In this lab we will choose the components for the 3525A PWM control IC. We will start by designing and testing the control circuit. Once we are sure that the PWM IC is working correctly, we will hook up the PWM drive outputs to the MOSFET gates and see if the entire supply works.

Design Procedure
We will start with the circuit shown in Figure 1. Note in this figure that the gate drive outputs (pins 14 and 11) of the 3525A are not connected. We will test the waveforms of the control chip before we hook up the MOSFET switches. We will now choose the components for the 3525A. Review the datasheet of the 3525A while reading this lab.

1. The 3525A is a pulse width modulation (PWM) feedback controller. It uses negative feedback to force the voltage at the inverting input (pin 1) of the error amp to be equal to the voltage at the non-inverting input (pin 2) of the error amp. (See the 3525A block diagram on page 1 of the data sheet.)
   - Choose R1 and R2 to produce 2.5 volts at Vx.
   - Choose R3 and R5 to produce 2.5 volts at Vout when the output voltage of your DC supply is 25 volts.

   The negative feedback will force Vout to be equal to Vx. Since the output of the supply is 10 times Vout, the negative feedback causes the output to be 25 volts. Note that you can make the output voltage variable by making Vx variable.

2. This PWM controller has two complementary outputs called Output A (pin 11) and Output B (pin 14). Both outputs have a duty cycle limited to less than 50% and both outputs are never high at the same time. If the frequency of each output is F, then the frequency of the sum of the outputs is 2F. Example waveforms are shown below:

   ![Waveform](image)

   The frequency of each output is 10 kHz. However, since we are using both outputs for two switches that are in parallel, the switching waveform at point V_Switch in the circuit of Figure 1 will have a frequency of 20 kHz as shown in the bottom waveform.

   This PWM IC also allows you to control a parameter called the dead time. This amount of time is a fixed length where both outputs are off. The negative feedback can easily force the PWM portion of the controller to go to 100% duty cycle, which means that the switches will never turn off. If the switches never turn off, the inductor will never discharge and the inductor current will become very large. The dead time is used to guarantee that both MOSFET switches have a guaranteed amount of off time, preventing this problem. You can also think of the dead time as a method of limiting the duty cycle to some maximum value. In our design, the duty cycle should be about 50% when the supply is working properly. As one method of circuit protection, we can use the dead time to limit the duty cycle to

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1 This lab refers to a datasheet for the 3525A PWM controller. There are several manufacturers for this device. The figure and page number references used in this lab refer to the datasheet produced by Unitrode.
something larger than 50% but significantly less than 100%. This eliminates one failure mode of our supply.

Choose \( R_s, R_d, \) and \( C_t \) to produce a switching frequency of 20 kHz and a dead time of 5 \( \mu s \). An equation is given on the bottom of page 3 of the data sheet, and there are graphs on pages 6 and 7 of the data sheet to help choose the values. **Note that the frequency of the ramp is twice the frequency of one of the gate drive outputs.**

3. When you first turn on your supply, the output voltage is much less than 25 V. The feedback tells the controller to go to maximum pulse width. Since the output voltage is close to the input voltage, there is not a large voltage across the inductor when it is discharging. Thus, at start-up, the inductor does not discharge much and the feedback forces maximum pulse width, which charges the inductor as much as possible. The result is a large inductor current at start-up. To prevent this problem, the 3525A has a soft-start feature. At start-up, the soft-start feature limits the pulse-width. Initially the pulse-width is limited to zero, and then is slowly allowed to increase. Once the pulse-width from the soft-start is greater than the pulse-width from the feedback, the feedback takes over. The soft-start only limits the pulse width at start-up or when an over-current fault is detected.

The rate at which the pulse-width is allowed to increase during start-up is determined by the softstart capacitor \( C_{SS} \). This capacitor is charged by a 50 \( \mu A \) current source. The cap voltage starts at zero and then charges positive with the equation \( \Delta V = \frac{I}{C_{SS}} \). When the capacitor reaches approximately 2.5 volts, the soft-start is complete, and the feedback takes over. Choose \( C_{SS} \) so that the soft-start takes between 0.5 and 1 second. (You can choose a longer time if you want to see the output voltage slowly increase. – This is annoying when you want to actually use the supply.)

4. Pin 10 of the 3525A is the shut down pin. This can be used as an on-off control as well as a cycle-by-cycle current limit. During a cycle, when the voltage at pin 10 goes above 1 volt, the output pulse (pins 11 or 14) will be set to zero and the MOSFETs will be turned off for the cycle. This is the cycle-by-cycle current limit. This mode is used to monitor the switch current and turn off the switch if the current becomes too large in any cycle.

If the voltage at pin 10 remains above 1 volt for an extended period of time, the 3525A discharges \( C_{SS} \) and initializes a soft-start. This mode can be thought of as an average current limit. If the current is too high, the supply turns off and then continually attempts to restart.

We will use pin 10 for both purposes. We are monitoring the switch current with the CS1050 current transformer. This is a 50 to 1 current transformer. The current through the output winding of the CS1050 is 50 times less that the current through the switches. This current then flows through R4 producing the voltage called \( I_{LIM} \).

All switching supplies produce a lot of noise, and pin 10 of the 3525A is designed to react quickly to protect the MOSFET switches. Thus, any noise on pin 10 can falsely trip the over current limit. To prevent this problem, careful wiring is needed and a low-pass filter comprised of R6 and C5 has been added.

Choose R4 to limit the switch current to a reasonable current.

Choose R6 and C5 to choose a cut-off frequency of 100 kHz.

Before wiring up this portion, ask me about the layout for this portion of the circuit.

Experimentally figure out the correct connections for the CS1050.

**Construction and Testing**

Wire the circuit of figure 1. Note that the circuit has a signal ground and a power ground. To keep high currents from flowing through the signal ground, we use physically separate grounds, and then connect them at a single point. This point is shown on the circuit drawing. Also note that we are wiring up the 12 volt supply as a two separate networks as well. Each network should be separate and then directly connected to the positive input power bus.

Using the following wire colors for your circuit:

- Black – Signal Ground
- Green – Power Ground
- Red – 12V
- Yellow – Vcc  Power
- Blue – Miscellaneous connections
Before testing, tie a temporary jumper across the gate and source of the MOSFETs to guarantee that they are off. Then, measure and verify the following:

1. The waveform at pin 5 is a 20 kHz ramp.
2. The waveforms at pins 11 and 14 are 10 kHz square waves with 12 volt amplitudes.
3. When you sum together the waveforms at pins 11 and 14, the waveform is a 20 kHz square wave with a 12 V amplitude and a maximum duty-cycle limited by the dead time.

**High Power Testing**

If your PWM IC passes the tests above, connect the gate drive circuitry that has been added in Figure 2. Choose R7 and R11 to limit the current of pins 11 and 14 to 2 amps peak. (Most of the good PWM ICs have an output drive current of 2 amps. This one only has a 200 mA output drive capability. However, we will pretend that it is 2 A.)

- Wire up the remainder of the circuit.
- Remove the static protection from the gates of the MOSFETS.
- Remove the temporary jumpers between the gate and source terminals of the MOSFETs.
- Use your protective eyewear when testing.
- Do not first test this supply unless I am present.
- Set the current limit of the input power supply to about 1 amp.
- Use the high current supplies in the cabinet to power your supply. Do not use the ECE351 power supplies, they may current limit and prevent your supply from turning on.
- With no-load hooked to the output of your supply, turn on the power and see if the output goes to 25 volts.
- If your supply works at no load:
  1. Increase the current limit of the power supply to 5 amps.
  2. Add the load resistor and test your supply with an output current up to 2 amps.

**High Power Measurements**

1. For $V_{IN} = 12$ volts, measure $V_{IN}$, $V_{OUT}$, $I_{IN}$, and $I_{OUT}$ as you change the output power from zero to full power. Obtain the following plots:
   - Output voltage versus output current.
   - Efficiency versus output power.
   - The ratio of input current to output current versus output power.

2. For $V_{IN} = 14$ volts, measure $V_{IN}$, $V_{OUT}$, $I_{IN}$, and $I_{OUT}$ as you change the output power from zero to full power. Obtain the following plots:
   - Output voltage versus output current.
   - Efficiency versus output power.
   - The ratio of input current to output current versus output power.

3. With an oscilloscope measure the output ripple using the AC setting of the oscilloscope. Measure the ripple at full load for $V_{IN} = 12$ V and $V_{IN} = 14$ V.

4. Measure the voltage at pin 10 of the 3525A with the oscilloscope and measure the DC output voltage of your converter with a Multimeter. Slowly increase the load and view these signals. Once you reach the current limit, the output voltage should decrease as you increase the output current. Increase the output current beyond 2 A and see if you can observe that the peak inductor current is limited to about 8 A and that once the peak current limit is reached, the output voltage of the supply starts to decrease. Reaching the peak current limit consistently may also cause the soft-start to kick in and you will see the output voltage of your supply cycle up and down.
Figure 1

RC Filters
Close to SG3525

\( C_t, R_t, R_d \) set the ramp frequency
\( C_{ss} \) is the soft start capacitor

12 Volt to 25 Volt Boost Converter
Figure 2

Positive Input

Input 12 - 14 Volts

Ground Input

Output Voltage

Ground Out

Output

J1

J2

J3

J4

Poly

Poly

Poly

Poly

Poly

Ct, Rt, Rd set the ramp frequency

Css is the soft start capacitor

Cts, Rs, Rs set the ramp frequency

Css is the soft start capacitor

RC Filters

Close to

SG3525

Signal Ground

Power Ground

Figure 2