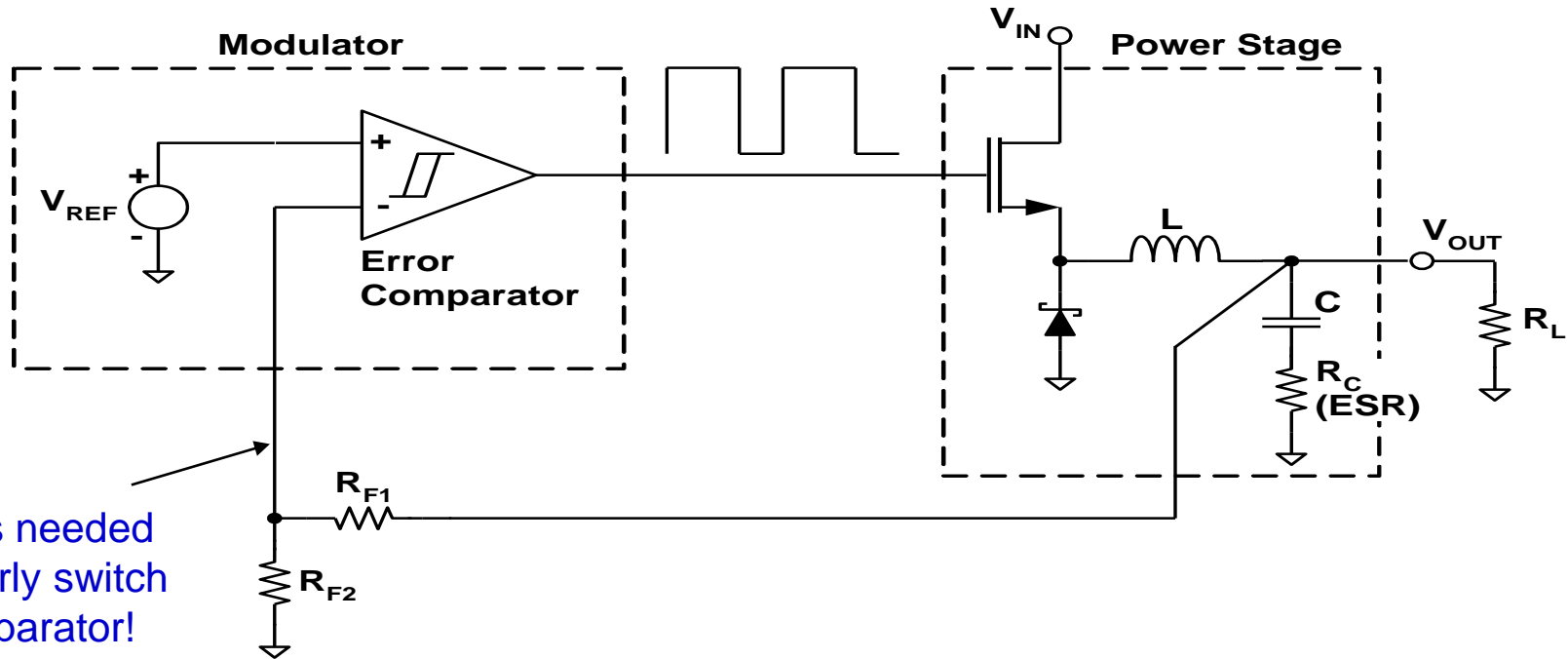




Buck Regulator Architectures

4.3 Hysteretic Buck Regulators

Hysteretic Buck-Regulator Architecture



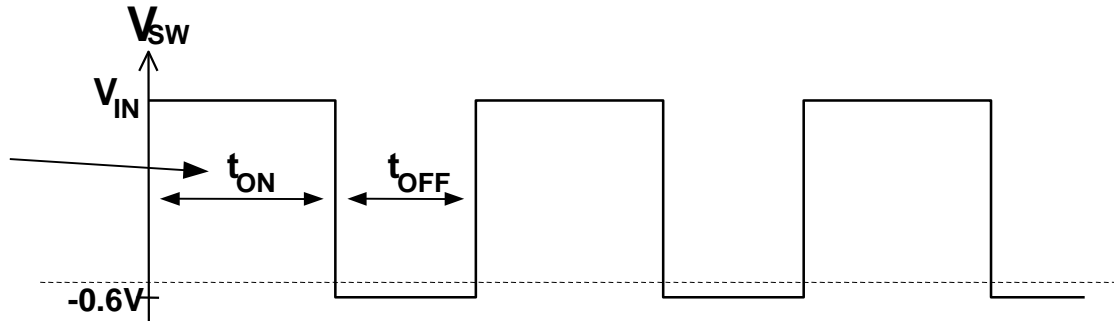
Ripple is needed to properly switch the comparator!

Simplest and fastest topology but variable frequency!

Hysteretic Regulator Waveforms

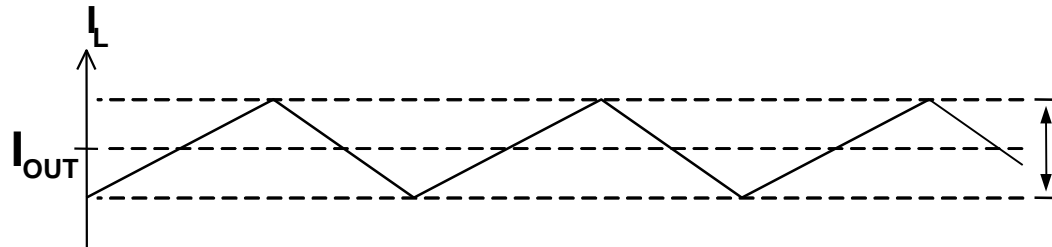


Buck Switch stays on for an On-time Determined by V_{IN} and R_{ON}



SW Pin

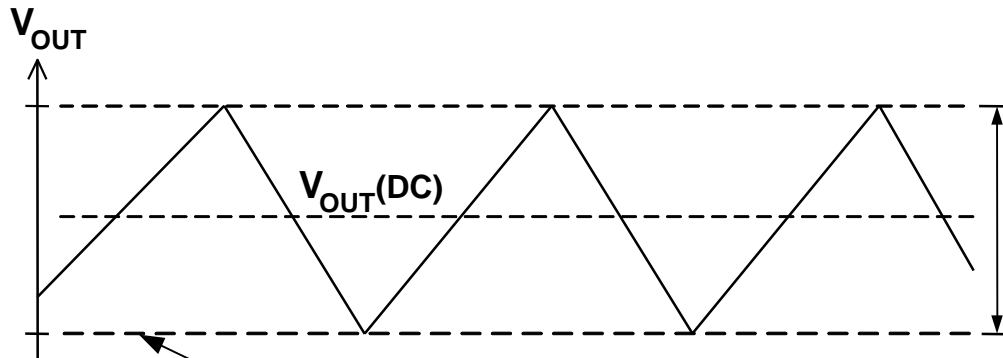
Inductor's current ripple determined by V_{IN} , V_{OUT} , On-time and L



Inductor Current

$$\frac{\Delta I}{\Delta t} = \frac{\Delta V}{L}$$

Output voltage ripple determined by inductor's and C_{OUT} ESR



Output Voltage

Reference Threshold

Output Ripple Voltage Detail



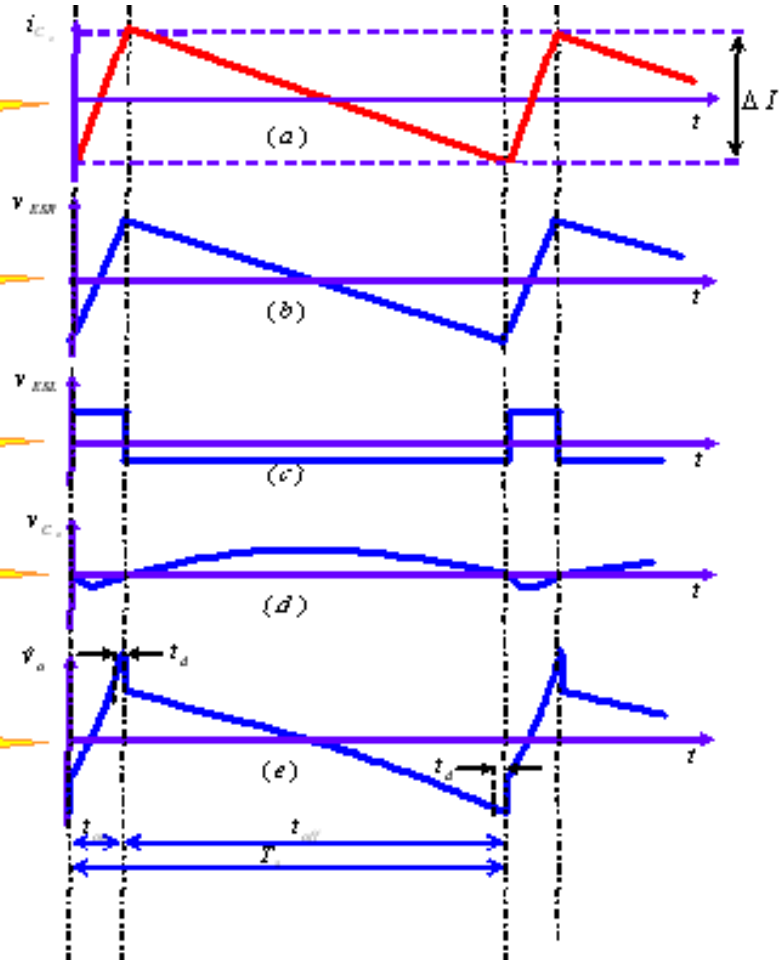
Current through output capacitor

ESR-caused ripple

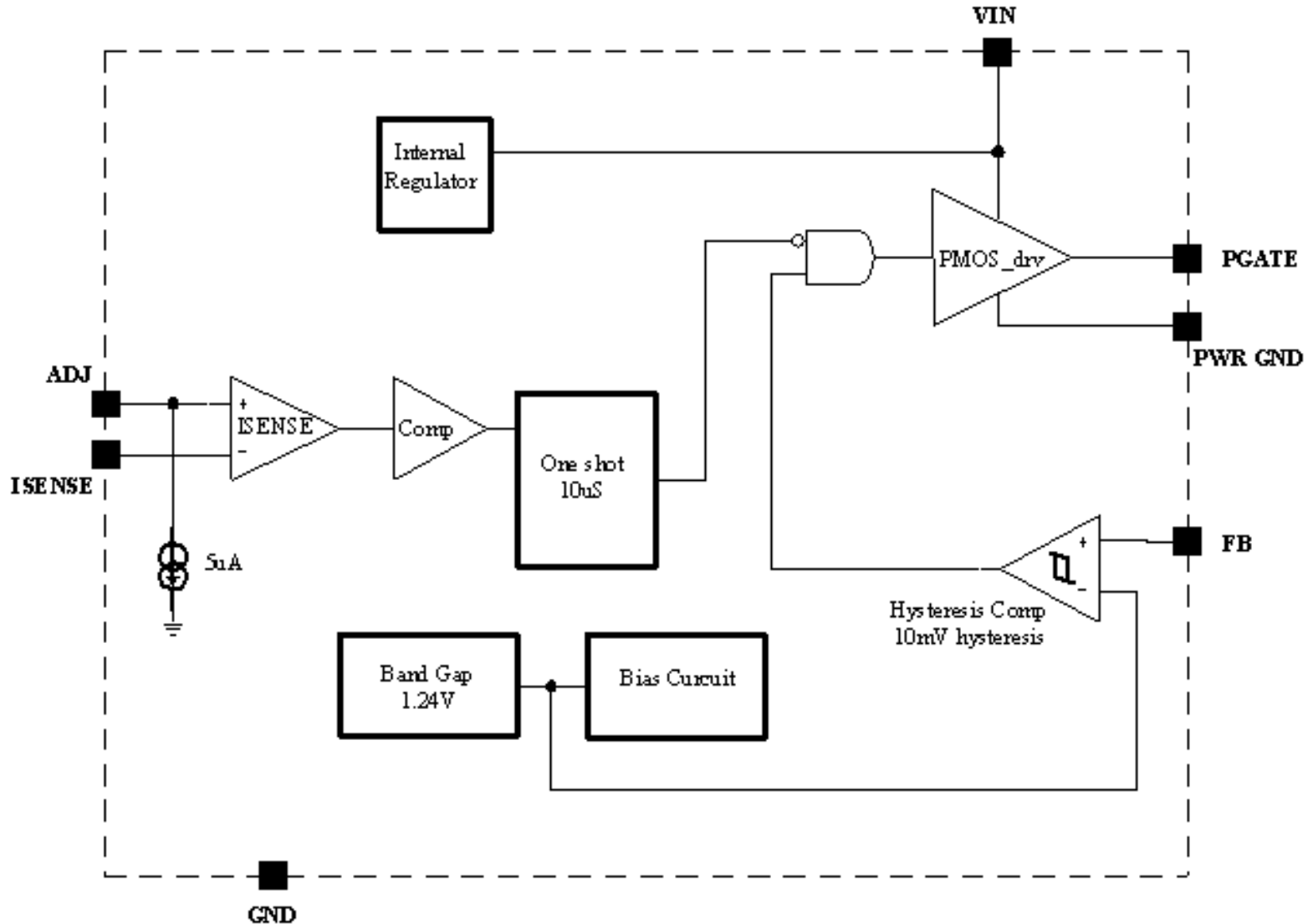
ESL-caused ripple

C_{out} - caused ripple

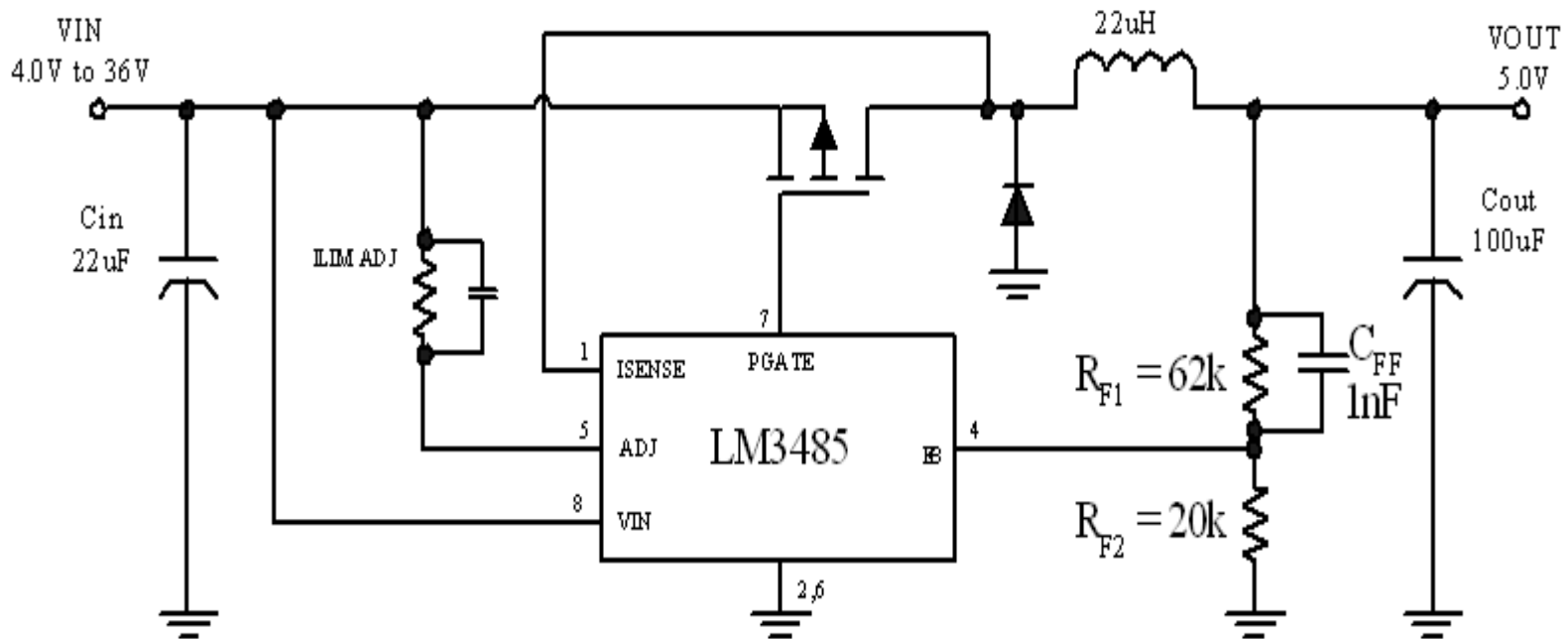
Composite ripple with delay



LM3485 Architecture



LM3485 Hysteretic Controller





Calculating Switching Frequency

- In most cases, switching frequency is determined by the output ripple voltage (ΔV_{OUT}) resulting from the output capacitor's ESR. The amplitude of ΔV_{OUT} is described by the following two equations:

$$\Delta V_{OUT} = \frac{V_{IN} - V_{OUT}}{L} \cdot DT \cdot ESR \quad DT = t_{ON} \quad D = \frac{V_{OUT}}{V_{IN}}$$
$$\Delta V_{OUT} = V_{HYS} \cdot \frac{R_{F1} + R_{F2}}{R_{F2}} + \left[ESR \cdot \left(\frac{V_{IN} - V_{OUT}}{L} + \frac{V_{OUT}}{L} \right) \cdot t_d \right]$$

- Combining these two equations yields an expression for the switching frequency. **Note:** If a speed up capacitor is used the circled term in the denominator of this equation becomes 1 which means the switching frequency value will increase.

$$\frac{1}{T} = f_{SW} = \frac{V_{OUT}}{V_{IN}} \cdot \frac{(V_{IN} - V_{OUT}) \cdot ESR}{\left(V_{HYS} \cdot \frac{R_{F1} + R_{F2}}{R_{F2}} \cdot L \right) + (V_{IN} \cdot ESR \cdot t_d)}$$

Using C_{FF} this term = 1

Pros & Cons of Hysteretic Control



Pros

- Hysteretic controllers have excellent load current transient-response characteristics compared to the other types of controllers (such as PWM voltage and current mode) with slow feedback loops
- The controllers react to transients within the same cycle in which the transient occurs and keep the corresponding FET in an on-state until the output voltage returns to the required dc level
- Thus a minimum number of bulk output capacitors are required, saving total system cost

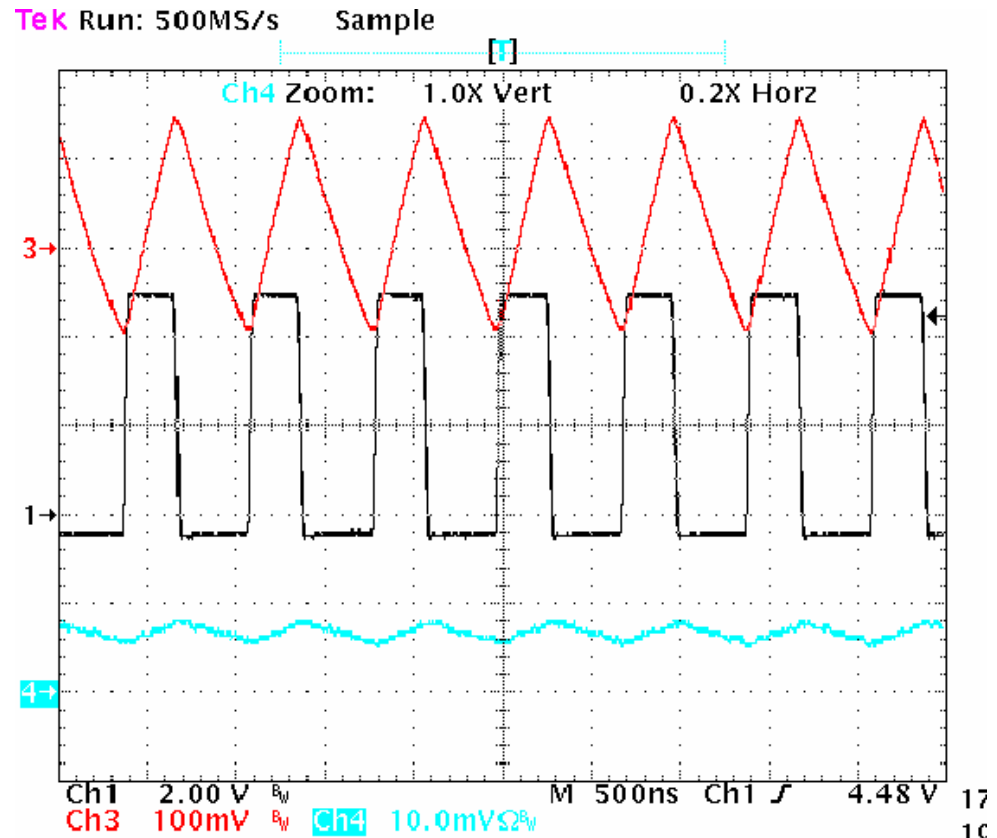
Cons

- The hysteretic regulator does not have compensation circuitry that requires an accurate design in the whole input-voltage, output-voltage, temperature, and load-current range
- This compensation can be further complicated if additional capacitors are added to the output of the voltage regulator around the microprocessor package

LM3475/85 Using Electrolytic C_{OUT}



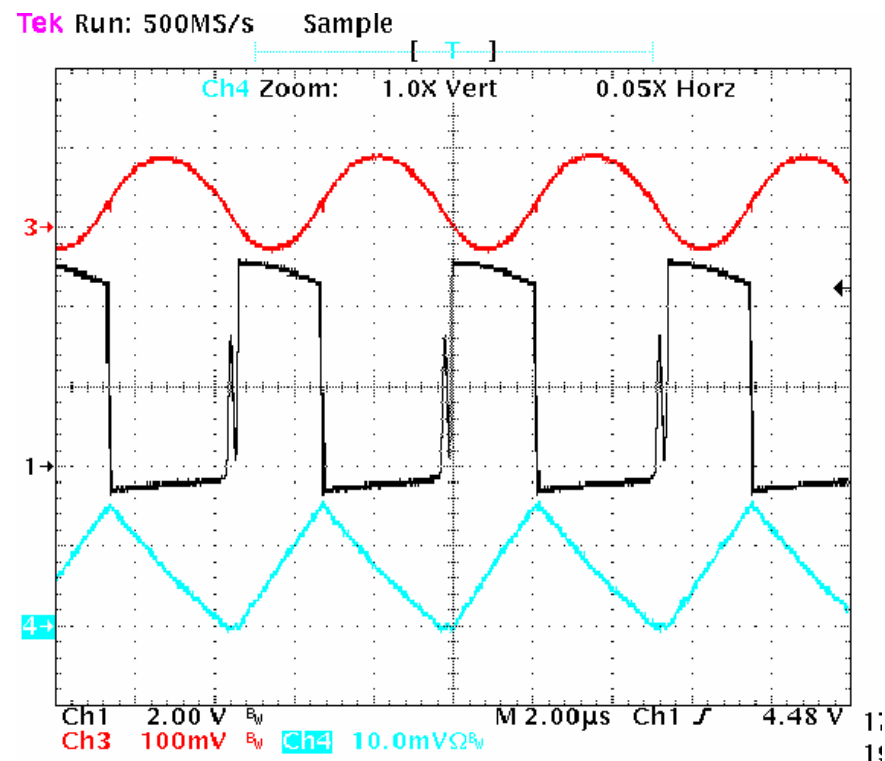
- The graphic shows the output ripple and switch node voltage
- The operating frequency is 1.43MHz
- The feedback network does not use a C_{FF} speed up capacitor





LM3475/85 Using Ceramic C_{OUT}

- An example of using a ceramic output capacitor with almost no ESR
- Operating frequency has dropped and can not be calculated using the equation mentioned previously
- **Reason:** The output ripple is 90° phase shifted from the switching action



LM3475/85 – Working with Ceramic Capacitors



- **Desire**

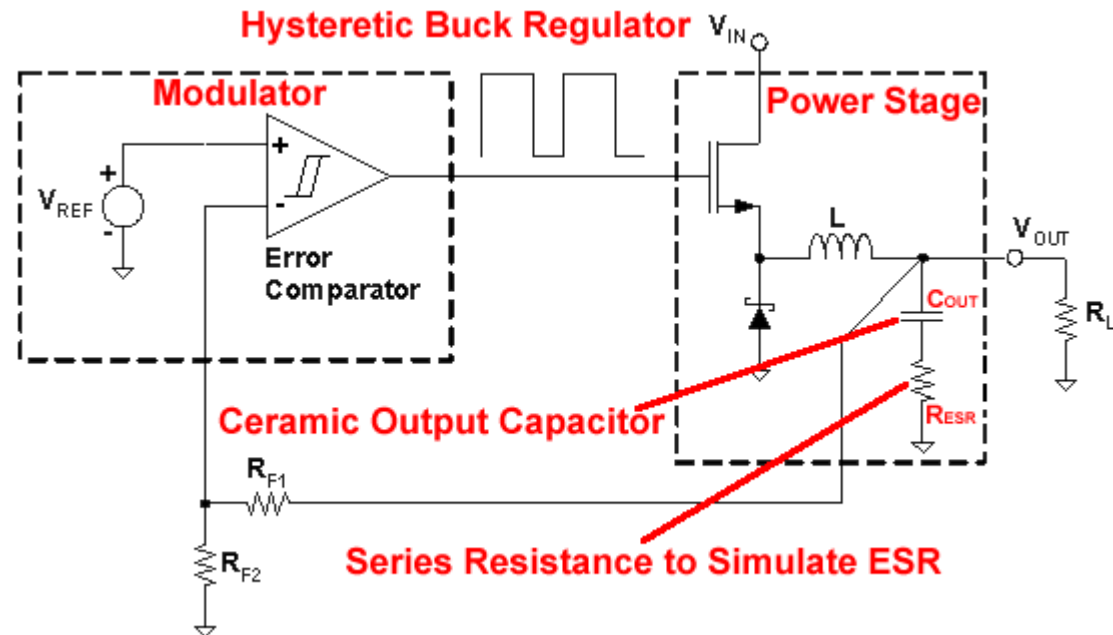
- Use ceramic capacitors

- **Challenge**

- Ceramic capacitors have very low ESR
- Results in 90° phase shift of output voltage ripple, resulting in low operating frequency and increased output ripple

- **Solution**

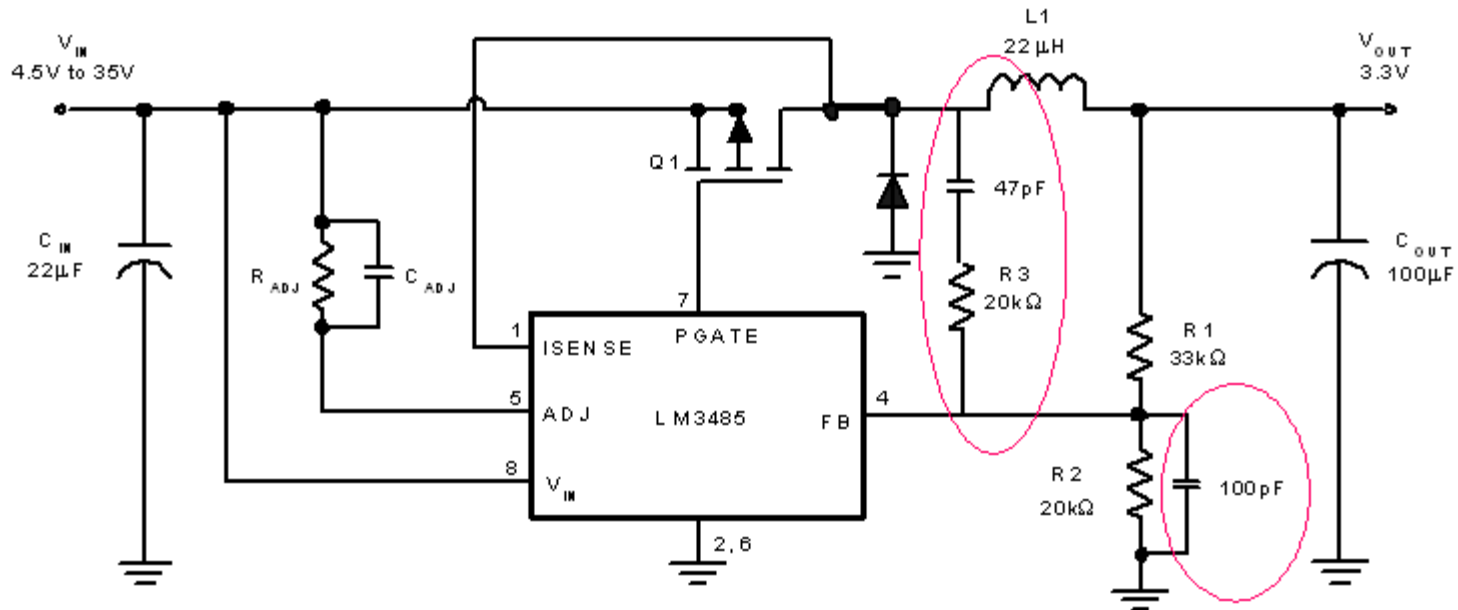
- Add a low value resistor in series with the ceramic output capacitor to provide an ESR value
- Although counter intuitive, this combination provides highly accurate control over output voltage ripple



Working with Ceramic Capacitors Another Technique



By adding the three components circled in the diagram, we provide AC feedback in phase with the switching action. The 100pF capacitor provides bypassing of any high frequency edge noise which may cause improper triggering of the FB comparator. This method has a number of advantages.





Thank you!