A. Voltage sources

1. You need three different voltages for this experiment,
namely, +12 VDC, -12 VDC and 3 VDC.
You will need a high current 12 VDC source, and a triple output supply.

2. +12 VDC is needed to power the LF353, LM35 and the bulb.
It is very important that you use the high current supply
(e.g. Loadstar or Ginza adjustable supply) for the +12 VDC.
This experiment will not work otherwise.
Adjust the supply for 12 V output,
connect the positive terminal to +12 VDC of your circuit and
the negative terminal to the ground.

2.1 Use thick wires for the +12 VDC since a significant amount of current
will be flowing from the high current supply.

3. -12 VDC is needed to power the LF353.
You should use one of the output of the triple output supply.
Adjust it for 12 V output, connect the positive terminal to the
ground of your circuit and the negative terminal to -12 VDC.

4. 3 VDC is needed as the input.
You should use the remaining adjustable output of the triple output supply.
Adjust it for 3 V output, connect the negative terminal to the
ground of your circuit and the positive terminal to the base resistor R1.

B. Brake lamp

1. The brake lamp typically has two filaments.
The brake lamp has three terminals, two at the bottom and the metal body.

2. Connection to each filament is through one of the terminals
at the bottom of the bulb and the metal body of the bulb.
The metal body is common for both filaments.

3. One filament lights up dimmer than the other.
For this experiment, determine and use the filament that
lights up dimmer than the other.

4. You may use a socket to make connections to the bulb or
solder wires directly to one of the terminals and the metal body.

C. Transistor and heat sink

1. Mount the heat sink on the TIP35C.
Make sure you use a bolt and nut for a firm connection.

2. Get the datasheet for TIP35C. Verify which terminals
are the base, collector and emitter.

3. The TIP35C does not fit into the breadboard.
You need to solder a short piece of wire to the terminals
to be able to mount the transistor on the breadboard.
Alternatively, you may trim the terminals, but this may be more difficult.

D. LM35 and x10 amplifier

1. Get the datasheets for the LM35 and LF353.

2. Verify the terminals for the LM35.
It is very important that you connect the LM35 correctly the first time.
Applying power to an incorrectly connected LM35 will
immediately destroy it.

3. Build a non-inverting amplifier with a gain of 10.

E. Testing each block

1. Build and test the blocks individually.

2. There are three blocks you can test individually, namely,
(a) resistor, transistor, bulb circuit (b) LM35 (c) x10 amplifier.

3. You should make sure all the three blocks are operating
as expected before connecting them together.

F. Resistor, transistor and bulb

1. You need to use a base resistor; start with a 1k resistor.
Do not connect the 3 VDC input directly to the base,
you will destroy the TIP35C.

2. You only need the +12 VDC and 3 VDC supplies to test this block.

3. If you built this block correctly,
the bulb should light up and/or
a voltage less than 12 V should appear across the bulb.

4. If step 3 is successful, you may now adjust/change the
base resistor R1 until you get a bulb voltage between 7 and 8 VDC.

5. Take note of the R1 you determined,
you will use this for the rest of the experiments.

G. The LM35 sensor

1. Connect the LM35 to the +12 VDC and ground.
Make sure the connections are correct, verify this before powering up.

2. Power up the supply.

3. Carefully probe the Vout and ground terminals.
Shorting the LM35 terminals will destroy the LM35.

4. You should now read approximately 0.3 V across the
Vout terminal and ground terminal of the LM35.

5. Verify your connections if you fail to get approximately 0.3 V.
If you connected the LM35 incorrectly,
you most probably have destroyed it.

H. The x10 amplifier

1. Power up the LF353 by connecting it to +12 VDC and -12 VDC.
Note that no other part/component uses the -12 VDC supply except for the LF353.

2. You may use the adjustable supply to check if your x10 amplifier
is working correctly.

3. You need to get a x10 (or close) operation before considering
this block functional.

I. Connecting the LM35 and x10 amplifier

1. After verifying the functionality of the above two blocks,
you may connect them together.

2. You should get 3 VDC (approximately) at the output of
the x10 amplifier.

J. Fastening the LM35 to the bulb.

1. If the bulb circuit is operational, fasten the LM35 to the bulb.
You need to use a good quality masking tape or electrical tape
as the bulb will get very hot.

2. The LM35 flat face should be in contact with the bulb.
The LM35 should not move relative to the bulb.
It should always be in contact with the bulb.

3. The data that you will be gathering will be incorrect
if the LM35 moves (relative to the bulb) during the experiment.

K. Powering up the entire circuit

1. After connecting all the blocks together,
you may now power up the entire circuit.

2. The bulb should light up and
the output of the x10 amplifier (Vtemp) should now steadily increase.

3. You are now ready to collect your data (step response).

L. Collecting your data

1. Disconnect the 3 VDC input (to R1). Do not power down the circuit.
Leave the power on for all the supplies.

2. The bulb should now be off. At the same time, you should observe
that Vtemp is slowly decreasing.

3. Wait for Vtemp to be 2.8 V or below
(corresponding to the bulb temperature of 28 degrees Celsius or lower).
You may fan the bulb to cool it down faster.
Do not touch anything else in the circuit.

4. Once the bulb temperature is at 28C or below,
the setup is ready for data collection.

5. Have a clean piece of paper and a timer (watch) ready.
You will be collecting Vtemp readings every 30 seconds.

6. Write down the initial Vtemp.

7. Connect the 3 VDC input to R1 and start timing.
The bulb should have immediately lit up and Vtemp should be increasing.

8. Every 30 seconds,
write down the total time elapsed and the corresponding Vtemp.
Continue taking readings while being careful not to disturb your setup.

9. Stop condition. You only stop taking readings when the
readings from the last 3 minutes are within 0.5 degrees Celsius of each other.
This means that the absolute difference of any pair of readings
from the last three should be less than or equal 0.5 degrees Celsius.