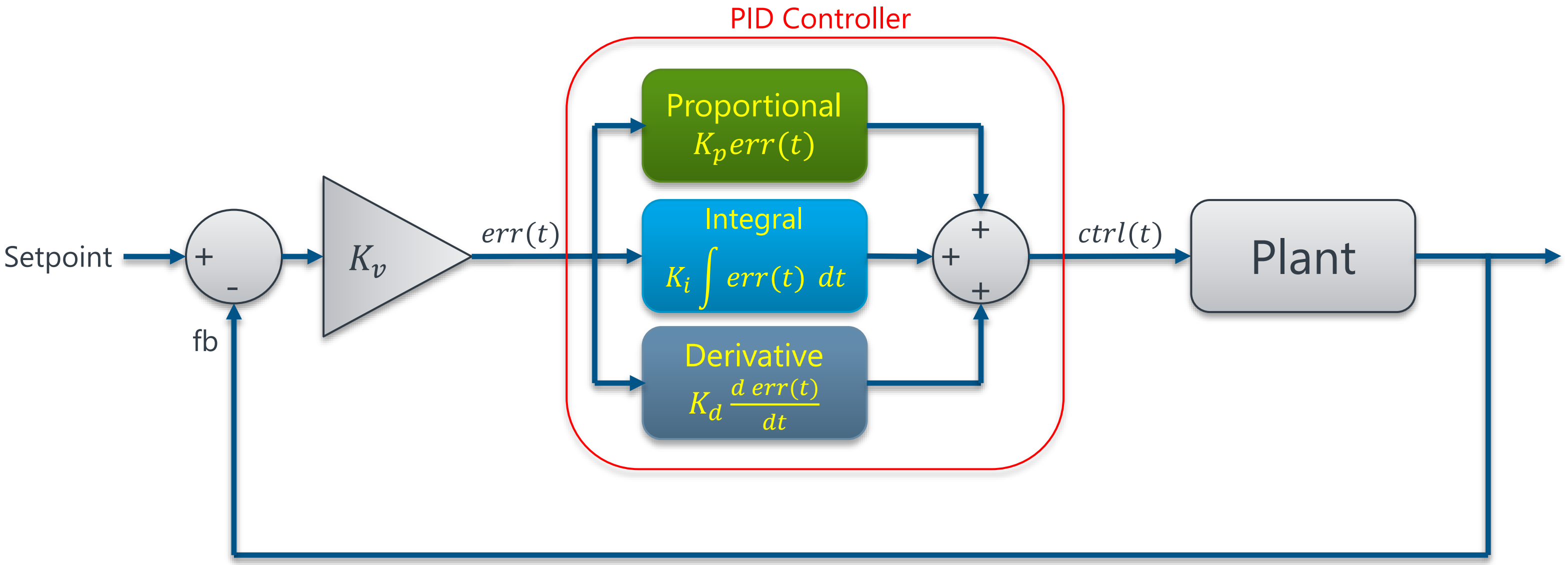
Qspice C++ Discrete PID Controller Implementation

Member : KSKelvin
Member : RDunn
https://forum.qorvo.com/

Last Update : 10-10-2023

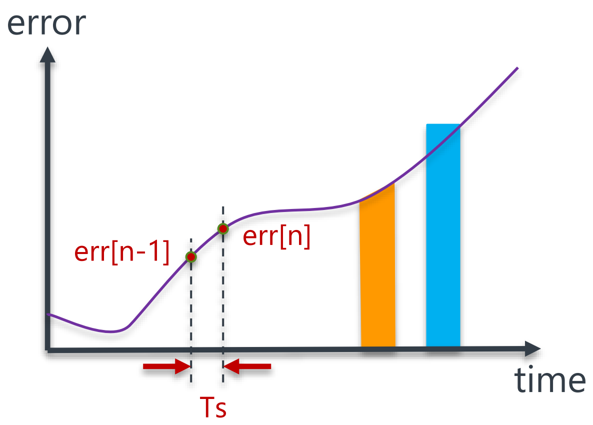
C++ PID Controller for Qspice

- Information
  - Project Title : C++ PID controller for Qspice
  - Performed by two Qspice forum members : KSKelvin and RDunn
  - Project file location : https://github.com/robdunn4/QSpice
  - Description : Proportional-Integral-Derivative (PID) control is the most frequently used control algorithm in control system, this project implement a digital PID with a Ø-Device in Qspice



Discrete PID Controller Implementation

- Fundamental of PID Controller
  - Time formula
    - $ctrl(t) = K_p err(t) + K_i \int err(t)\,dt + K_d \frac{d\,err(t)}{dt}$
    - $err(t) = K_v \times (setpt(t) - fb(t))$
      - In general, $K_v = 1$ for textbook PID controller
      - K_v is for ease of overall gain adjustment, for example, it is useful to adjust loop gain without affecting phase in bode plot
  - Laplace function : $G_c(s) = \frac{err}{ctrl} = K_p + \frac{K_i}{s} + K_d s$
  - Discrete formula
    - $ctrl[n] = K_v \times (setpt[n] - fb[n])$
    - $ctrl[n] = K_p \times err_p[n] + K_i \times err_i[n] + K_d \times err_d[n]$
      - proportional error : $err_p[n] = err[n]$
      - integral error (Trapezoidal rule) : $err_i[n] = (err[n] + err[n-1]) \times \frac{T_s}{2} + err_i[n-1]$
      - integral error (Rectangle method) : $err_i[n] = err[n] \times T_s + err_i[n-1]$
      - derivative error : $err_d[n] = \frac{err[n]-err[n-1]}{T_s}$
      - T_s is sampling period (i.e. = 1 / clock frequency)

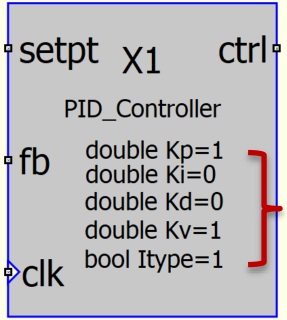


Part 1
Implementation of PID Controller in C++

PID C++ Implementation

Qspice : pid_controller.qsym ; pid_controller.cpp

- pid_controller.qsym
  - I/Os
    - clk : input (↑ trigger)
    - setpt : input
    - fb : input
    - ctrl : output
  - Input parameters
    - Kp, Ki and Kd : PID gain
    - Kv : Overall gain
  - C++ file
    - pid_controller.cpp



pid_controller symbol in Qspice

Default Value

Itype:
0=rectangular integration
1=trapezoidal integration

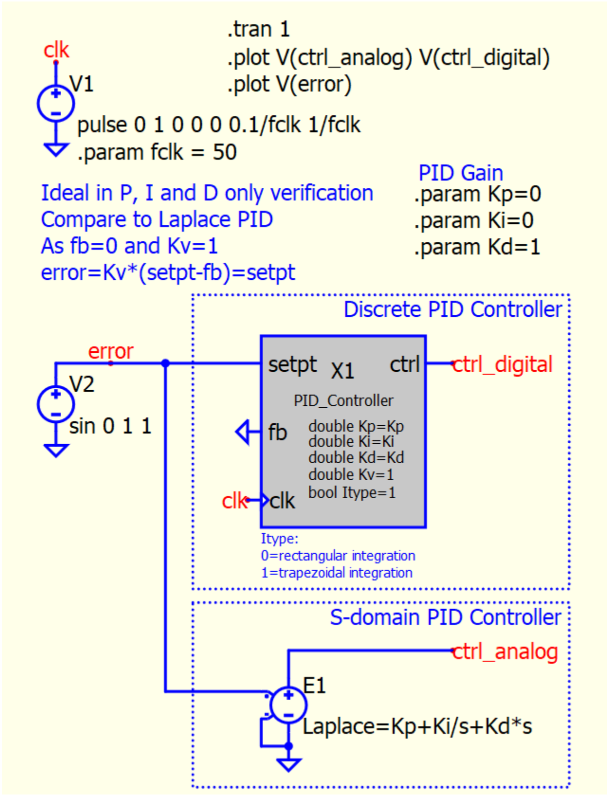
Main Code (written by RDunn)

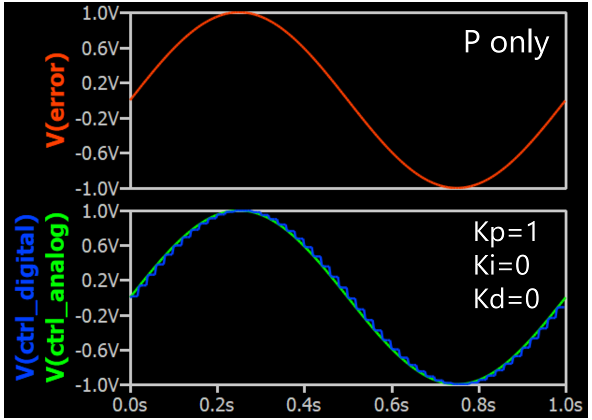
```
// if not rising clock edge, we're done
if (clk == inst->clk_n1) {
  if (!clk) {
    inst->clk_n1 = clk;
    return;
  }
}

// save clock state
inst->clk_n1 = clk;

// time between samples
double Tsampling = t - inst->lastT;
inst->lastT      = t;

// calculate error
double error = Kv * (setpt - fb);

// calculate proportional, integral and derivative error
double errorP = error;

double errorI;
if (Itype)   // trapezoidal rule
  errorI = (error + inst->error_n1) * Tsampling / 2 + inst->errorI_n1;
else   // rectangular method
  errorI = error * Tsampling + inst->errorI_n1;

double errorD = (error - inst->error_n1) / Tsampling;

// PID formula
ctrl = Kp * errorP + Ki * errorI + Kd * errorD;

// store [n-1] sampling
inst->error_n1  = error;    // error[n-1] = error[n]
inst->errorI_n1 = errorI;   // errorI[n-1] = errorI[n]
```

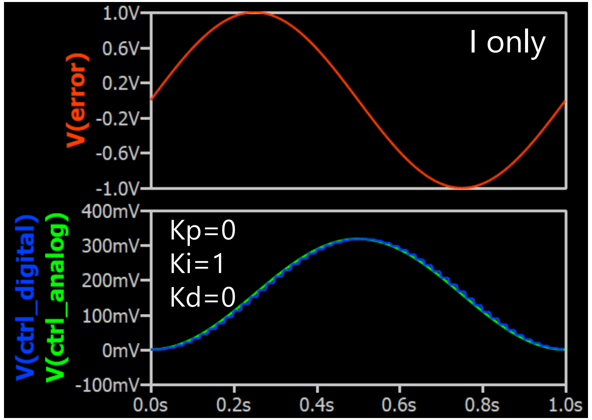
T_s sampling time is calculated in code, not a user input parameter

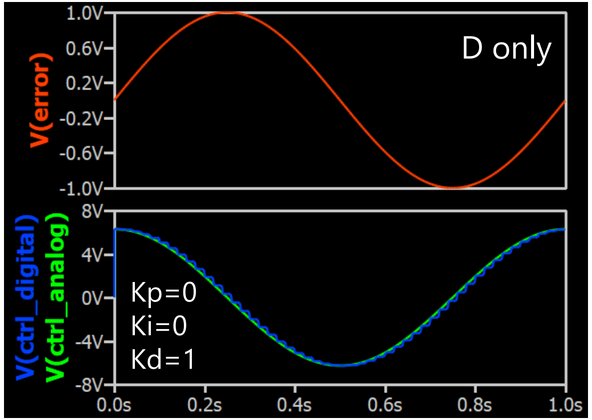
PID C++ Controller Algorithm Verification

Qspice : Parent - PID_Controller - Discrete and Laplace.qsch







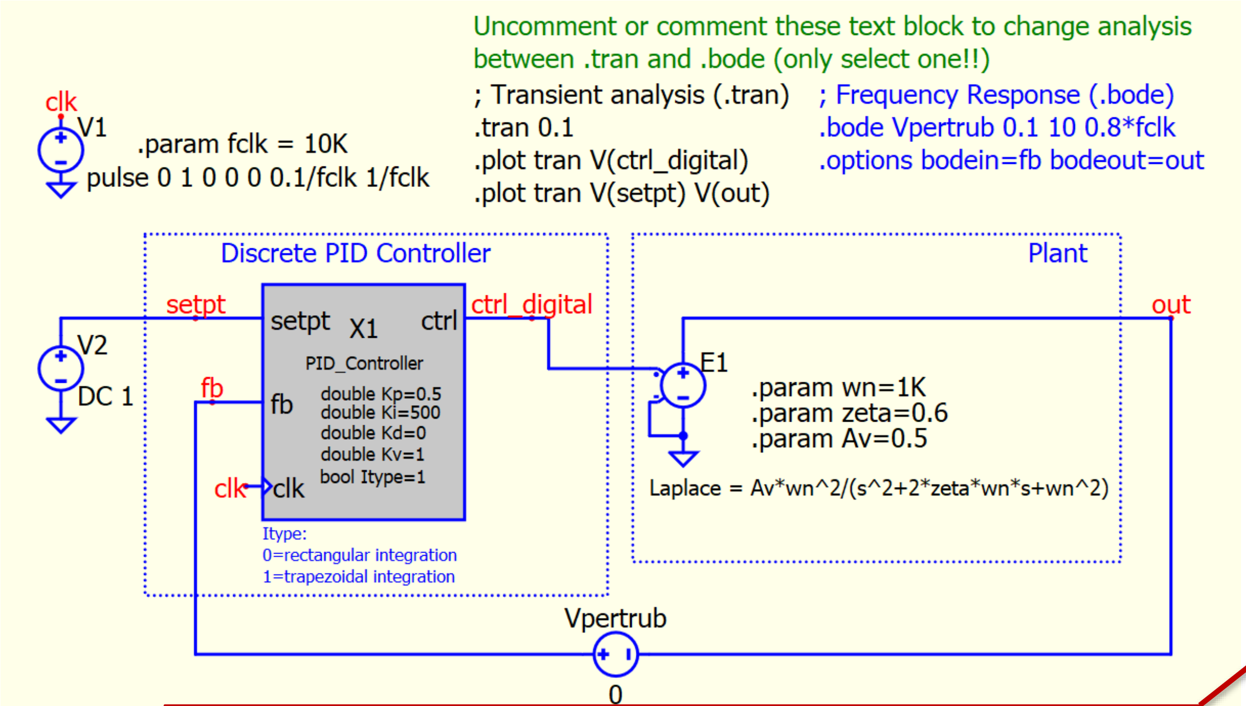


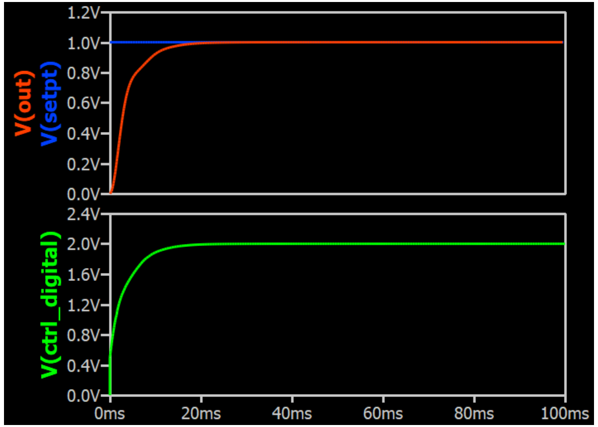
- Conclusion
  - PID controller C++ block is compared to Laplace E-source in Qspice to verify concept and equation are properly implemented

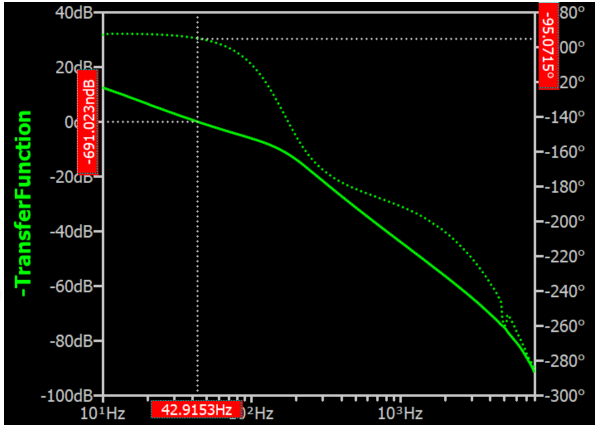
Part 2
Close Loop Examples

Example 1 : Second-Order Laplace System with PID Control

Qspice : Parent - PID_Controller - Second-Order Laplace.qsch







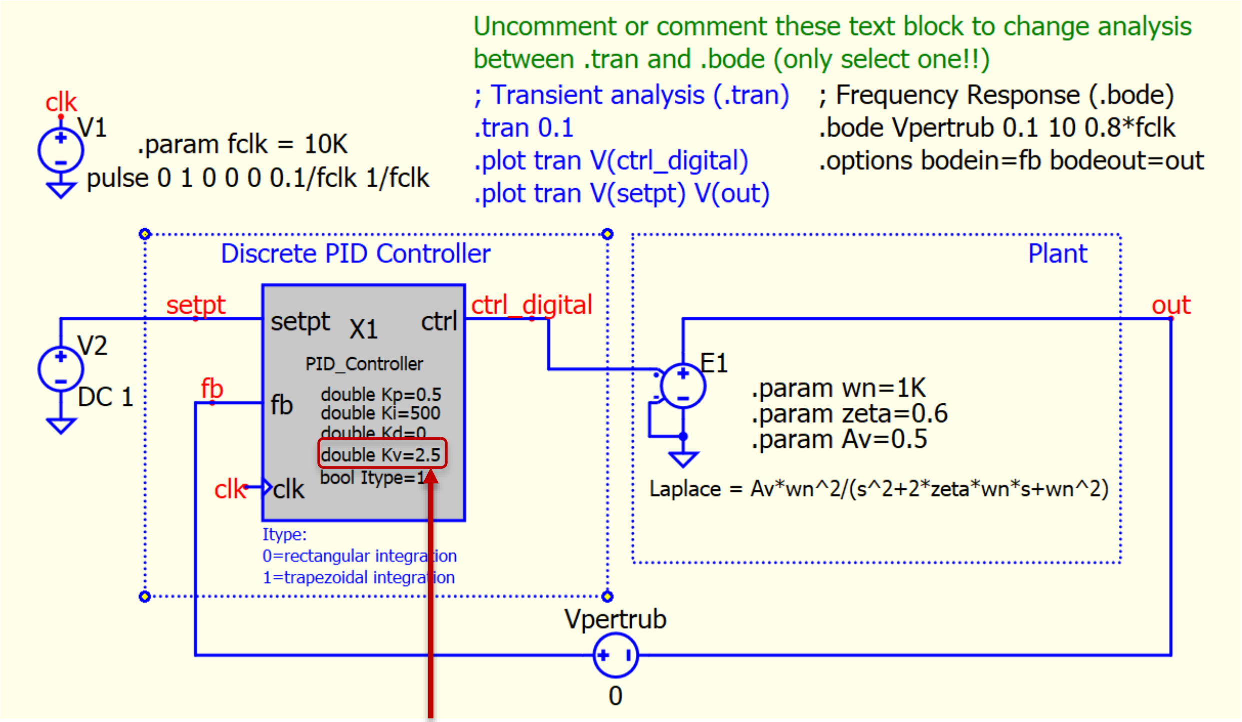
Why –ve TransferFunction is used (use +ve or –ve depends on your practice)

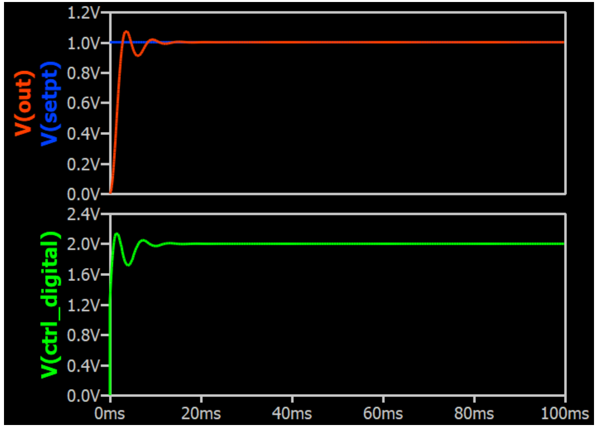
- TransferFunction = bodein/bodeout = fb/out
- GH(s) = -fb/out = -TransferFunction

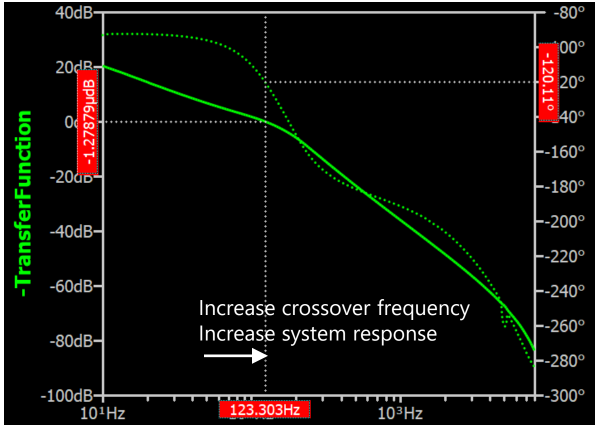
But discussion of .bode is not the scope of this presentation

Example 1 : Second-Order Laplace System with PID Control

Qspice : Parent - PID_Controller - Second-Order Laplace.qsch







Tune system response by adjusting overall gain (Kv) from 1 to 2.5

Therefore, Gain increased by $20\log_{10}(2.5) = 7.96\text{dB}$

Example 2 : Close Loop control of a Buck Converter

Qspice : Parent - PID_Controller - Buck Converter.qsch

- Close Loop Control of Buck Converter
  - This is a demo to use PID controller for switching mode power supply
  - Sawtooth frequency set to 50kHz and controller sampling frequency set to 1MHz (20 times of switching action)
  - As this is an ideal discrete controller, if Vsetpt reduce Vsetpt rise time, V(ctrl) will shoot up further as derivative error $err_d = \frac{\Delta error}{\Delta t}$, and if rise time tends to 0s, $err_d \rightarrow \infty$ and give a huge V(ctrl)
    - A voltage limiter can be added at PID output to restrict its min and max output voltage