Servos

Servos are everywhere
Elements of servo

- System -- to be controlled
- Sensor or detector -- measure quantity to be controlled
- Reference -- desired system output
- Diff amp -- compare sensed signal to reference
- Error signal -- produced by diff amp
  - = voltage proportional to system error
- Integrator -- integrates error to give correction signal
- Correction signal -- will be used to modify system and correct output
- Transducer -- converts correction voltage into action to control system
Example: Stabilize laser intensity

- System is laser source plus AOM to deflect some (most) of laser power
- Sensor is photodiode w/ preamp
  - converts optical power to voltage (Volts/Watt opt)
- Reference is stable voltage
  - can be ac voltage -- ex: quiet amplitude modulation is desired
- Transducer is RF driver to AOM
  - converts voltage into RF power (Watts RF/Volt)
- System converts RF power to optical power (Watts opt / Watts RF)
- Overall units of sensor, transducer, system cancel
Servos and noise

Frequency dependence of noise

- Low frequency $\sim 1/f$
  - example: temperature (0.1 Hz), pressure (1 Hz), acoustics (10 -- 100 Hz)
- High frequency $\sim$ constant = white noise
  - example: shot noise, Johnson noise, spontaneous emission noise
- Servo must compensate noise spectrum
  - integrator
  - servo bandwidth out into white noise region

\[
\log(V_{\text{noise}}) = \log(f) - \frac{1}{f_{\text{noise}}}
\]

Desired servo gain

\[
\log(\text{gain}) = \log(f) - \frac{1}{f_{\text{noise}}}
\]
Servo stability

- Real servo will have second pole eventually
  - 12 dB/octave rolloff
  - converts negative feedback to positive feedback
  - causes oscillations, noise, instability
- Must have closed loop unity gain point before second pole
- Real servo also has finite dc gain -- like op amp
Closed loop response

- Closed-loop gain and phase depend on all parts of servo
  - Closed loop gain is product of all gains
    - Includes sensor and transducer
    - Recall product of gain units must cancel
  - Closed loop phase is sum of all phases
  - Chain is as strong as weakest link

Shunted integrator

Integrator w/lead

Effective “servo”

\[
\log(\text{gain}) = \log(f)
\]

Single pole 6 dB
Double pole 12 dB
Unity gain
Laser intensity noise

- Laser intensity noise
  - due to mode competition, power supply noise, resonator acoustics
  - can also pass laser beam through spatial filter, fiber, etc before using
- May also want controlled modulation
  - ultra-quiet intensity modulation

![Diagram of laser system with acoustic and electronic noise sources and spatial filter]
AOM = acousto optic modulator

- AOM = acousto optic modulator (or deflector)
- RF signal converted to sound waves in crystal
  - Use fast piezo-electric transducer like Li NbO₃
- Sound waves are collimated to form grating
- Bragg scatter from grating gives deflected beam
  - can separate from original
- Problem with AOM -- weak link
- Sound takes time to travel from transducer to laser beam
  - Time delay: \( t_D = \frac{l}{v} \) -- acts like multi-pole rolloff
  - (phase shift increases with frequency)

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![Diagram of AOM](image.png)

- **Input laser beam**
- **Sound transducer** ex: LiNbO₃
- **RF signal** ~ 1 Watt 40 MHz
- **Sound absorber** (suppress reflections)
- **Deflected beam**
- **Undeflected beam**
- **Aperture**
- **Refractive index variations due to sound waves**
- **AOM crystal/glass**
Photodiode with pre-amplifier

- Photodiode like current source but with capacitor
- Input capacitor causes op amp gain to diverge at high freq.
  - Amplifies high freq noise
  - Oscillation
- Solution:
  - Shunt capacitor in feedback

Gain response

\[
\log\left(\frac{V_{\text{out}}}{I_{\text{in}}}\right) \quad \text{vs} \quad \log(f)
\]

Unshunted

Shunted

Photo-diode amplifier

Photo-diode equiv. circuit
Servo design procedure

• Measure gain and phase response of photodiode/preamp
  – use LED driven with signal generator
• Measure response of AOM
  – use photodiode (PD) -- correct for PD response
• Design integrator to compensate for first pole
• Gain control to set max gain w/o oscillation ??
  – variable resistor at integrator input

• Sign of correction signal
  – each op amp reverses sign
  – overall servo must be negative feedback
  – sign change in transducers unknown until measured
• may have to add op amp
• Use undeflected beam from AOM ?
  – More laser power
Measure servo performance

- Insert noise using transducer
- Summing junction
  - extra op amp ?
- Measure frequency response, phase delay
  - both error and correction signals

System to be controlled

Laser → AOM
  Laser beam → Photodiode & preamp
  RF signal → RF driver
  Stable voltage → Diff amp
  Error signal → Integrator
  Correction signal → Summing

Add error

Oscilloscope