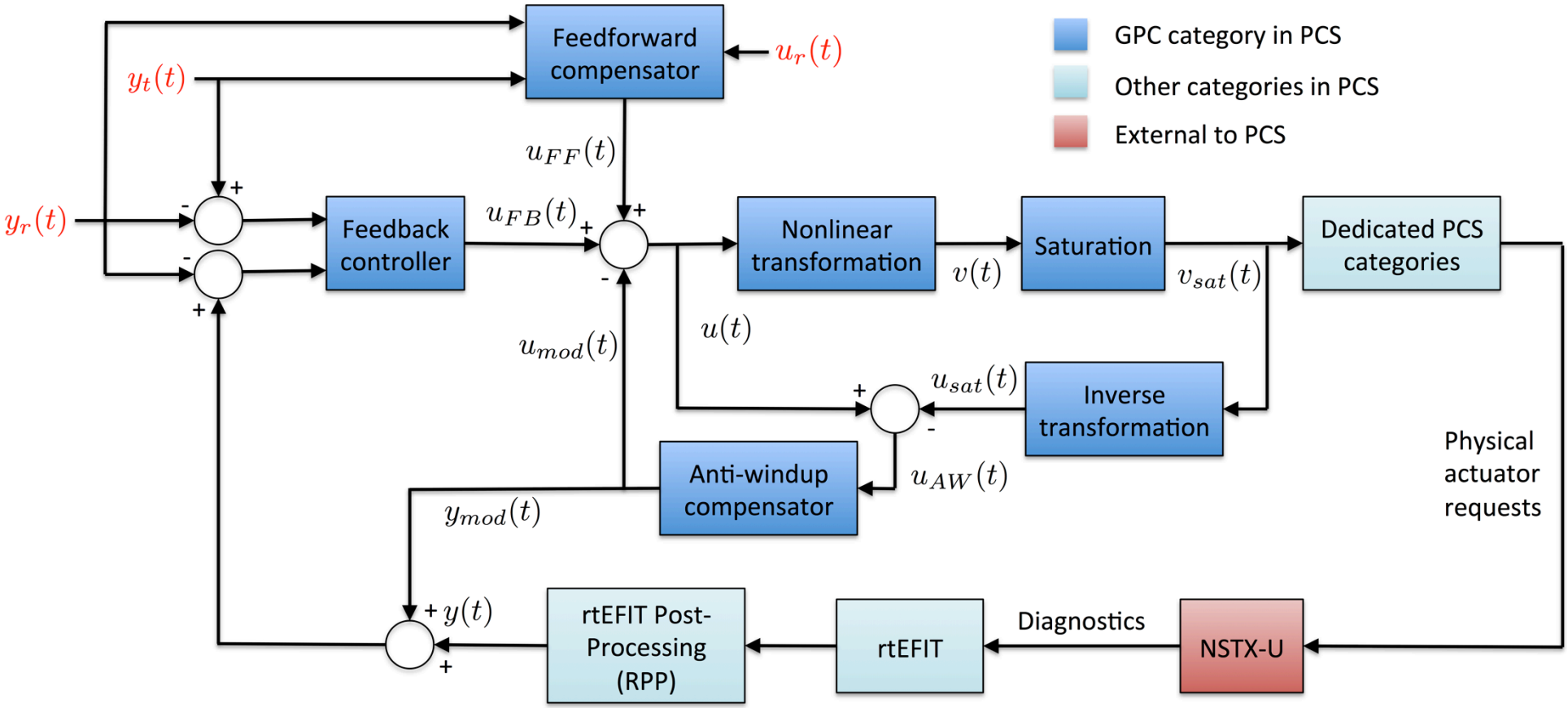
- Output will be a set of requests to be sent to other categories:

Symbol	Definition	Units	Category	
V_{loop}	Loop voltage	V	IpOH	Choose 1
I_p	Total plasma current	MA	IpOH	
$\bar{n}$	Line-averaged density	$\# \times 10^{19}/m^3$	Density	
g_{outer}	outer-gap size	m	ISOFLUX	
P_{tot}	Total beam power	MW	NBI	Choose 1
P_n	Individual power for beam n	MW	NBI	
I_{TF}	Toroidal field current	MA	TF	

GPC Algorithm #1: State-space Controller 1 (SC1)

- **Flexible** structure to enable variety of control experiments to be performed
- **Target waveforms** entered from GUI
- **Feedforward actuators** calculated online or entered by operator
- **Feedback control** implemented as **matrix multiplication**
- **Controller parameters** loaded from text files
- Optional **nonlinear transformations** of controller outputs to help account for system nonlinearities and put the output into the correct scale/units
- Includes **saturation** to prevent violation of actuator constraints and **anti-windup** to reduce effects of the imposed actuator limits on controller performance

GPC Algorithm #1: State-space Controller 1 (SC1)



rtEFIT Post-Processing Category (RPP) Overview

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- Algorithms will **perform operations on the output of rtEFIT** to prepare it for use by GPC (or future profile control category)
- **Deglitching and smoothing** to minimize spikes and noise
- **Observers** to improve parameter estimation by merging measured data with **dynamic models**

RPP Algorithm #1: Data Smoothing (DS)

- Checks for **invalid data**
  - rtEFIT valid data flag
  - Limits change in parameters from cycle to cycle to within expected range (GUI editable)
- Applies **median filter**
  - GUI editable filter time window
- Applies **smoothing filter**
  - GUI editable filter constants

Issues, extensions

- Handling transitions between controllers
  - Need to avoid jumps in physical actuator requests by carefully handling transition
  - Planning to implement a `fuzzy logic' type solution, but specifics may differ for each type of actuator
- Enable time-varying controller matrices
  - Upload multiple matrices and use a waveform to schedule updates
  - Can be done to some degree in the present specification by using different phases
- Use as the basis for the design of profile control category
  - Code for most necessary actuators will be developed for the GPC category
  - Some additional code will be needed for providing full profile information from RPP
  - Controller calculations will be very similar