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Electronic Engineer
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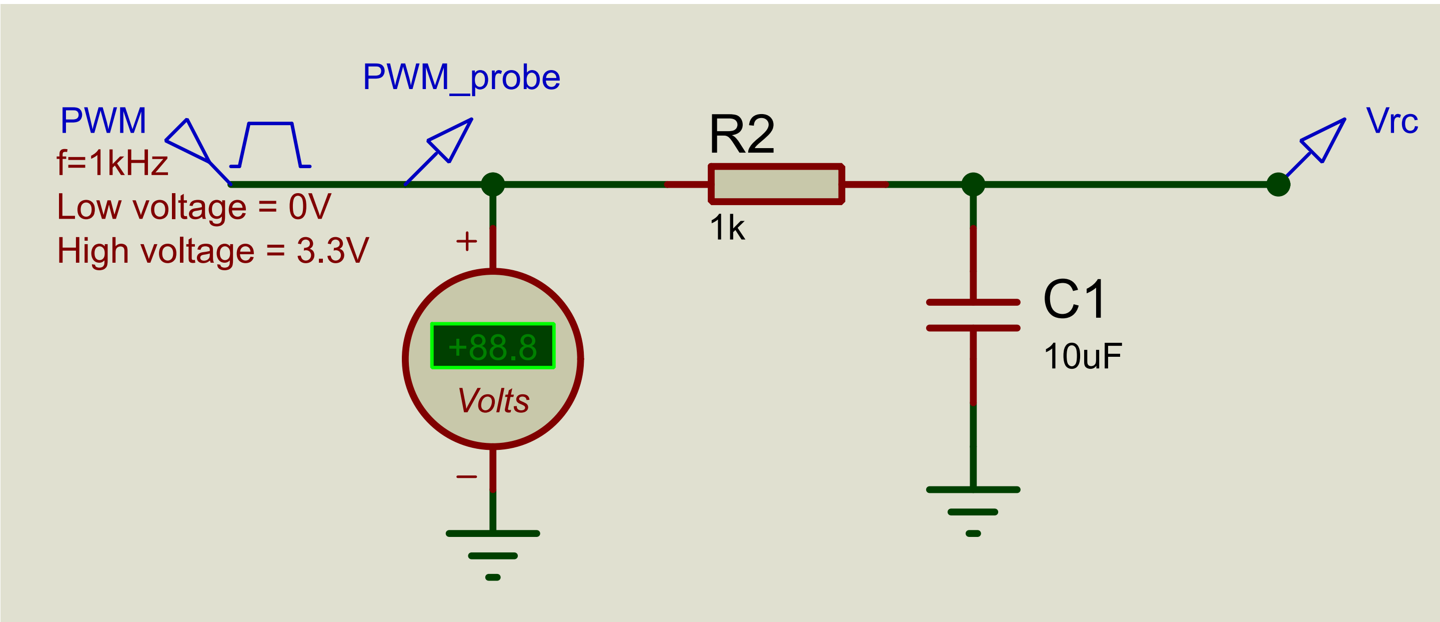
RC Filter Design for PWM Signal



Determine if your RC values are suitable, let's analyze the RC low-pass filter with the following values:

- $R2 = 1\text{k}\Omega$
- $C1 = 10\mu\text{F}$
- PWM frequency $f_{\text{PWM}} = 1\text{kHz}$

Cutoff Frequency Calculation

The cutoff frequency f_c of the RC low-pass filter is given by:

$$f_c = \frac{1}{2\pi R2C1}$$

Substituting the given values:

$$f_c = \frac{1}{2\pi \times 1000 \times 10 \times 10^{-6}}$$

$$f_c \approx 15.9\text{Hz}$$

Comparison with PWM Frequency

The PWM frequency is 1kHz. For effective smoothing of the PWM signal into a DC voltage, the cutoff frequency of the RC filter should be much lower than the PWM frequency.

In this case:

$$\frac{f_{\text{PWM}}}{f_c} = \frac{1000\text{Hz}}{15.9\text{Hz}} \approx 62.9$$

A ratio of ≈ 62.9 indicates that the RC filter will effectively smooth the PWM signal, as the cutoff frequency is much lower than the PWM frequency.

Time Constant

The time constant τ of the RC filter is:

$$\tau = R2 \times C1$$

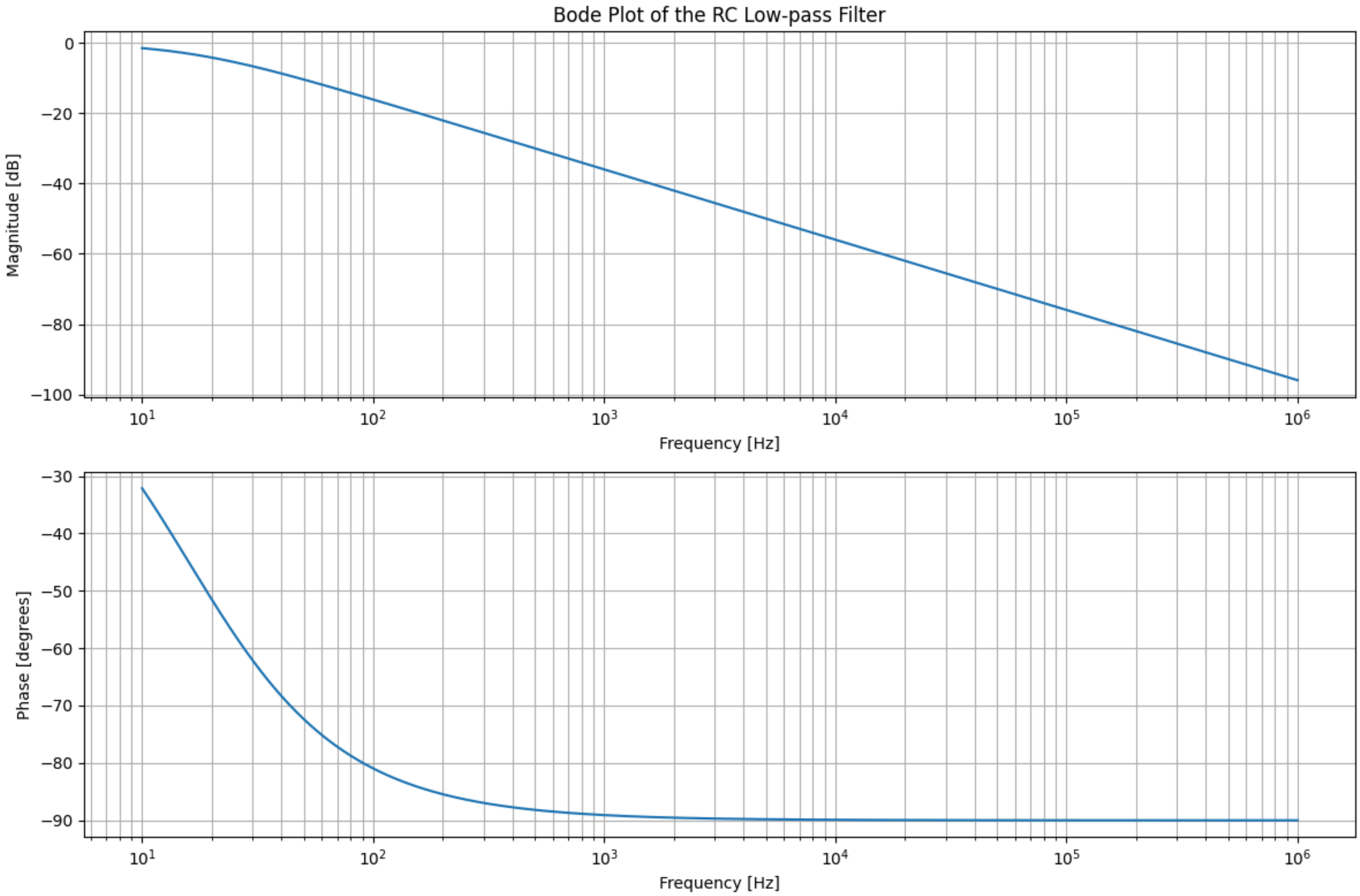
Substituting the given values:

$$\tau = 1000 \times 10 \times 10^{-6}$$

$$\tau = 0.01\text{s} = 10\text{ms}$$

The time constant indicates how quickly the filter responds to changes in the PWM signal. A 10 ms time constant is reasonable for a 1 kHz PWM signal, allowing the filter to respond smoothly to the changes in the PWM duty cycle.

Simulation



Bode Plot of the RC Low-pass Filter
Magnitude [dB]
0
−20
−40
−60
−80
−100
Frequency [Hz]
10^1
10^2
10^3
10^4
10^5
10^6
Phase [degrees]
−30
−40
−50
−60
−70
−80
−90
Frequency [Hz]
10^1
10^2
10^3
10^4
10^5
10^6

Conclusion

The chosen RC values ($R2 = 1\mathrm{k}\Omega$ and $C1 = 10\mu\mathrm{F}$) are good for filtering a 1 kHz PWM signal. The cutoff frequency is low enough to effectively smooth the PWM signal into a stable DC voltage, which can then be used to control the MOSFET and thus the load current accurately.

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PWM Signal to Load Current Conversion

The circuit in the schematic is a typical application of a Pulse Width Modulation (PWM) signal used to control the current through a load. Here's a step-by-step explanation of how the PWM signal affects the current drawn from the load:

1. **PWM Signal:**
   - The PWM signal has a frequency $f = 1\text{kHz}$ and a duty cycle (pulse width) of 50%.
   - The low voltage of the PWM signal is 0V, and the high voltage is 3.3V.
2. **RC Low-pass Filter:**
   - The resistor $R2 = 1\text{k}\Omega$ and the capacitor $C1 = 10\mu\text{F}$ form a low-pass filter.
   - The purpose of this filter is to convert the PWM signal into a DC voltage.
3. **Voltage Conversion:**
   - The DC voltage after the filter V_{DC} can be calculated using the duty cycle D of the PWM signal:

     $$V_{\text{DC}} = D \times V_{\text{high}}$$

     Where $V_{\text{high}} = 3.3\text{V}$.
     For a 50% duty cycle:

     $$V_{\text{DC}} = 0.5 \times 3.3\text{V} = 1.65\text{V}$$
4. **Operational Amplifier:**
   - The operational amplifier $U2:A$ (AD8032) is configured as a voltage follower or buffer.
   - The voltage at the non-inverting input (pin 3) is the filtered DC voltage V_{DC}.
5. **MOSFET Control:**
   - The MOSFET $Q1$ (2N7269) is controlled by the output of the operational amplifier.
   - The current through the load $R1$ (1Ω) is determined by the voltage at the gate of the MOSFET.
6. **Load Current Calculation:**
   - The voltage across $R1$ is the same as the voltage at the source of the MOSFET, which is V_{DC}.
   - The current through the load I_{load} can be calculated using Ohm's Law:

$$I_{\text{load}} = \frac{V_{\text{DC}}}{R1}$$

Given $R1 = 1\Omega$ and $V_{\text{DC}} = 1.65\text{V}$:

$$I_{\text{load}} = \frac{1.65\text{V}}{1\Omega} = 1.65\text{A}$$

Relation Between PWM Duty Cycle and Load Current

The load current I_{load} is directly proportional to the duty cycle D of the PWM signal:

$$I_{\text{load}} = D \times \frac{V_{\text{high}}}{R1}$$

Effect of Frequency

The frequency of the PWM signal affects the efficiency of the low-pass filter. The cutoff frequency f_c of the filter should be much lower than the PWM frequency to ensure proper smoothing. For $R2 = 1\text{k}\Omega$ and $C1 = 10\mu\text{F}$:

$$f_c = \frac{1}{2\pi R2C1} \approx 15.9\text{Hz}$$

Since 15.9 Hz is much lower than 1 kHz, the filter effectively smooths the PWM signal, and the frequency does not directly affect the load current but ensures the DC voltage is properly formed.

Summary

- The load current is proportional to the PWM duty cycle.
- For a duty cycle D and high voltage $V_{\text{high}} = 3.3\text{V}$, the load current I_{load} is:

$$I_{\text{load}} = D \times \frac{3.3\text{V}}{1\Omega}$$

- The frequency ensures the PWM signal is properly filtered to a DC voltage by the RC filter.

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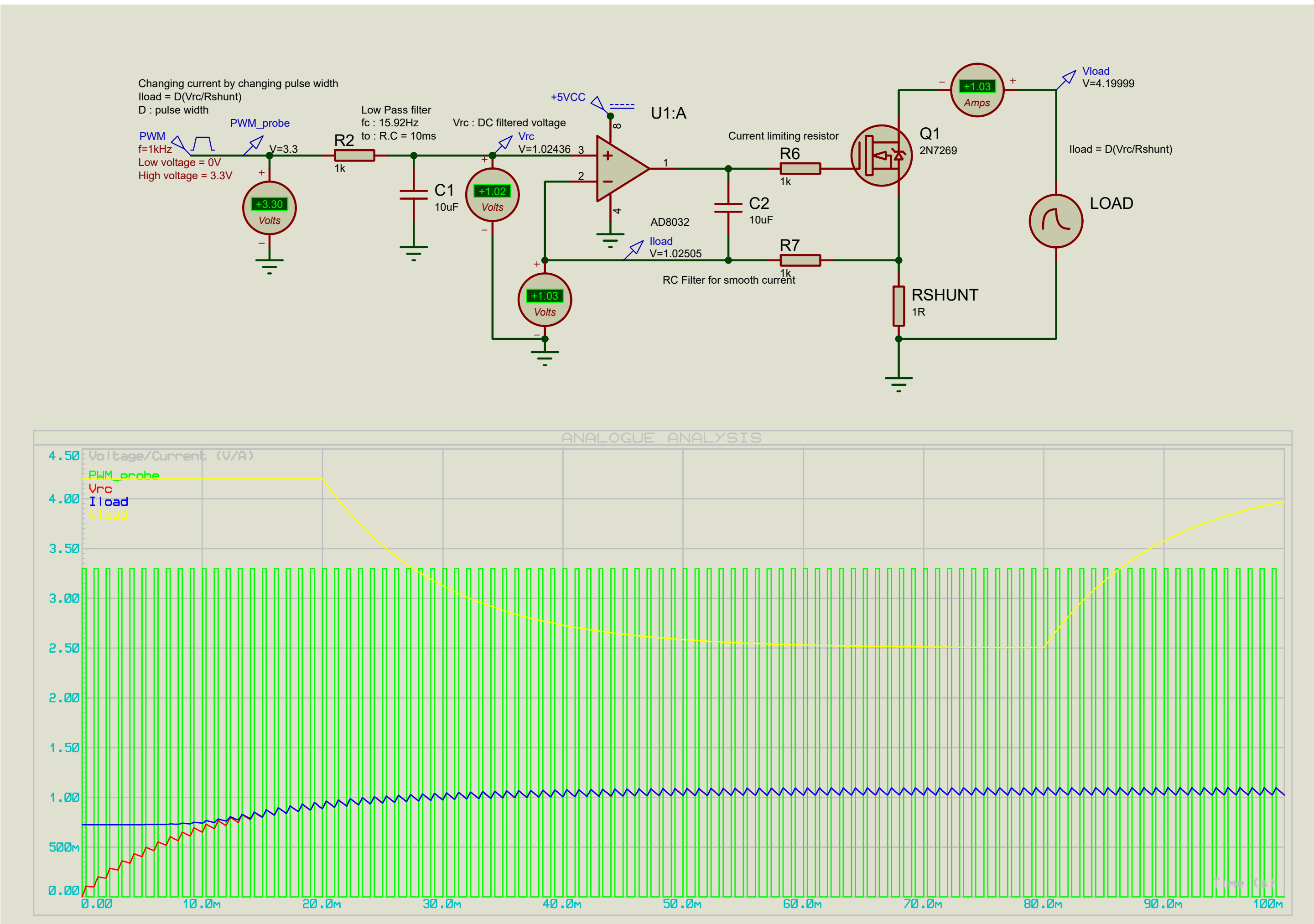
PWM Control of Load Current

This circuit diagram represents a DC electronic load, which is commonly used for testing power supplies, batteries, and other DC power sources by providing a controlled current load. Here's a detailed explanation of each part of the circuit:



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Components:

1. **PWM Source and RC Filter:**
   - **PWM Source:** The PWM signal (PWM probe) has a high voltage of 3.3V, low voltage of 0V, and a frequency of 1kHz.
   - **R2 (1kΩ) and C1 (10μF):** This forms a low-pass filter with a cutoff frequency of approximately 15.92Hz. The filtered PWM signal is converted to a DC voltage (Vrc) at node 1, which is a smoothed version of the PWM signal.
2. **Operational Amplifier (Op-Amp) U1:A:**
   - **U1:A (AD8032):** This op-amp is configured as a voltage follower (buffer) to isolate the low-pass filter from the rest of the circuit and provide a stable DC voltage to the gate of the MOSFET (Q1).
   - **R6 (1kΩ) and C2 (10μF):** These components form an additional filter to smooth out any remaining ripple from the filtered PWM signal.
3. **MOSFET (Q1 - 2N7269):**
   - **Q1:** This is an N-channel MOSFET acting as the variable resistor controlled by the voltage from the op-amp. The MOSFET regulates the current flowing through the load (represented by a voltage source in series with RSHUNT).
4. **Current Sensing and Feedback:**
   - **RSHUNT (1Ω):** This shunt resistor is used to measure the current flowing through the load. The voltage across RSHUNT (Vload) is directly proportional to the current (Iload).
   - **R7 (1kΩ):** This resistor, along with C2, forms a filter to smooth the current measurement signal.

Working Principle:

1. **PWM Control:** The PWM signal is filtered by the RC network (R2 and C1) to produce a DC voltage (Vrc). The duty cycle of the PWM signal determines the average DC voltage output by the filter.
2. **Voltage Buffering:** The filtered voltage (Vrc) is fed into the non-inverting input of the op-amp (U1:A), which buffers the signal and drives the gate of the MOSFET (Q1).
3. **Current Regulation:** The op-amp adjusts the gate voltage of Q1 to regulate the current flowing through the load. The current through the load is given by $I_{load} = D\frac{V_{rc}}{R_{shunt}}$, where D is the duty cycle of the PWM signal.

4. **Feedback Loop:** The voltage across the shunt resistor (RSHUNT) is fed back to the inverting input of the op-amp (U1:A). This feedback mechanism helps maintain a constant current through the load, as determined by the voltage Vrc.

Simulation Results:

- **Green Trace (PWM_probe):** This shows the PWM signal with high frequency and varying duty cycle.
- **Red Trace (Vrc):** This represents the filtered DC voltage after the low-pass filter.
- **Yellow Trace (Vload):** This represents the voltage across the load, varies between 4.2 and 2.5V.
- **Blue Trace (Iload):** This shows the current through the load, which stabilizes around 1.03A, showing the effective regulation of the load current despite the variation of the load voltage.

In summary, this circuit uses a PWM signal to control a MOSFET via an op-amp buffer, allowing precise control of the load current. The current is sensed through a shunt resistor, and feedback ensures stable current regulation. This setup is ideal for creating a programmable electronic load for testing power supplies and batteries.

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