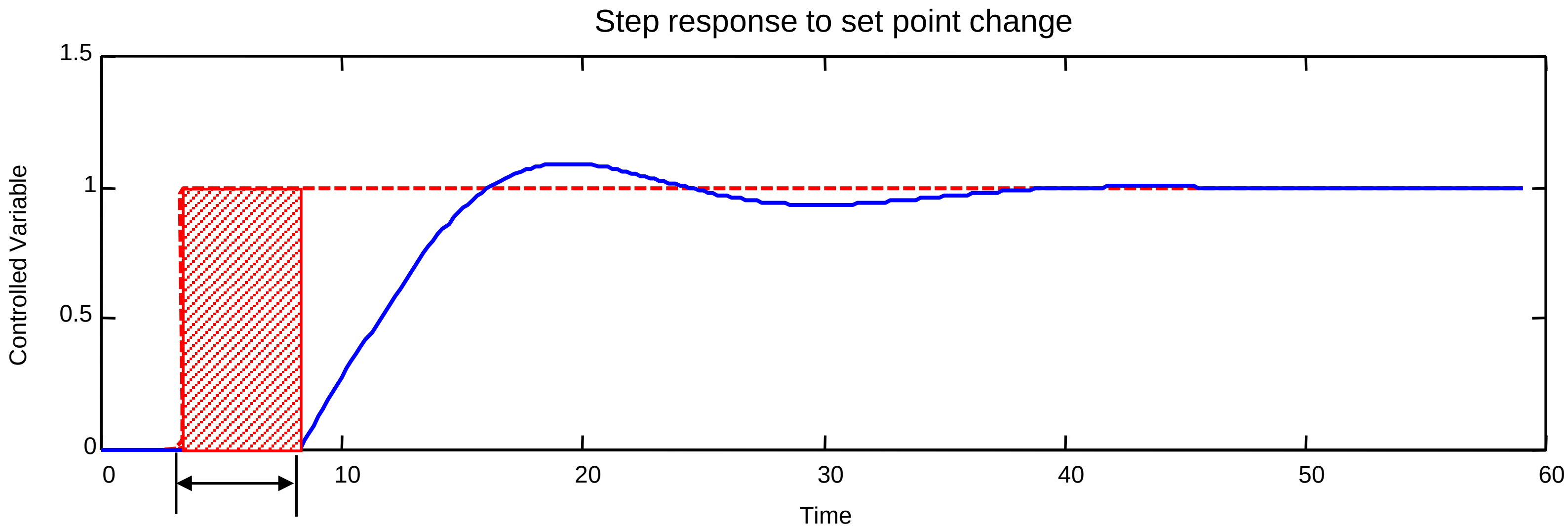
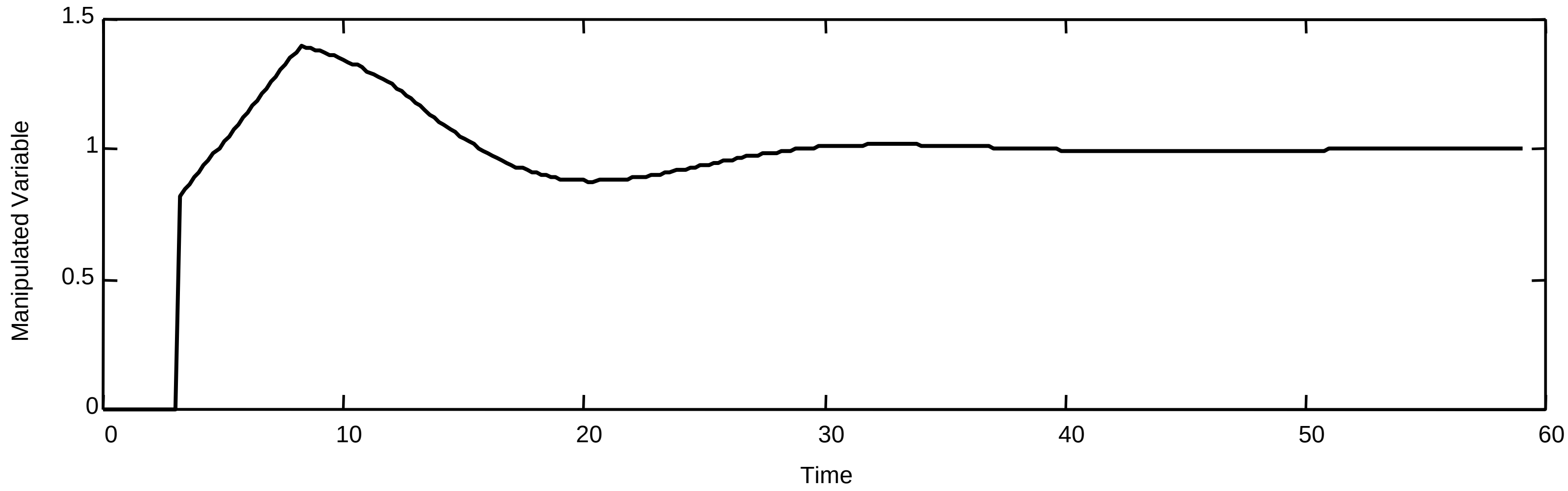
These slides are from Dr. Thomas Marlin

Feedback dead time limits best possible performance

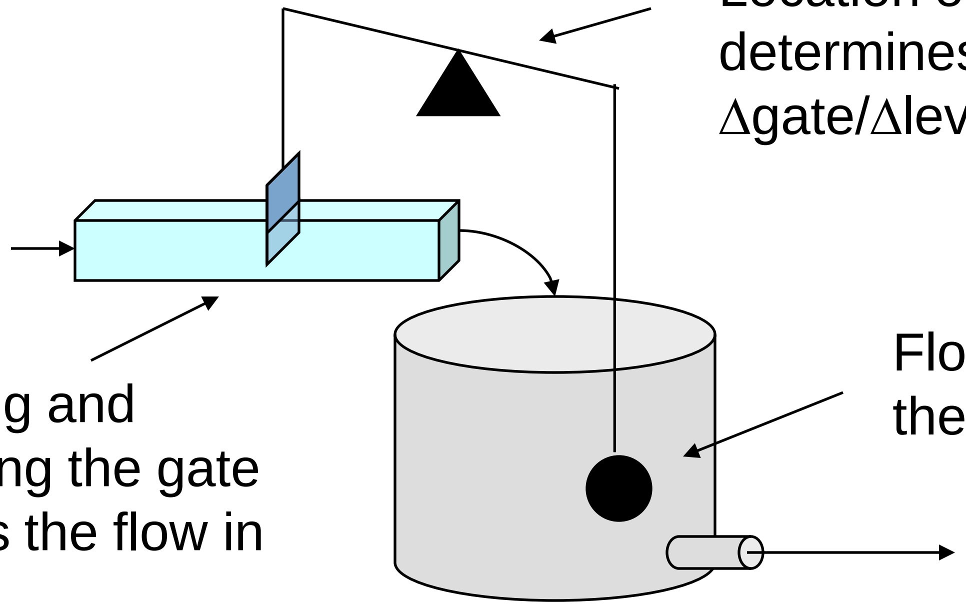


θ = dead time



Mechanical Device

The value of the variable is represented by position of equipment.



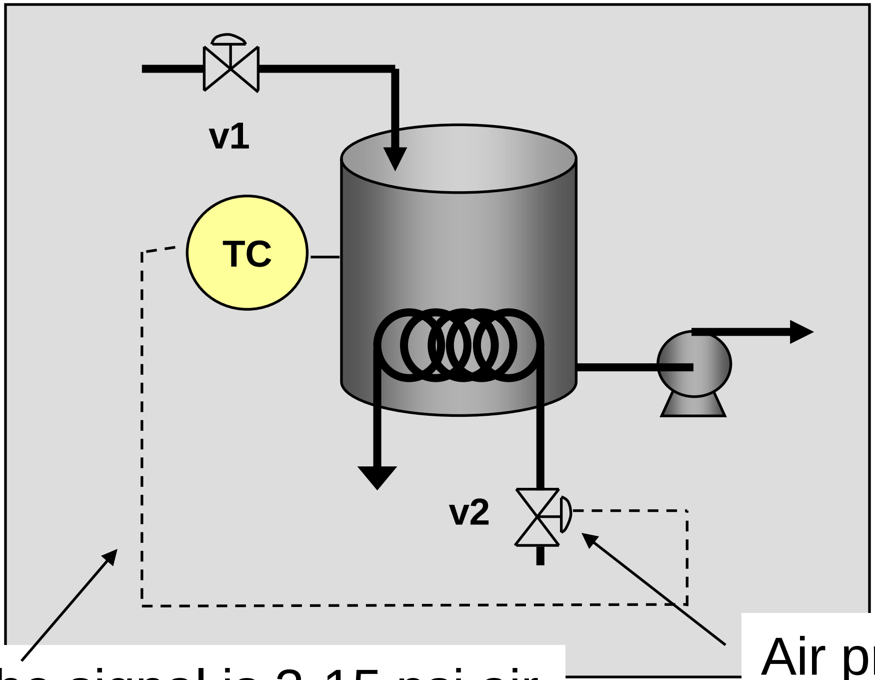
Location of the fulcrum determines the Δgate/Δlevel

Raising and lowering the gate affects the flow in

Float measures the liquid level

Pneumatic Device

The value of the variable is proportional to air pressure (50 to 150°C = 3 to 15 psi).

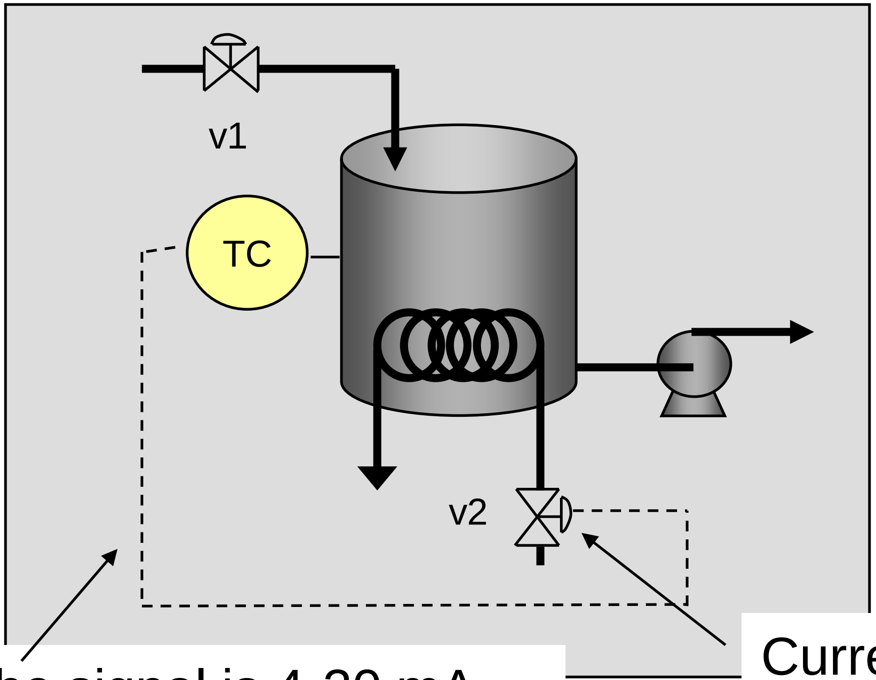


The signal is 3-15 psi air pressure in a pipe.

Air pressure moves flexible diaphragm

Electronic Device

The variable is proportional to current or voltage (50 to 150°C = 4 to 20 mA).



The signal is 4-20 mA transmitted by wire

Current converted to air pressure to affect valve

$$MV(t) = K_c \left[E(t) + \frac{1}{T_I} \int_0^t E(t')dt' - T_d \frac{d\,CV}{dt} \right] + I$$

Build a physical system that (approximately) obeys the same model.

Pneumatic

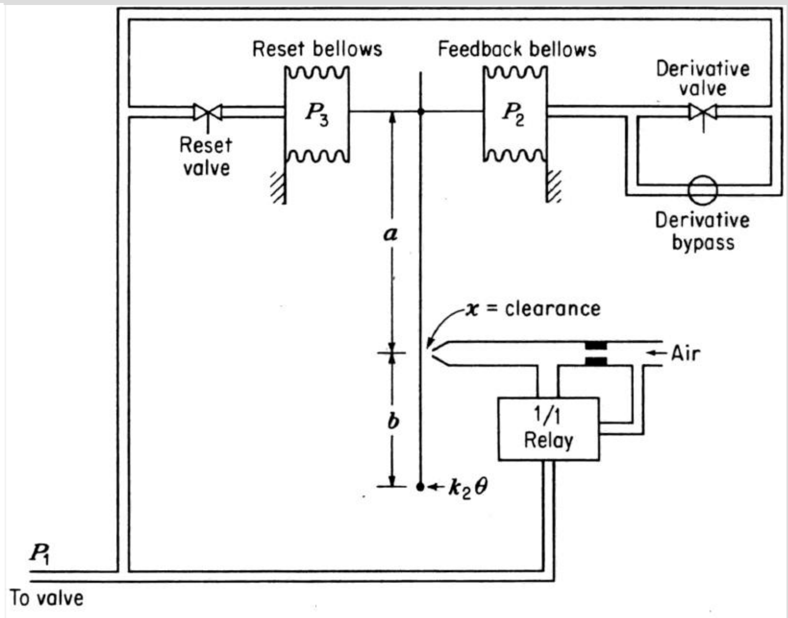


FIGURE 6-9 Three-mode controller with parallel feedback.

Electronic

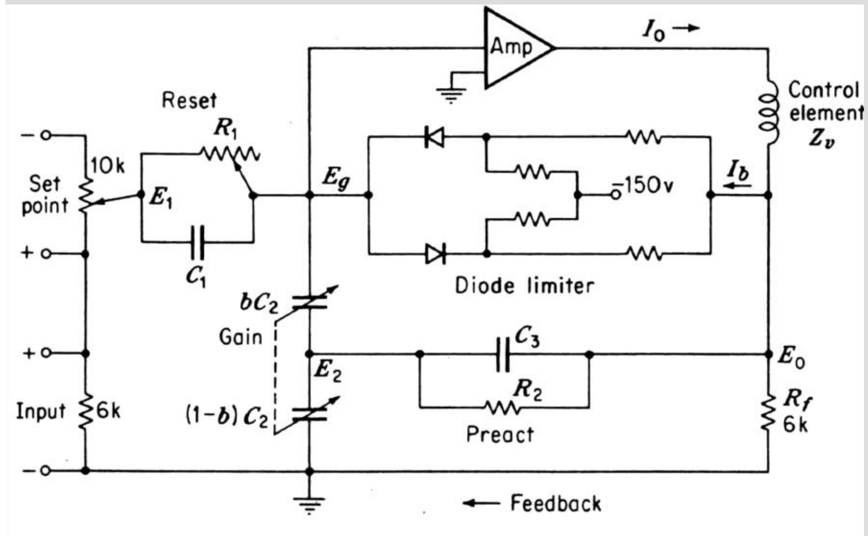


FIGURE 6-15 Simplified diagram of Taylor Transcope electronic controller, model 70RF.

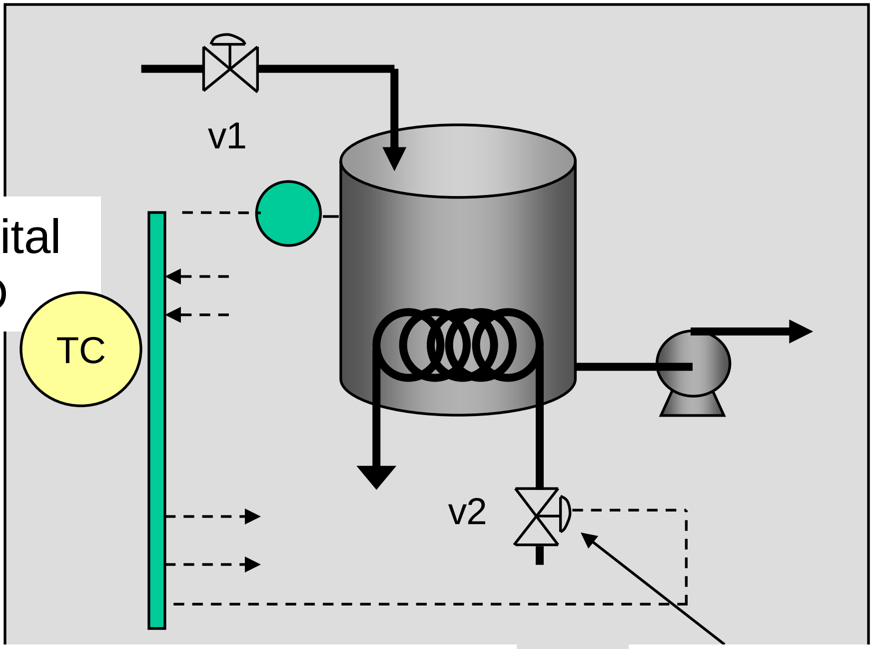
From Harriott, P., Process Control, McGraw-Hill, New York, 1964

Digital Calculation and Communication

Digital calculations with transmission over the local area network (LAN).

Sensor and valve can have microprocessors too!

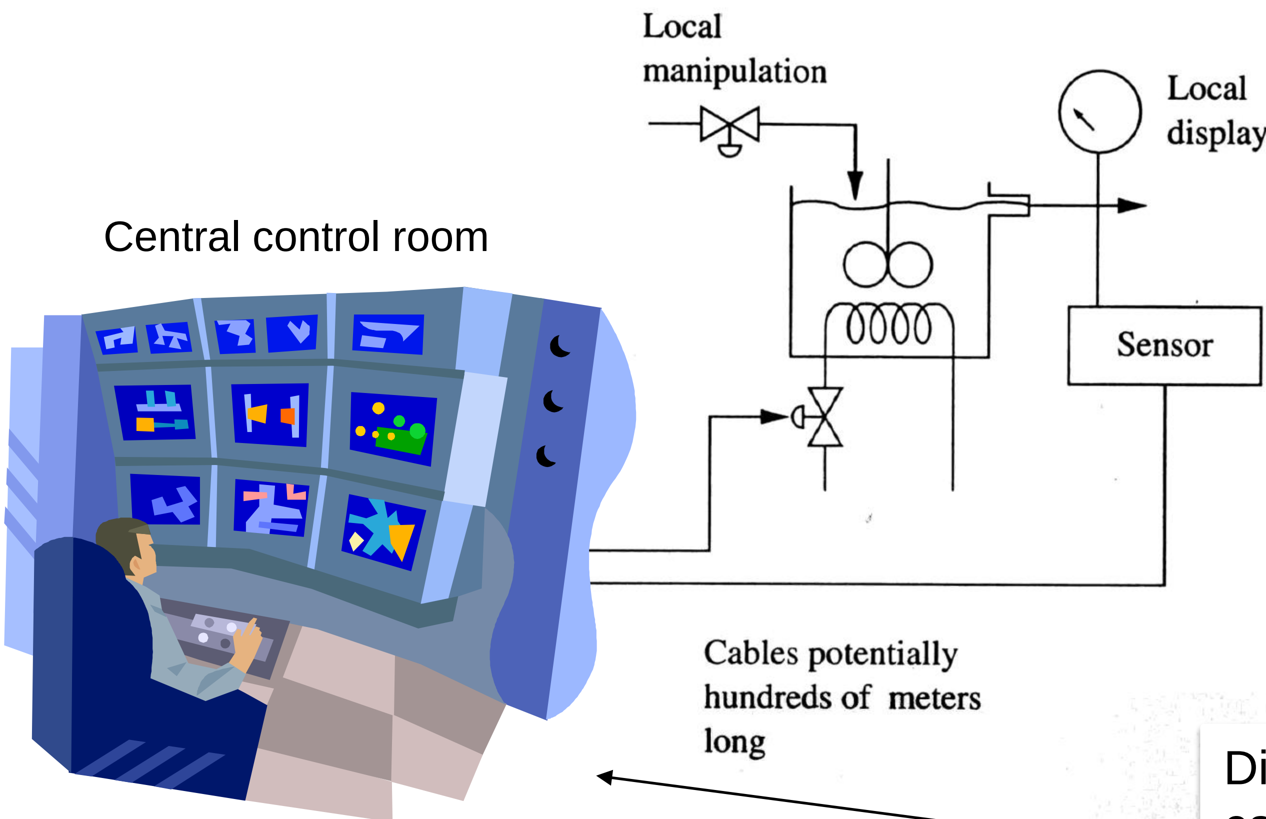
Digital PID



The signal transmitted digitally.

converted to air pressure to affect valve

Let's remember that control is performed many places; locally and remotely by people and equipment.

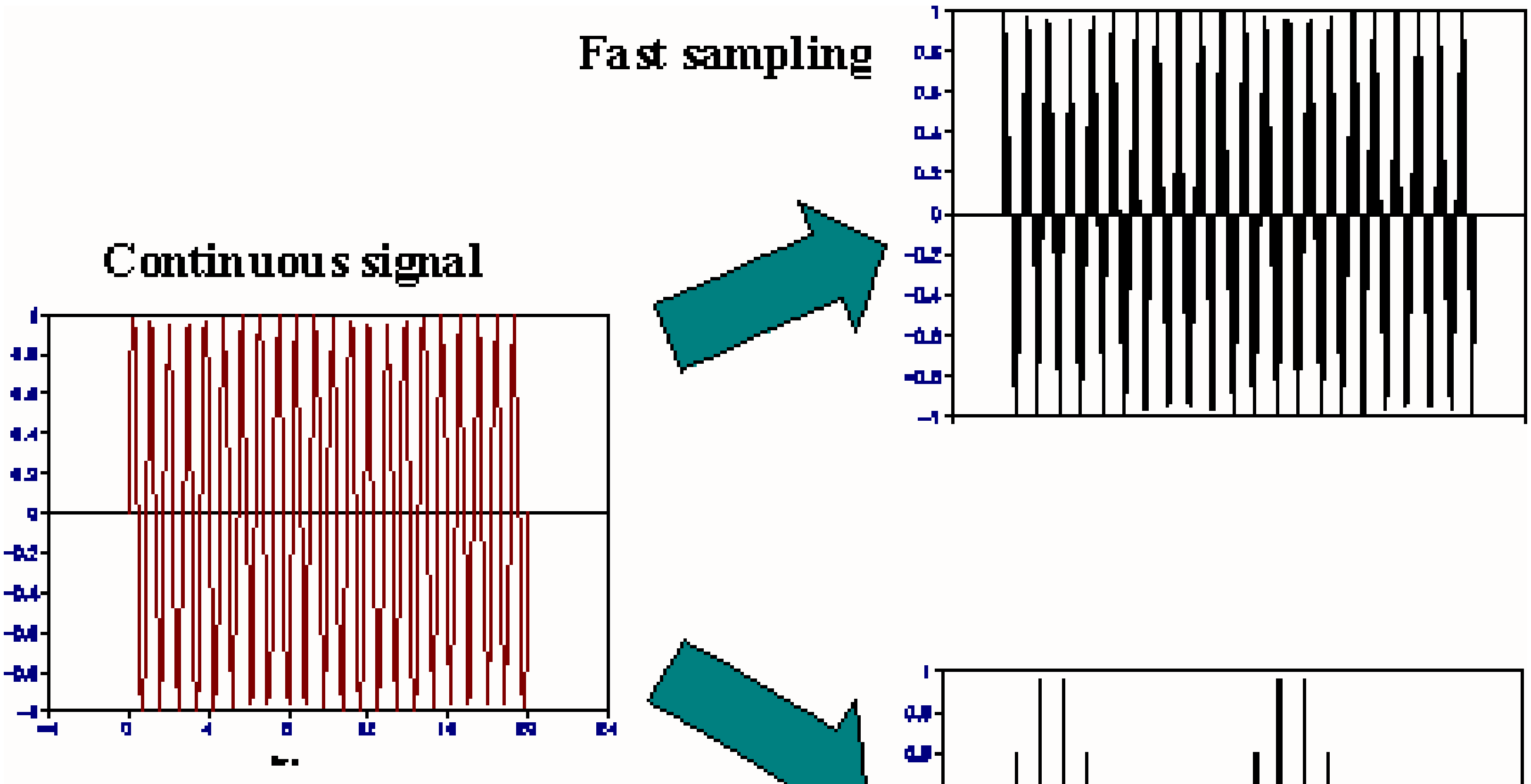


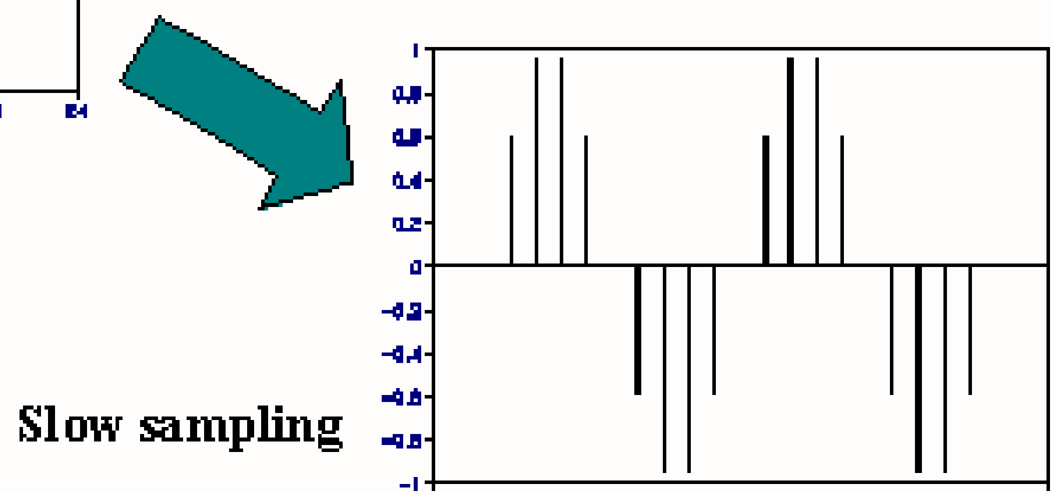
Sensors, local indicators, and valves in the process.

Some actions and automation done here.

Displays of variables, calculations, and commands to valves are in the centralized control center.

FIGURE 1.6

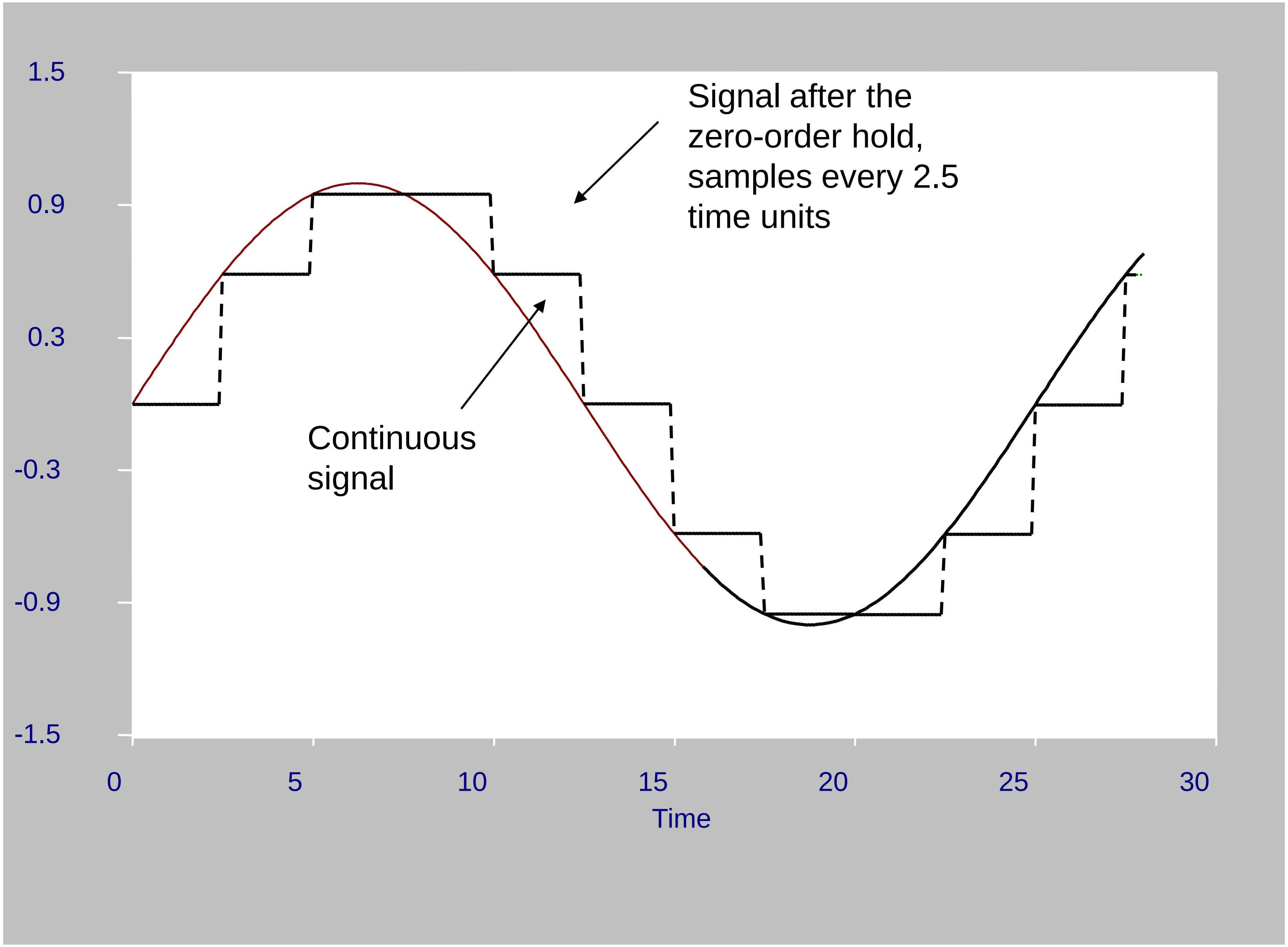




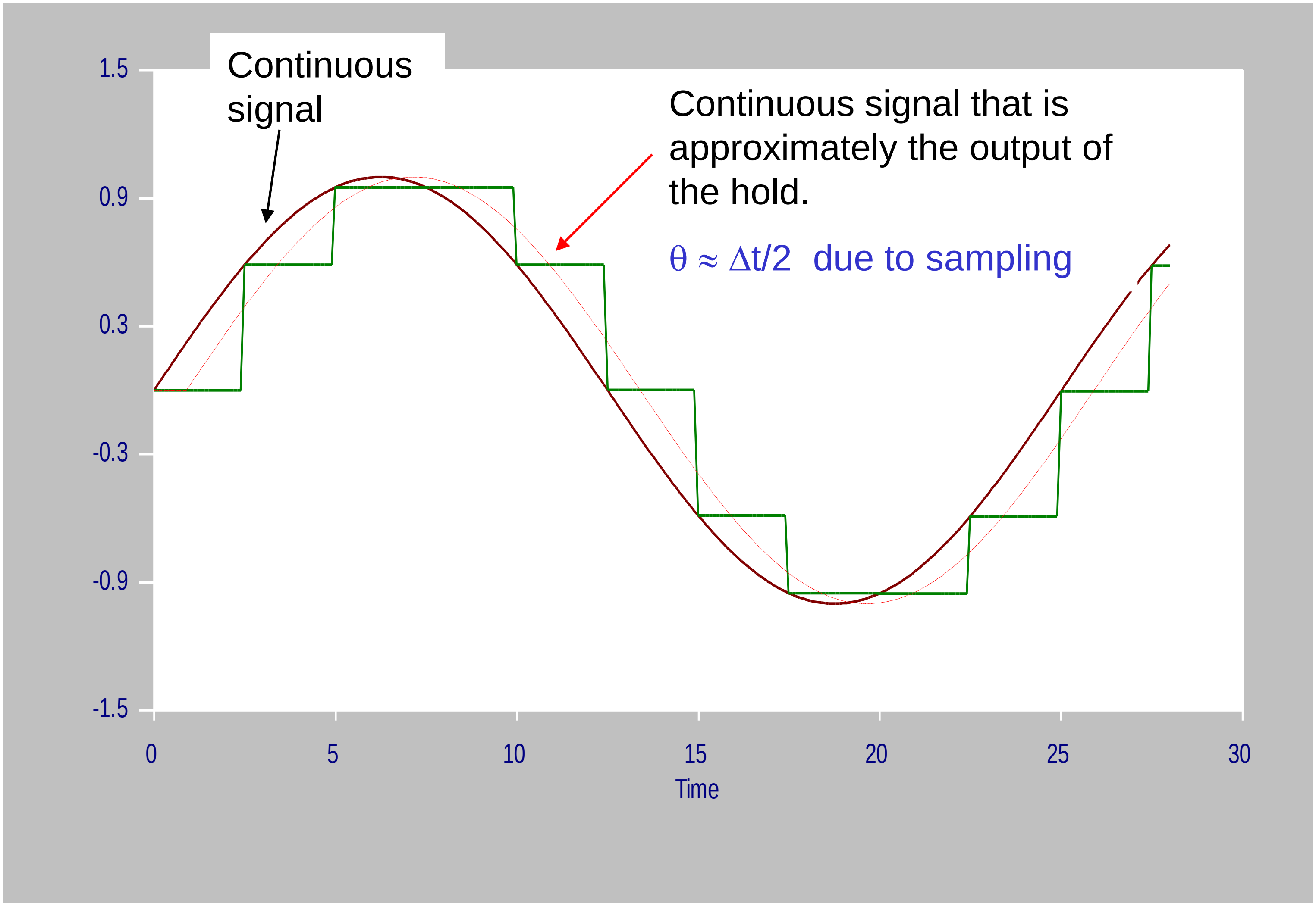
Aliasing: Sampling much slower than the measurement changes causes significant loss of information.

Engineer should design for sampling “fast enough”.

We “hold” the last sampled value between control executions



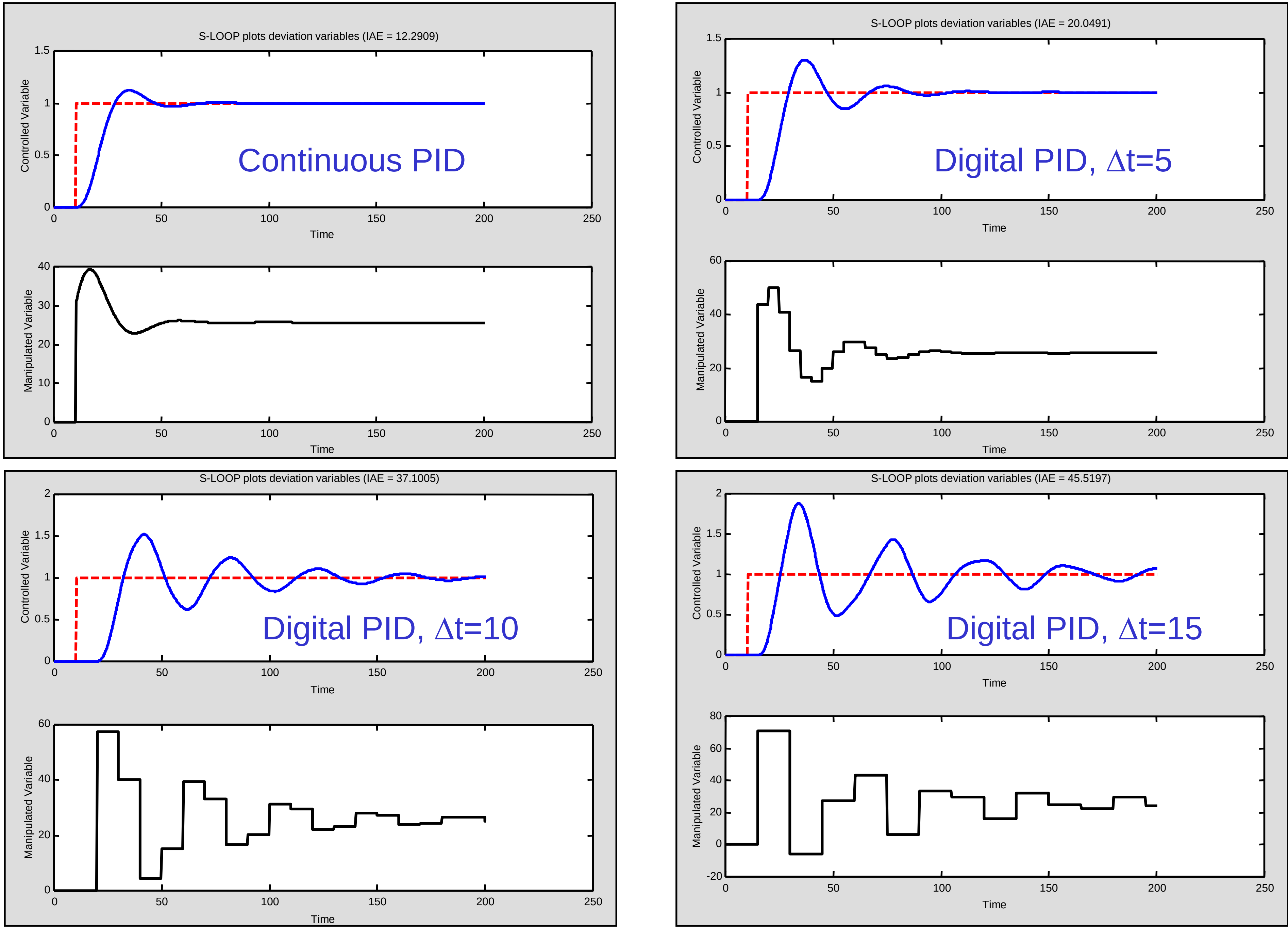
The shifted red line is the continuous approximation of the signal after the sample & hold. This shows that the effect is to introduce a “dead time” of about $\Delta t/2$.



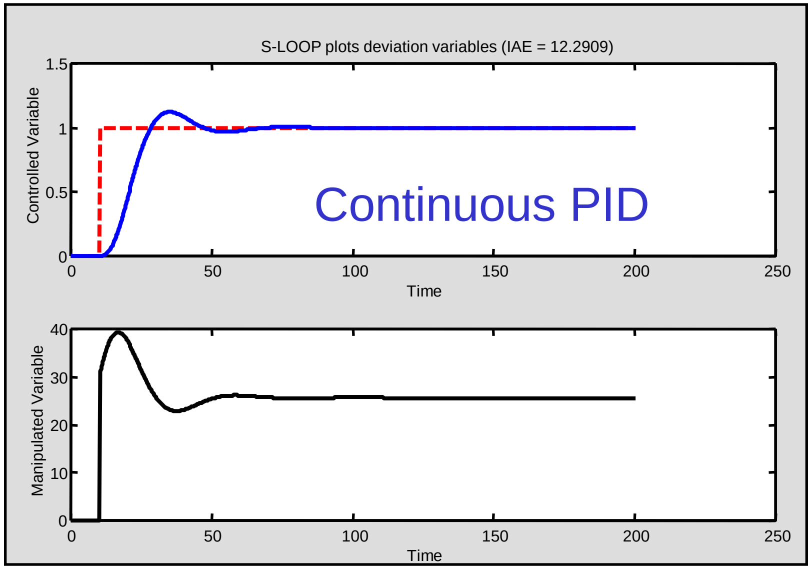
$$MV(t) = K_c \left[E(t) + \frac{1}{T_I} \int_0^t E(t')dt' - T_d \frac{d\,CV}{dt} \right] + I$$

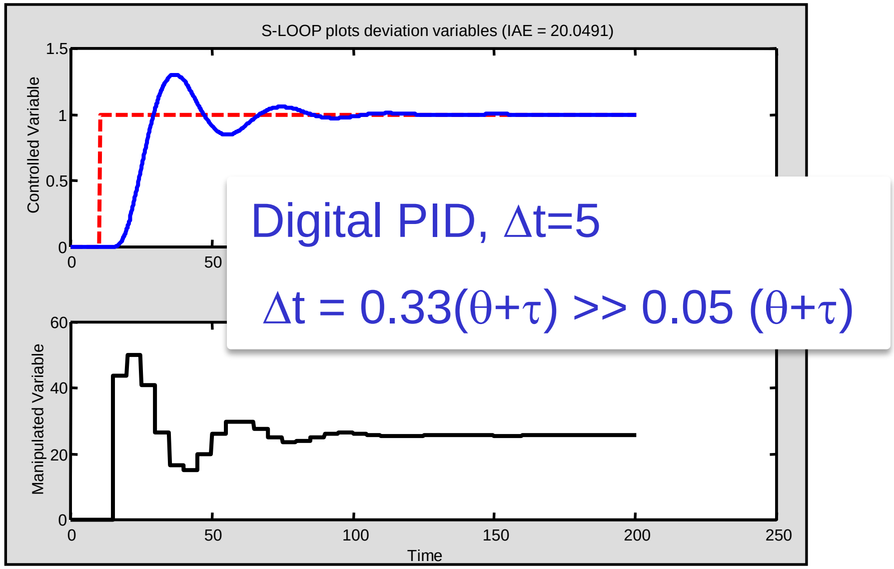
Digital PID, positional form calculates the output to the final element

$$MV_N = K_C \left[E_N + \frac{\Delta t}{T_I} \sum_{i=1}^{N} E_i - \frac{T_d}{\Delta t} (CV_N - CV_{N-1}) \right] + I$$



S-LOOP plots deviation variables (IAE = 12.2909)
Controlled Variable
Continuous PID
Time
Manipulated Variable
Time
S-LOOP plots deviation variables (IAE = 20.0491)
Controlled Variable
Digital PID, Δt=5
Time
Manipulated Variable
Time
S-LOOP plots deviation variables (IAE = 37.1005)
Controlled Variable
Digital PID, Δt=10
Time
Manipulated Variable
Time
S-LOOP plots deviation variables (IAE = 45.5197)
Controlled Variable
Digital PID, Δt=15
Time
Manipulated Variable
Time





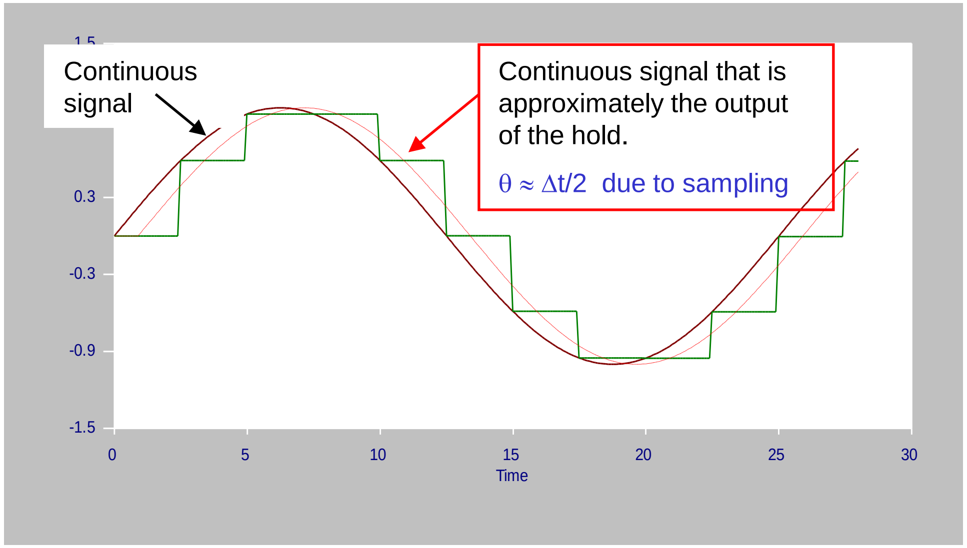
Guideline for selecting the execution time:

To prevent degradation of control loop performance, select a controller execution time of $\Delta t \leq 0.05(\theta+\tau)$.

Note: Typical sample period for chemical process control is 1/3 to 0.5 second. Much faster is possible, if needed.

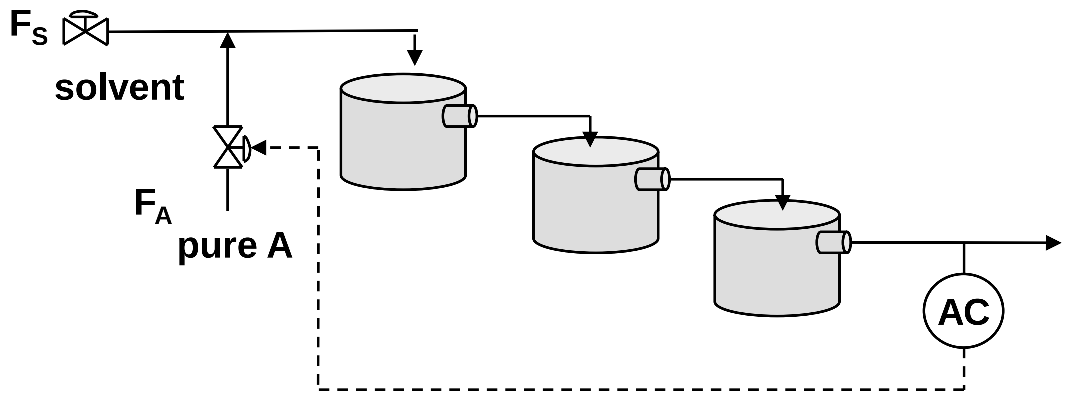
Modified PID tuning for digital controllers - this is a guideline that usually works adequately.

We learned that sampling introduces an additional dead time of about Δt/2.



1. Obtain model, usually using empirical method
2. Determine the sample period, $\Delta t \leq 0.05(\theta+\tau)$, if possible
3. Recalculate the dead time as $\theta' = \theta + \Delta t/2$
4. Calculate tuning using continuous method
5. Implement and fine tune as needed

Let's apply this guideline for the three-tank mixer with a long sample time of 15 minutes.



Process reaction curve

Kp = 0.039 %A/%open

θ = 5.5 + ?? = ?? min

τ = 10.5 min

Tuning from chart

Kc = ??

TI = ??

Td = ??

The performance is about as good as possible with this very long sampling time! Would you fine tune further?

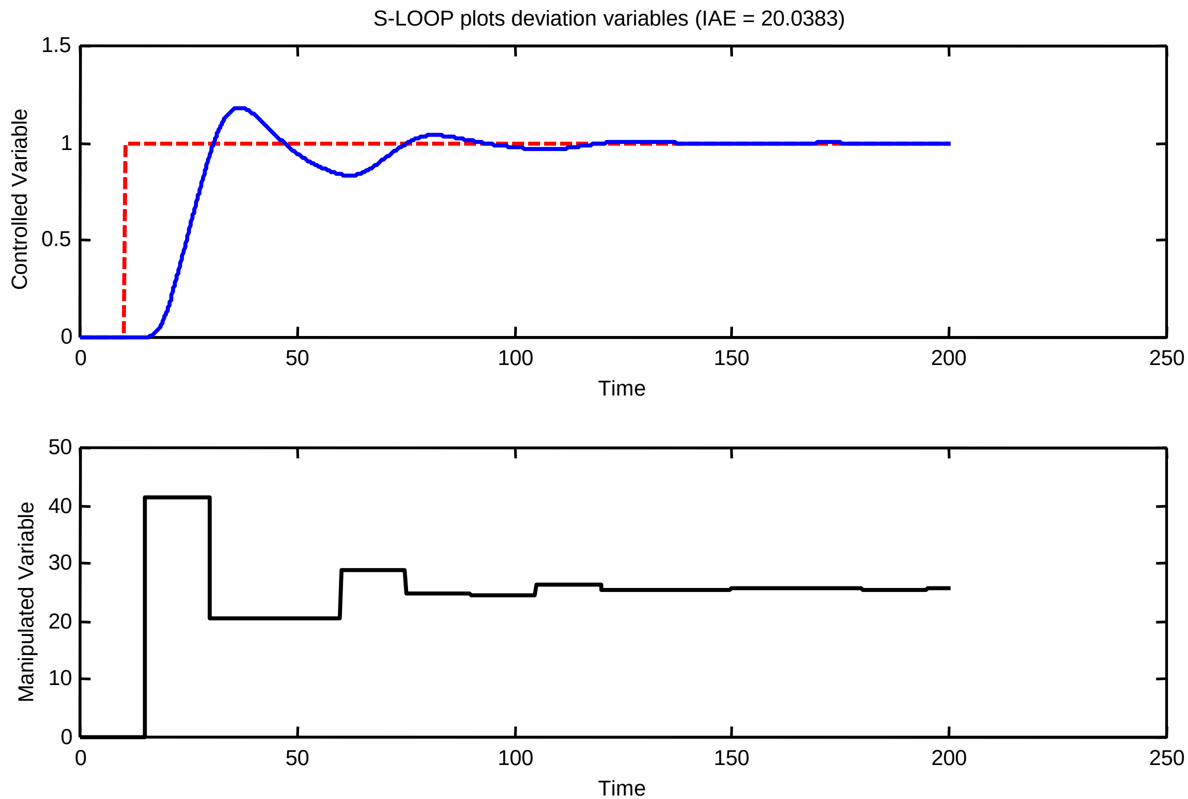
Tuning from chart

Kc = 20

TI = 14

Td = 2.35

IAE increased from 12.2 to 20+



If the PID is no better in digital form, why did we spend decades of engineering time and billions of dollars converting the world's control to digital?

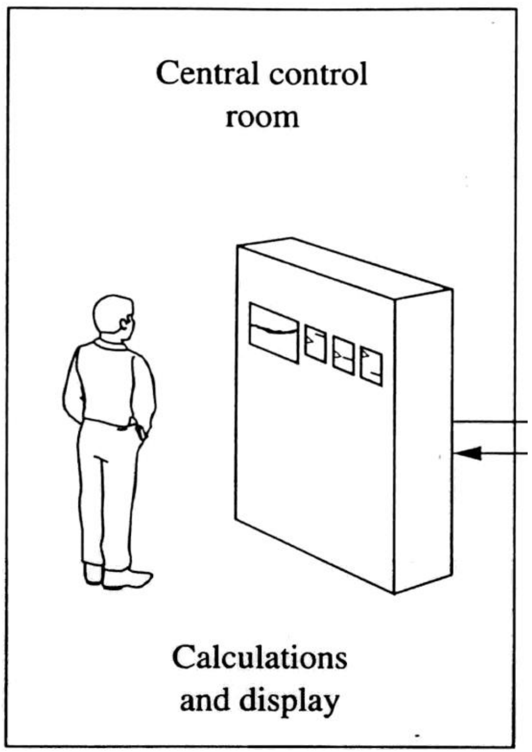
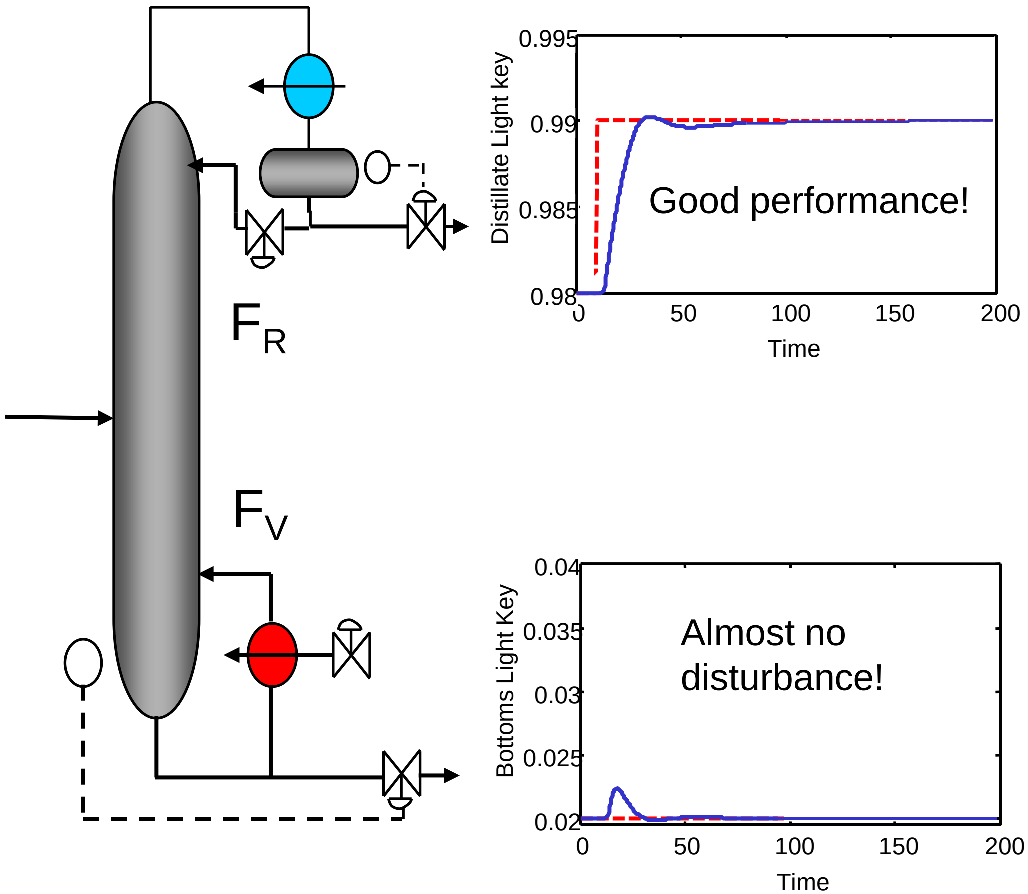


FIGURE 1.6

Why did we convert the world's control to digital - **Complex controllers**



Improved performance can be achieved with algorithms that optimize the path to the set point, every controller execution!

(See Chapters 19 and 23)

Why did we convert the world's control to digital - **Process monitoring**

We have a digital history of measurements for

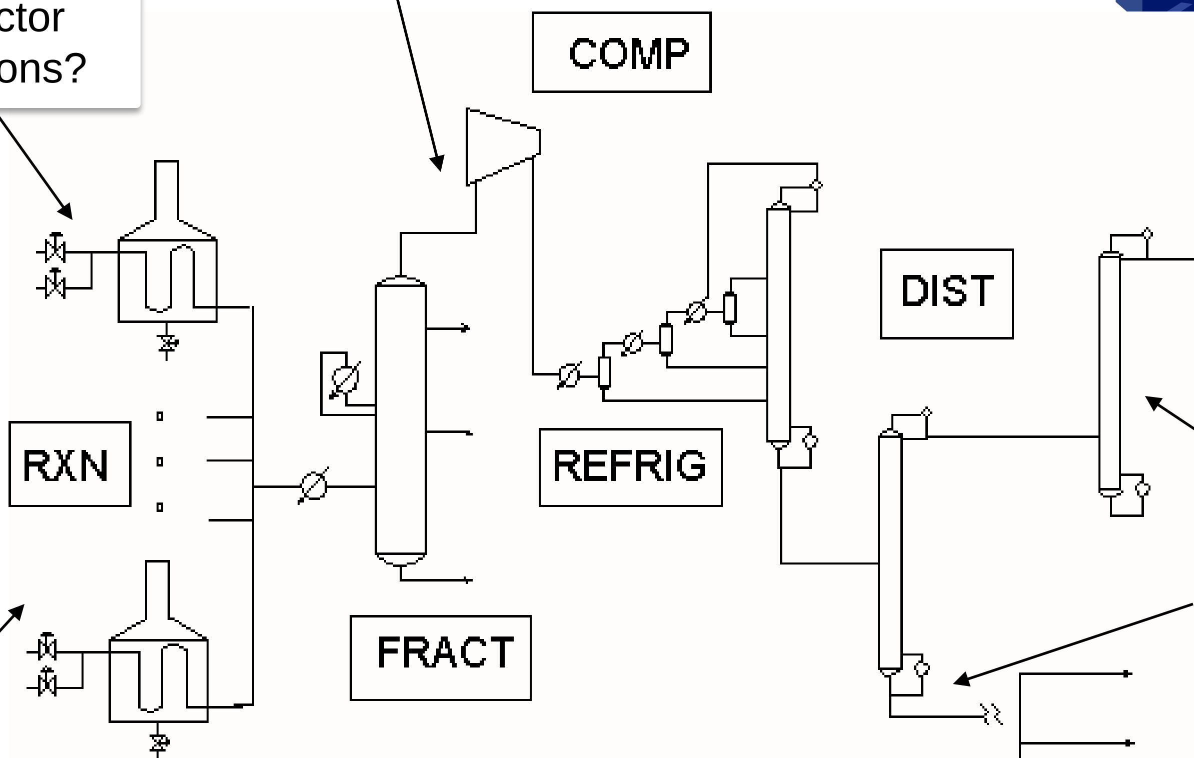
- Recall at any time for trouble shooting
- Calculation of process performance indicators, heat transfer coefficients, reactor yields, energy/kg of product, and so forth
- Excellent graphical displays with data in context of process schematic

(See Chapter 26)

Why did we convert the world's control to digital - **Process optimization**

Best suction pressure?

Best reactor conversions?



Best product/ recycle purities?

Best feed rates, each feed type

(See Chapter 26)

Why did we convert the world's control to digital - **Diagnostics**

We have digital monitors at sensor, controller and valve!

- Compare signal to valve with actual valve position - report significant errors
- Diagnose problems with sensor (voltage, etc.)
- Do not take feedback control action on questionable loop - alarm operator