Human body model (HBM) for electrostatic discharge (ESD)

Commonly, electrostatic charges are created by the contact and separation of two materials. This process is called "triboelectric charging", which involves the transfer of electrons between two materials. Once charges are created and remain on a material, they become electrostatic charges. The imbalance of charges produces an electric field between material bodies. Meanwhile, the built-up electric field can result in the transfer of charges due to the electrical potential difference. This phenomenon is known as *electrostatic discharge* (ESD).

One of the most common causes of electrostatic damage is the direct transfer of electrostatic charge from the human body to a device, as shown in *Fig*. 1(a). The sudden release of charges into the device can produce extremely high voltage or current at the device that can results in irreversible transformation and destruction of the device.

The equivalent electric circuit, which simulates the discharge from a person delivered to the device, is shown in *Fig*. 1(b). This electrical circuit is called the *human body model* (HBM) and it is a very commonly used model for testing the sensitivity of a device to ESD. The model has a 100 pF capacitor that discharges through a 1.5 kΩ resistor and a switch into the device under test (DUT).
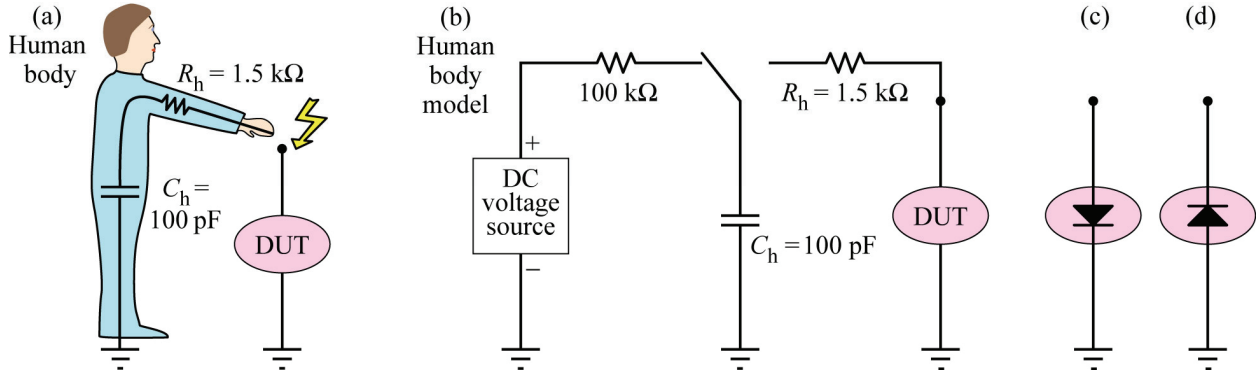

Fig. 1: (a) Human body cause a electric discharge on a "device under test" (DUT); (b) the equivalent circuits used to test the discharge sensitivity of a device based on human body model; (c) the LED device is connected to the testing circuit in forward direction; (d) the LED device is connected to the testing circuit in reverse direction.

When an LED is connected to the testing circuits in *forward direction*, as shown in *Fig*. 1(c), the positive charge $+Q$ stored in capacitor C will dissipate through the resistor ($R_h = 1.5$ kΩ) and the diode junction R_f over the approximate time given by $\tau = RC$. The average flowing current is expected to be $I = +Q/\tau$. Thus, the energy E_f dissipated in the junction during the forward discharge process can be given by:

$$E_f \;=\; I^2 R_f \tau \;=\; \frac{Q^2}{\tau} R_f \;=\; \frac{Q^2}{(R_h + R_f)\,C} R_f \;\approx\; \frac{Q^2}{C}\frac{R_f}{R_h} \;\rightarrow\; 0 \qquad (1)$$

in which, $R_f \ll R_h$. So the energy dissipated in the junction is very small.

When the LED is connected to the testing circuits in *reverse direction*, as shown in *Fig*. 1(d), the resistance of the reverse-biased junction is R_r. The energy E_r dissipated in the junction can be given by:

$$E_r \;=\; I^2 R_r \tau \;=\; \frac{Q^2}{\tau} R_r \;=\; \frac{Q^2}{(R_r + R_h)\,C} R_r \;\approx\; \frac{Q^2}{C} \qquad (2)$$

Because $R_r \gg R_h$, most of the power is dissipated in the junction of the LED.

An ESD simulator based on human body model has been built. The circuit of the ESD simulator consists of three main parts: DC voltage supply part, voltage adjustment and measurement part, and HBM discharging part, as illustrated in *Fig*. 2.
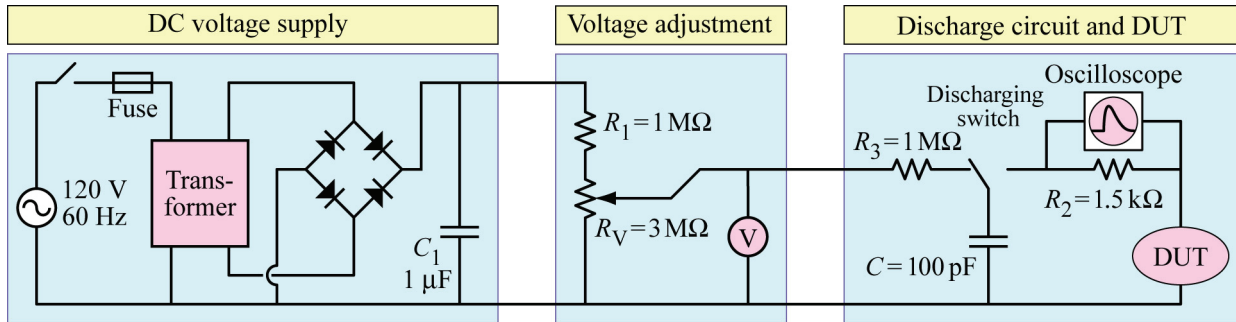

Fig. 2: The circuit of ESD simulator that is based on the human body model.

Figure 3 shows the photo of the front panel of the ESD simulator. The power switch controls the "on/off" of the whole system. The adjustable knob controls the resistance of the potentiometer (R_v) and thus the ESD voltage. The voltage is measured and shown by the panel voltmeter, which has a range from 0 to 1000 V. The discharge switch controls the charging and discharging of capacitor C. At normal position, the capacitor is being charged to the high voltage chosen by the potentiometer. When pushing the discharging switch, the charge stored in the capacitor will discharge through R_2 into the device under test (DUT). The system has two sets of terminals. The top set of terminals is connected to an oscilloscope, which monitors the discharging signal. The bottom set of terminals is connected to the DUT.
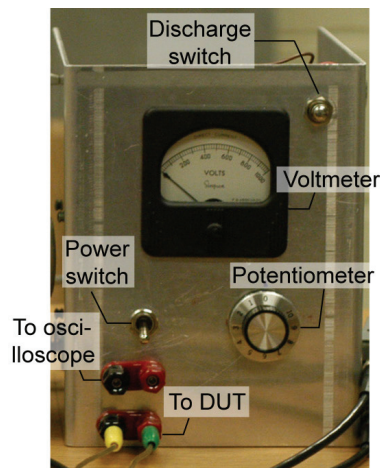

Fig. 3: The front panel of the home-made ESD simulator.

After the discharge is completed, the post-stress *I-V* characteristics of the device is measured to check if the device has failed. The highest voltage level that the device can survive is called "ESD withstand voltage (V_w)", which can be used to classify the ESD sensitivity of the device. The ESD sensitivity classification for a device tested by HBM is shown in *Table* 1, which gives an indication of the level of ESD protection required.

Class	ESD withstand voltage, V_w
0	$0 \sim 250$ V
1A	$250 \sim 500$ V
1B	$500 \sim 1000$ V
1C	$1000 \sim 2000$ V
2	$2000 \sim 4000$ V
3A	$4000 \sim 8000$ V
3B	> 8000 V

Table 1: ESD sensitivity classification for HBM test

The ESD capability measurement setup includes the home-built ESD simulator, a switch box, an oscilloscope, a semiconductor parameter analyzer, and a probe station, as shown in *Fig*. 4. The cathode and anode of the DUT is contacted by the needle tips on the probe station, which is connected to either the ESD simulator or the semiconductor parameter analyzer through the switch box. When the switch is at position "1", the DUT is connected to the ESD simulator and ready for ESD testing. During the test, a discharging pulse is applied 3 sequential times at a certain ESD voltage. After the discharging pulse has been applied, the DUT is connected to the semiconductor parameter analyzer by changing the switch to position "2". Then the reverse current (I_r) of the device at -5 V and forward voltage (V_f) at 1 mA can be inspected to see if the device has failed.
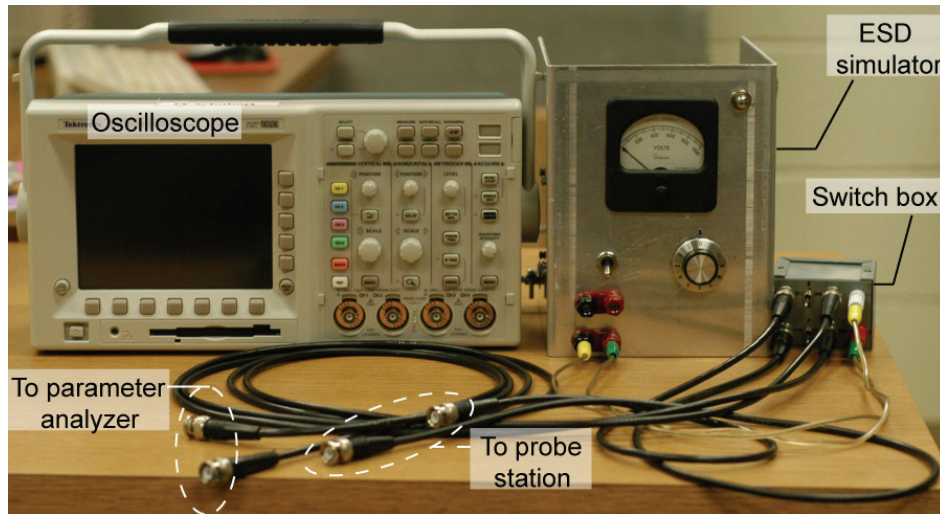

Fig. 4: The setup of ESD capability measurement system, which includes the home-built ESD simulator, a switch box, Tektronix oscilloscope, Agilent 4155C semiconductor parameter analyzer, and Karl Suss PM5 probe station.