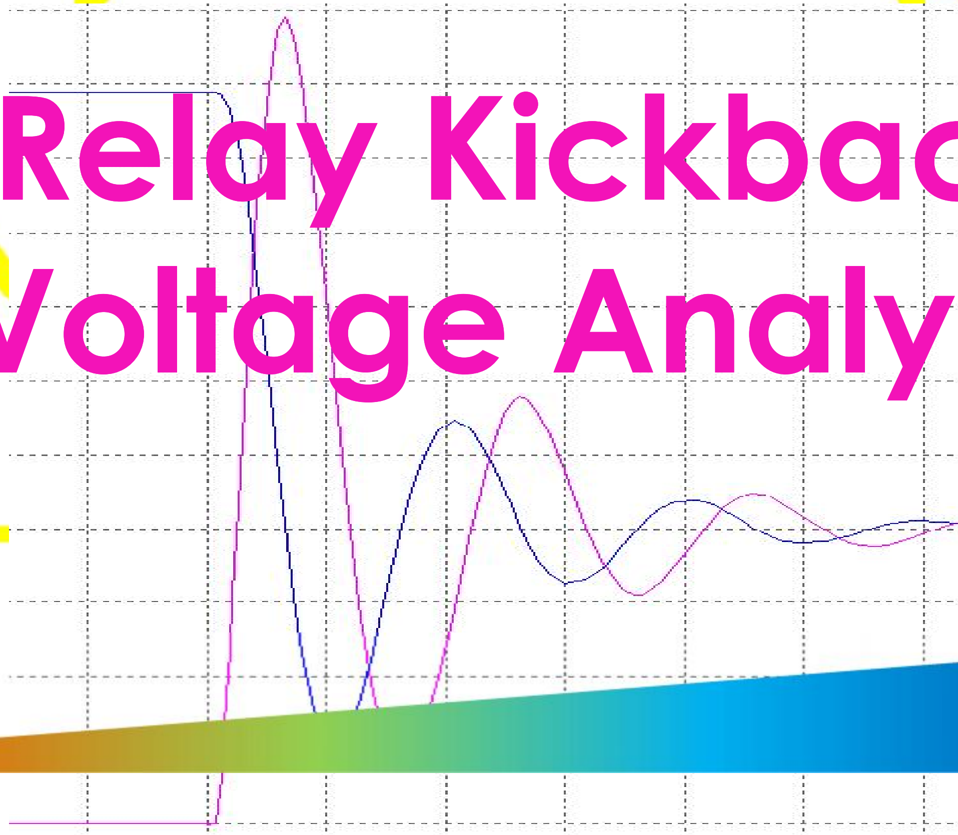
# Relay Kickback Voltage Analysis



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# Introduction

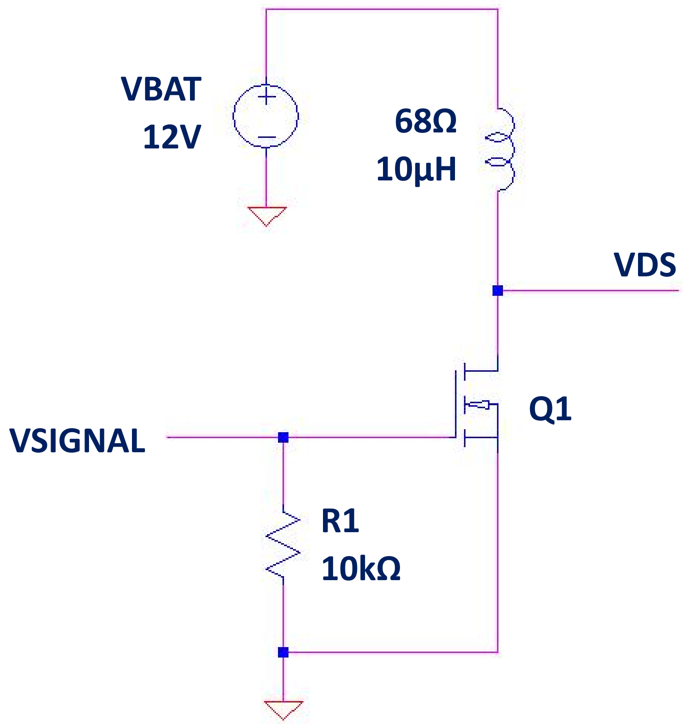
## Objective:

- ✓ To analyze kickback voltage on relay, derive working equations and perform simulation

## Topics:

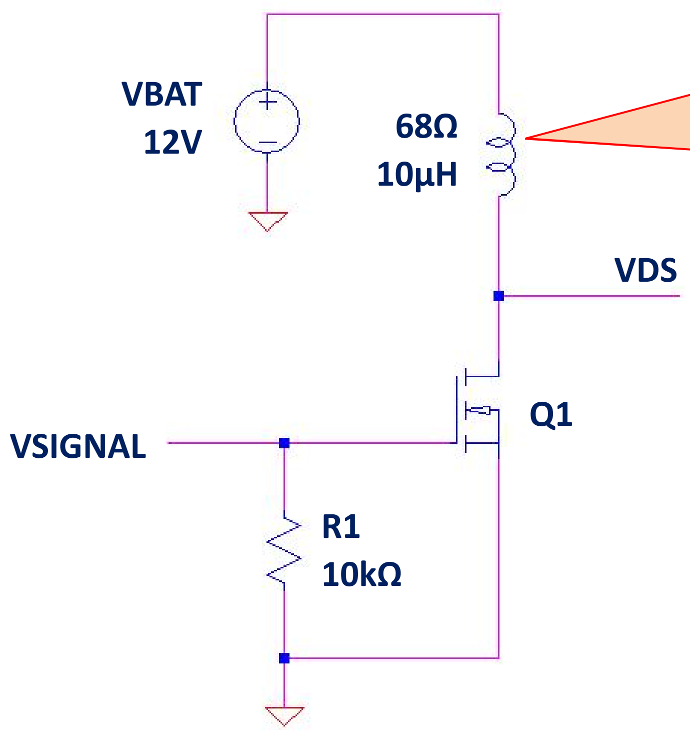
- Model Circuit
- Analysis During ON Time
- Analysis During OFF Time
- Deriving the Maximum $\Delta I$
- Deriving the $\Delta t$
- Solving the Coil Voltage and VDS
- Simulations
- Reviewing What We Have Learned

# Introduction




- ✓Relays are commonly use to drive a high current load from a low voltage low current signal such as signals coming from MCU, DSC, DSP and other digital circuits
- ✓Relay drivers are devices that drive the relay coil to change its contact state
- ✓Relay driver is can be a MOSFET, BJT or opto-coupler

# Model Circuit



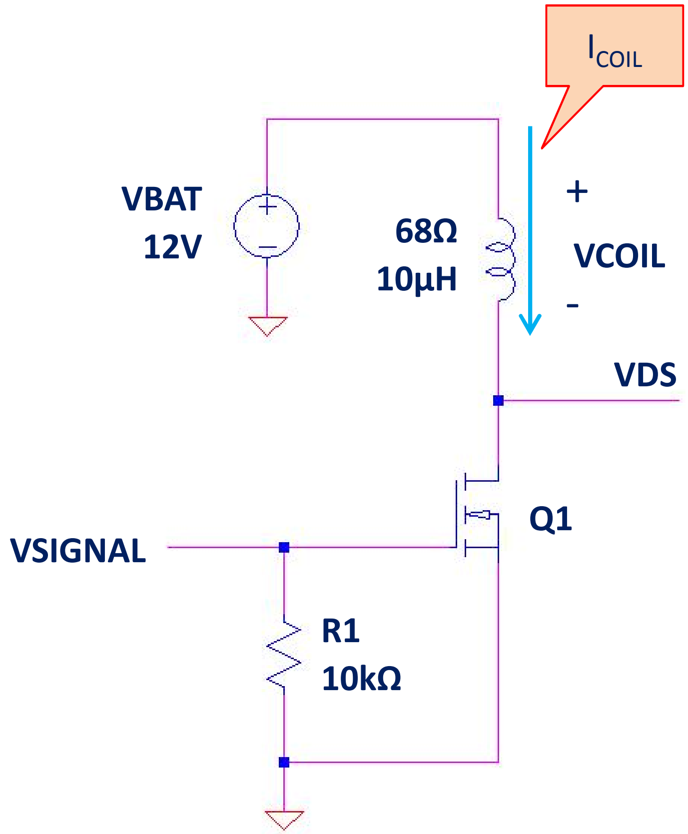

Relay coil with 68 ohm internal series resistance and 10uH inductance. The contact side is not anymore shown because it is not relevant in the analysis.

Drain-source voltage of the transistor Q1. The kickback voltage will be shown in this node.

When VSIGNAL is high, Q1 will saturate and the VDS is ideally zero. Once VSIGNAL is turned low, Q1 will turn off and this time the kickback voltage will occur.

*Relay Kickback Voltage Analysis*

# Analysis During ON Time

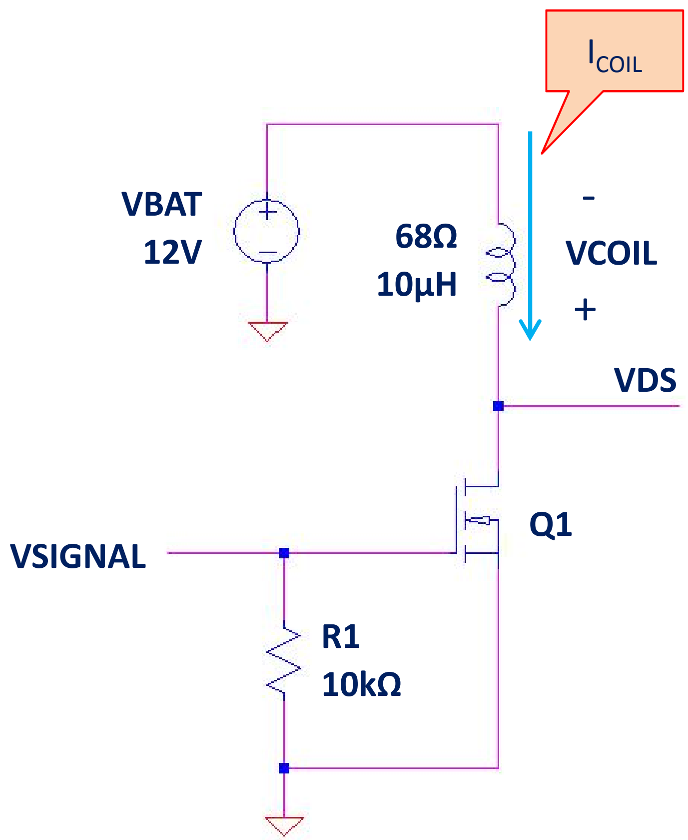



- ✓When Q1 is ON, the current will flow from VBAT to the coil then to Q1 and return to the ground
- ✓The current will flow as shown in the arrow direction
- ✓During this time the upper side of the coil is positive while the lower side has negative sign
- ✓During this time also, the VDS is approximately zero

$$VDS = VBAT - VCOIL \quad (1)$$

$$VDS = VQ1 \sim 0V \quad (2)$$

# Analysis During OFF Time



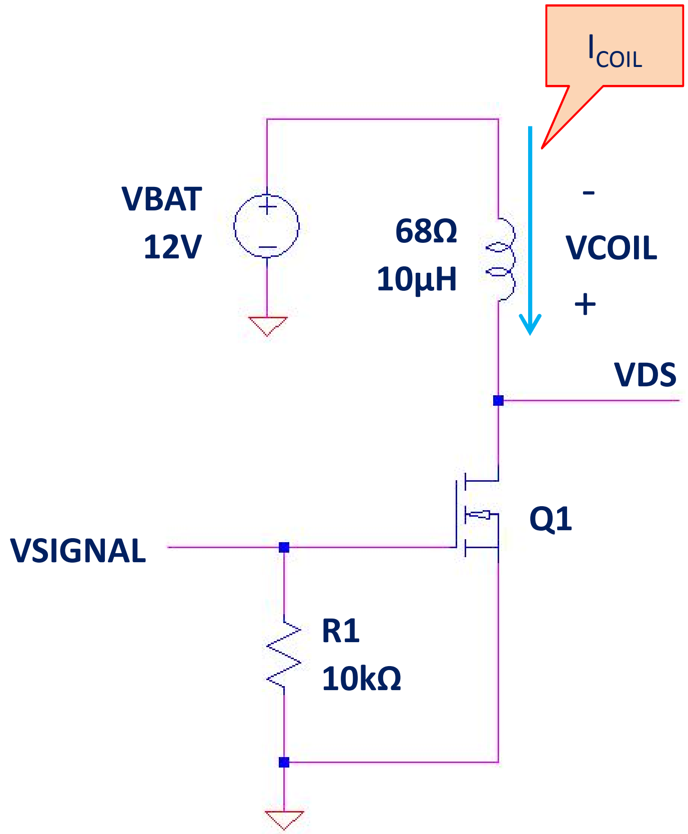

✓When Q1 is OFF, there is a sudden change in the circuit current. However, the coil will not let it to happen immediately. It will maintain the current direction momentarily by reversing its polarity.

✓During this time the upper side of the coil has negative sign while the lower side is positive

**VBAT + VCOIL – VDS = 0**

**VDS = VBAT + VCOIL** 3

# Analysis During OFF Time



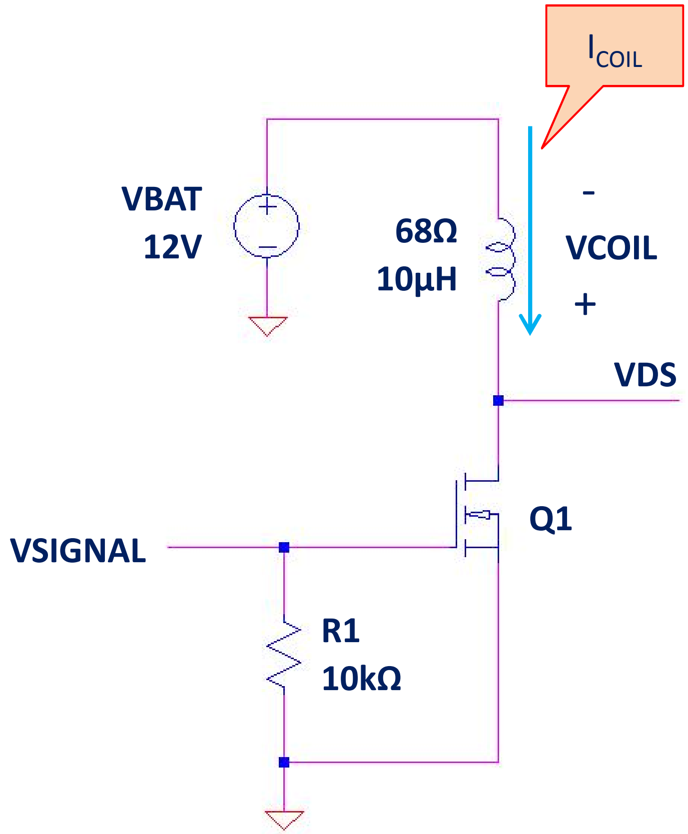

✓From equation 3, the VDS which is the voltage seen by the MOSFET is the sum of VBAT and the coil voltage.

$$VDS = VBAT + VCOIL \quad (3)$$

Coil Voltage Equation

$$VCOIL = L \times \Delta i/\Delta t \quad (4)$$

# Deriving the Maximum $\Delta$i



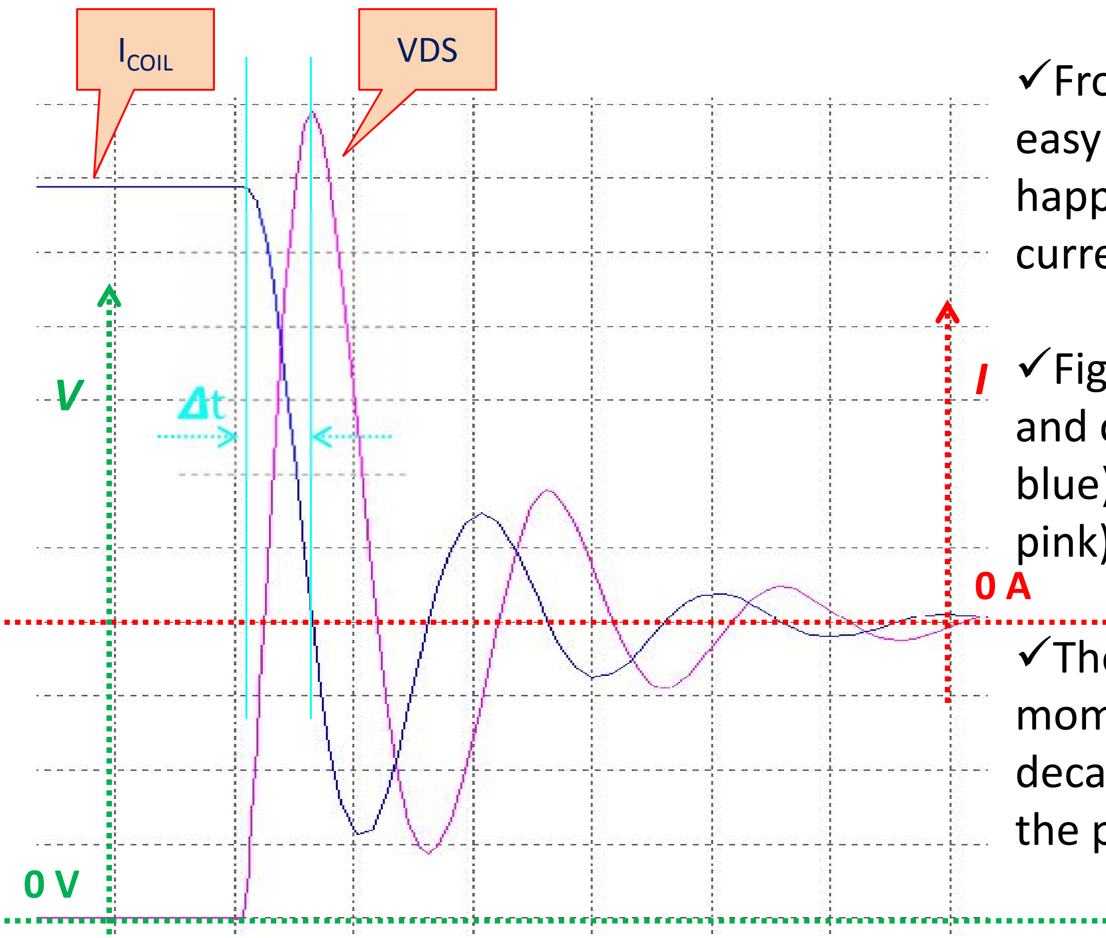

✓ $\Delta$i is final current minus initial current. Final current would be zero and the initial current is the running current.

✓ Do not be confused if the $\Delta$i is negative. A negative sign just means that the inductor reverses its polarity

✓ The maximum value is can be
( neglecting the drop of the
I

$\Delta$i is final cu12V/68Ω) – 0A = 0.176 A
ırrent. Final

# Deriving the Δt

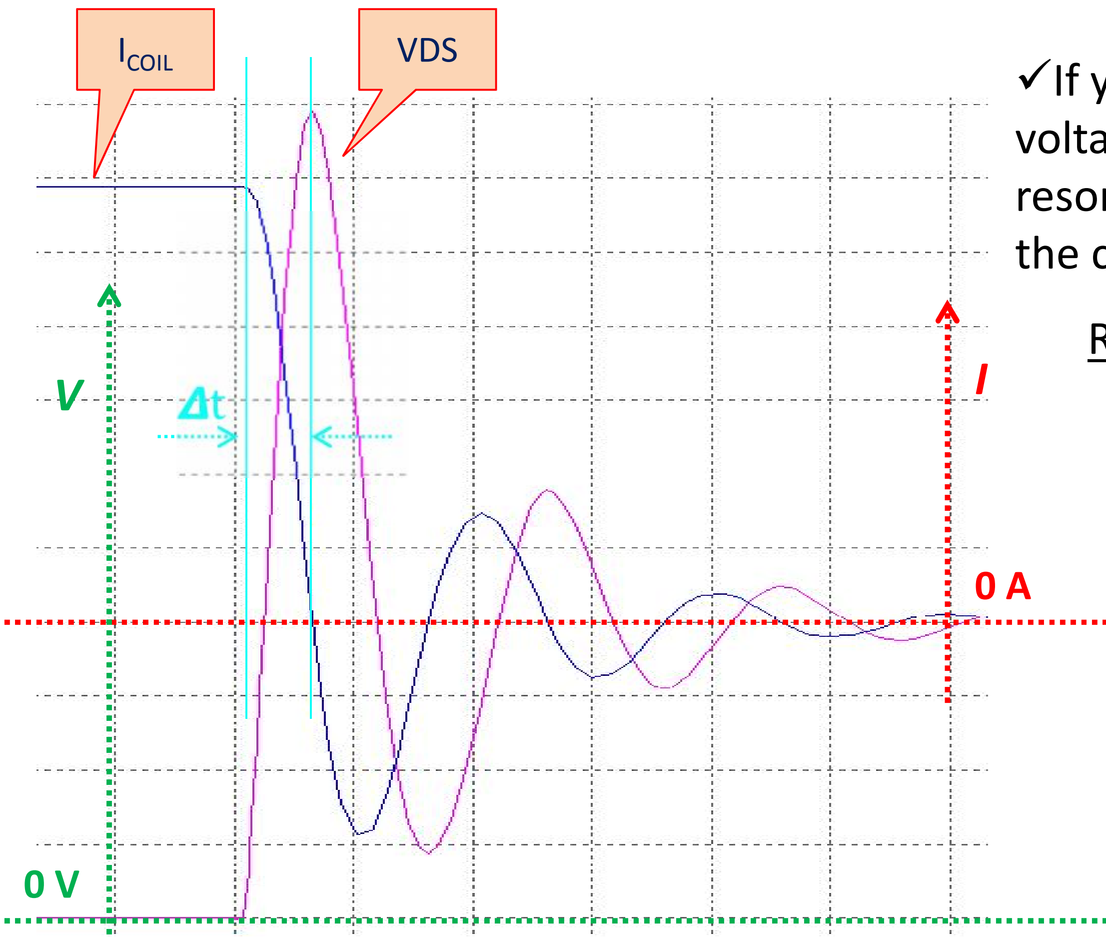



✓From the coil voltage equation, it is easy to tell that the maximum level is happening at the maximum change in current

✓Figure in the left is a simulated VDS and coil current. When the current (in blue) is at the zero level, the VDS (in pink) is at its peak level.

✓The **Δ**t is measured from the moment the coil current starts to decay until 0A wherein the VDS is at the peak level

# Deriving the Δt



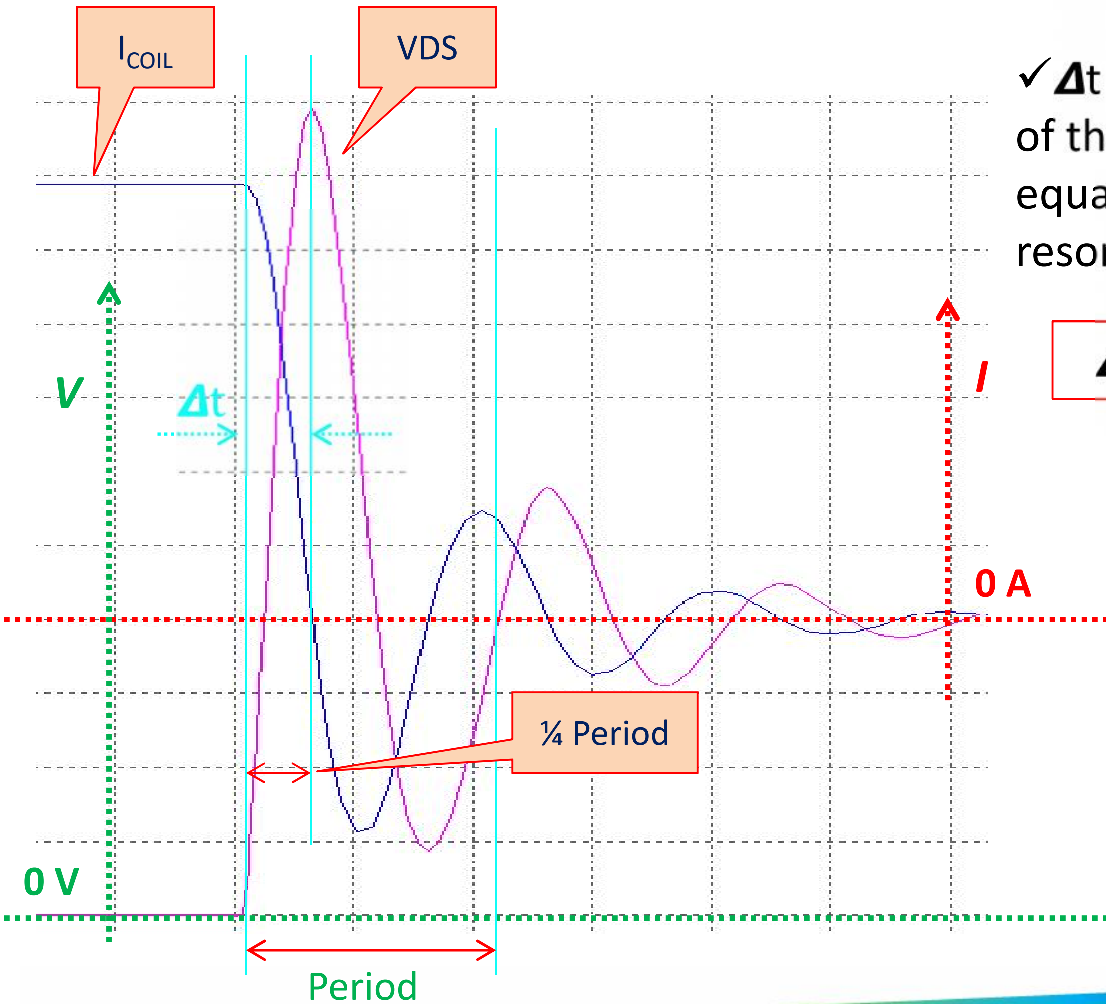

✓If you wonder why the current and voltage oscillates; it s due to the resonance of the coil inductance and the capacitance of the MOSFET

Resonance Frequency Equation

$$F_{RESONANCE} = \frac{1}{2\pi\sqrt{LC}} \quad (5)$$

***Where***
*L is the coil inductance while C is the MOSFET output capacitance plus stray capacitances*

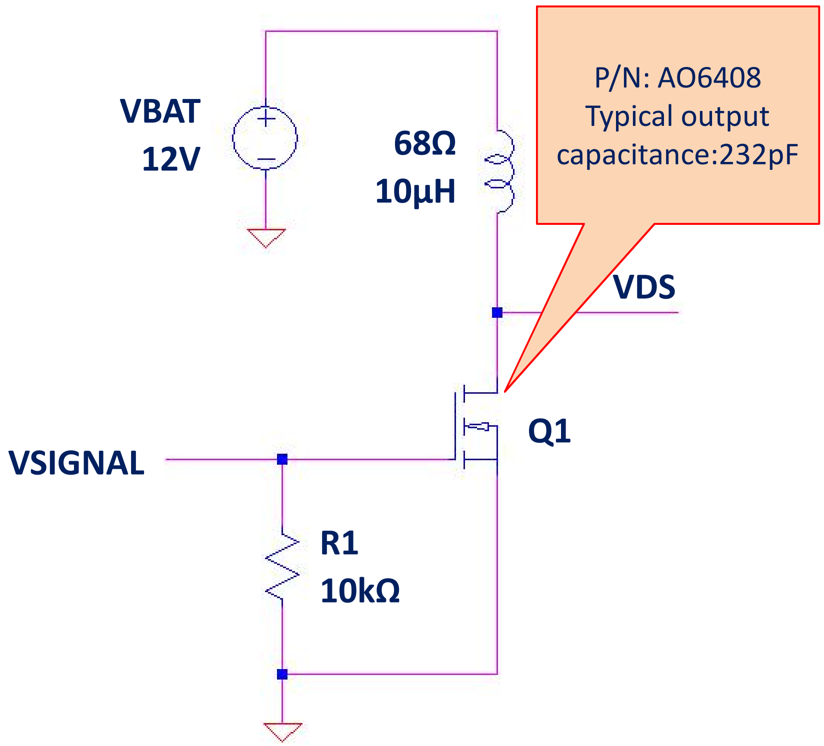
# Deriving the Δt




✓**Δ**t is just ¼ of the one cycle period of the oscillation. The period is just equal to the reciprocal of the resonance frequency.

$$\Delta t = \frac{1}{4} \times (1/F_{RESONANCE}) \quad (6)$$

# Solving the Coil Voltage and VDS




$\Delta i_{maximum}$ = (12V/68Ω) – 0A = **0.176 A**

$$F_{RESONANCE} = \frac{1}{2\pi\sqrt{LC}}$$

$F_{RESONANCE}$ = **3.3043 MHz**

Period = 1/ $F_{RESONANCE}$ = **302.64 nsec**

$\Delta t$ = ¼ x Period = **75.66 nsec**

VCOIL = L x $\Delta i/\Delta t$ = **23.26 V**

VDS = VBAT + VCOIL = 12V + 23.26 V = **35.26V**

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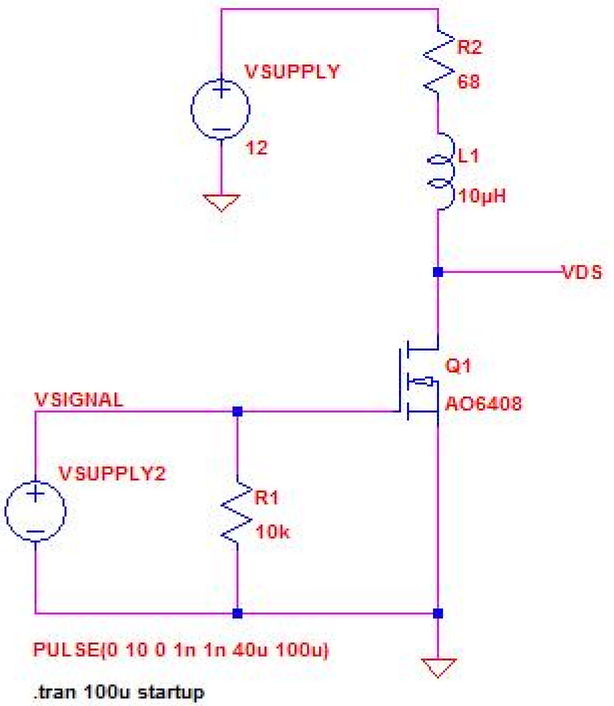
# Simulations




VDS: Almost 35V same with the computed value.

# Reviewing What We Have Learned

✓Inductive kickback on relay is can be computed using simple circuit analysis
✓The challenging part is how to get the change in time or $\Delta$t
✓$\Delta$t is can be solved by studying the resonance of the coil inductance and the output capacitance of the MOSFET
✓The change in time is measured from the moment the inductor current starts to decrease up to the time where the VDS is at its peak level
✓$\Delta$t is just ¼ of the period of the oscillation of the coil inductance and the output capacitance

Reference:
http://electronicsbeliever.com/?s=relay+kickback+voltage

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