Hysteretic Buck Regulators
Hysteretic Buck Regulator

**Basic Architecture**

- \( t_{\text{ON}} \) and \( t_{\text{OFF}} \), and therefore the frequency, are functions of: 
  - \( V_{\text{IN}}, V_{\text{OUT}}, I_L, L, \text{ESR}, \text{ESL}, V_{\text{HYS}} * (R_{F1} + R_{F2})/R_{F2}, \) and \( t_d \)

- Frequency is difficult to control!!

**Advantages:**
- Wide Bandwidth means fast transient response.
- No frequency compensation (poles, zeroes) to deal with.
- VIN feedforward is inherent.

**Disadvantages:**
- Ripple is needed to properly switch the comparator!!
Constant On-Time (COT)
Hysteretic Regulator
ON-time is constant, for a given $V_{IN}$, as load current varies.

- **Advantages**
  1. Constant frequency vs $V_{IN}$
  2. High Efficiency at light load
  3. Fast transient response

- **Disadvantages**
  1. Requires ripple at feedback comparator
  2. Sensitive to output noise, because it translates to feedback ripple

Ripple is needed to properly switch the comparator!!

![COT Diagram](image-url)
COT regulation with $V_{IN}$ Feedforward

**Definition of Duty Cycle:**

$$D = \frac{t_{ON}}{T} = \frac{f_{sw}}{f}$$

**For Buck Regulator:**

$$D = \frac{V_{OUT}}{V_{IN}}$$

**Setting EQ1 = EQ2:**

$$t_{ON} \cdot f_{sw} = \frac{V_{OUT}}{V_{IN}}$$

**For COT with Feed-forward:**

$$t_{ON} = \frac{K \cdot R_{ON}}{V_{IN}}$$

$K$ is a constant = $1.3 \times 10^{-10}$

**Insert EQ4 in EQ3:**

$$\frac{K \cdot R_{ON}}{V_{IN}} \cdot f_{sw} = \frac{V_{OUT}}{V_{IN}}$$

**Solve for $f_{sw}$:**

$$f_{sw} = \frac{V_{OUT}}{K \cdot R_{ON}}$$
Constant ON-Time Achieves Nearly Constant Frequency

Switching frequency is almost constant; the variations are due to effects of $R_{DS-ON}$, diode voltage and input impedance of the $R_{on}$ pin

Note: A resistor from $V_{IN}$ to $R_{on}$ sets the ON-time
COT needs ESR for Sufficient Ripple on $V_{OUT}$

- COT regulates by comparing $V_{OUT}$ to $V_{ref}$
- $V_{OUT}$ ripple must be large enough to overcome the comparator hysteresis
- ESR of output capacitor is directly proportional to $V_{OUT}$ ripple
- ESR must be large enough to create sufficient $V_{OUT}$ ripple to properly switch the comparator!!

Ripple is needed to properly switch the comparator!!
New Emulated Ripple Mode (ERM) Constant-On-Time

New patented ERM technology allows COT regulators to:

- Eliminate the need for large output ripple
- Eliminate the need for high ESR output capacitor
- Allows the use of smaller, less expensive ceramic capacitors
ESR current can be sensed through $R_j$ ($R_{DS\_ON}$ of the Low Side Mosfet).

The inverted $V_{SEN}$ is the replication of $V_{ESR}$ ripple during $t_{OFF}$.

This is added to the DC reference voltage $V_{ref}$ before comparing to $V_{OUT}$.

No ESR is required on the output capacitor.
New ERM Constant-On-Time Allows Use of Ceramic Capacitors

Benefits of Ceramic Capacitors:

Clean Output Voltage
  • Low Output Ripple
  • Comparable to voltage-mode and current-mode control schemes

Low profile and small size
  • Can reduce required output ESR ~ 1/3
  • Save PCB area

Not sensitive to Transient Voltage Stress
  • Higher reliability

No polarity – ease for production
Summary of Advantages of Constant On Time with ERM

• No loop compensation needed
  – Low external component count
  – Excellent transient response
    • Lower cost
    • Easy to use
    • Reliable

• Operates in fixed frequency mode
  – External discrete component values don’t affect frequency
    • Reliable/Robust Operation
    • Makes design easier

• Emulated Ripple Mode (ERM) Circuitry
  – Allows the use of low ESR output capacitors without additional ESR compensation
    • Lower output ripple
    • Smaller size (ceramic caps)
    • Lower cost