**Laboratory Assignment 3 : I/V characteristics**

*Suggested reading and connection time: 20 min.*

**Goal:**

In this assignment we will learn a useful technique to *characterize* an electronic part, i.e. obtain it’s I/V characteristics. We will use some of the more advanced features of a DSO to make such possibly tedious measurements easier. No graph papers will be used.

You have already learnt the basic operation of a Function Generator and Digital Storage Oscilloscope in Lab 2.   
In this lab, we will use the *differential* voltage signal provided by the function generator on a red cable connected from its back panel. This cable has three connectors – the red and white present a differential voltage which swings between +V and –V and the green connector presents the halfway point: it is always at (+V-V)/2 = 0. Note that this 0V is not related to the ‘earth-ground’ potential.

For this entire experiment, connect a circuit in the configuration shown in Fig 1.



Fig 1: Setup for Assignment 3

X

Function

Generator:

Sine wave

*voltage*

Variable

Freq.

+ Amplitude

Use *differential* signal (rd/wht) on red cable from back of unit.

Part to

be tested

Rref = 1000 Ω

**+**

**-**

**+**

**-**

**+**

**-**

To DSO Channel 1abelled '1'

To DSO Channel labelled '2'

*I*

DSO

*A*

*BX*

*BR*

Here are a few things you should notice when making the connections:

* The function generator is producing a *differential voltage* signal swinging between

+V and -V: (the amplitude is set by the knob on the front panel). The green wire is not used for this setup.

* On the DSO both channels have their negative terminals (the outer shields of the BNC connector) internally connected to earth ground for safety.
* You must learn to keep track of this distinction between a differential (+/-) signal, and a signal whose negative terminal is fixed at ground potential (a single-ended signal). It is very important in analog electronics – we will use it many times during the semester.
* The number of connections to be made in the above circuit is very small: however, you must make sure that the connections are secure. A loose wire can inject a lot of noise into your measurement and lead you off into completely wrong conclusions

Note: The following experiments *must* be performed in the suggested times. So make doubly sure that your connections are secure before putting in the part X to be characterized.

**Part 1: The Diode** *Suggested times: Part A: 40 min, Part B: 30 min*

Put in a diode as Part X in Fig 1. Use input signal frequency of 100 Hz.

**Part A)** By adjusting the various controls on the DSO, obtain the I/V characteristics of the diode.

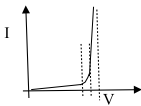
Normally, the DSO plots the signals measured on channels 1 and 2. However, it can be put into a mode which plots channel 1 v/s 2 (it’s called X-Y mode). Determine which control button does this.

Observe and note the following:

1. From the markings on the DSO probe, what is the input resistance seen by the points  
   *(BX-A)* i.e. device X and *(BR-A)* i.e Rref looking into the DSO? \_\_\_\_\_\_~ 1 MΩ || pF
2. Based (1), what is the path of current *I* at the junction A? \_\_\_\_\_through X and Rref (no I into DSO)
3. Accordingly, what does channel 1 measure? \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_VX
4. What does channel 2 measure? \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_VRref

Using Ohm’s law and the above information, assuming *Rref* is a perfect resistor, one axis of the X-Y measurement plot can be simply converted into a different quantity

1. What is this quantity? \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_IX

Based on the answers to all the above questions, draw a plot of the measured I-V characteristic of the diode here:

*Hint: Consider carefully the voltage polarities applied to Part X and Rref with respect to the junction point A : you may need to invert one of the channels to get a sensible V/V graph. You can go into the Channel menus of the DSO to invert the signal.*

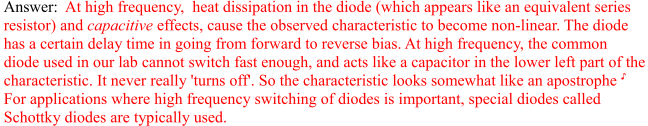
1. What is the voltage at which the diode just starts conducting? \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_
2. What is the voltage at which the diode reaches full conduction? \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**Part B)** Keeping the above setup same, change the input function generator signal to a high frequency:   
Redraw the new observed I-V characteristics here, and state a hypothesis to explain your observations

i) For frequency = 1 kHz ii) For frequency = 10 kHz

At ~ 1 kHz hysteresis is seen in forward bias At 10 kHz, in reverse bias too, the diode current is>0

Diode’s depletion zone width acts as an effective capacitor in parallel. When voltage changes, the capacitor has a finite time constant to discharge and remove stored charge in the depletion layer.



Note: you will have to magnify the scale and examine the traces around the origin to notice peculiarities.

*Hint: Normally, diodes are specified to operate at AC line voltage (60 Hz) as rectifiers. For high frequency operation, a different type of diode, called a ‘Fast Recovery’ diode must be used.*

**Part 2: The Resistor** *Suggested times: Part A: 20 min, Part B: 30 min, Part C: 30 min*

Put in a resistor of *unknown* value *Runknown* in place of Part X in Fig 1.

**Part A)** (You are *not allowed* to use a DMM!)

**Q.1)** Repeat the technique developed for Part 1A to obtain the I-V characteristic of the resistor.

At first try a sine wave input of ~ 2V amplitude at frequency ~ 200Hz..

This should let you make a straightforward measurement.

Draw your observed I-V characteristic here, making careful note of the slope:

Linear I-V trace: slope gives *Runknown*

Based on your observations, determine Runknown=\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**Part B)** Keeping the amplitude low, increase the frequency of the input signal up to ~ 10 kHz

Redraw the observed I-V characteristic:

Curve becomes non-linear above ~ 5 - 10 kHz : an effect of the parasitic parallel capacitance and series inductive wire connections depending on how the connections have been made. See Lecture notes for details.

**Q.2)** If the observation is different from Part A, state a hypothesis that accounts for the difference:

Bare minimum acceptable hypothesis: each resistor can be modeled as *(R + 1/jωC + jωL)*. In this measurement, at high frequencies the complex term is non-negligible and different for the two devices. *(RX + 1/jωCX+ jωLX)* and  
*(Rref + 1/jωCref + Lref)*. This causes the elliptical ‘Lissajous’ type curve observation.

In principle, from the observed major and minor axes of the ellipse, *LX* and *Lref* can be derived.

/6

/2+2

/3

/1

/1

1.A

1.B

2.A

2.B.1

2.B.2

/15

Total

**Observations made by PSarin in testing the setup with DSO on Aug 16, 2012-08-16**

**(and during the lab)**

**Diode I-V characteristics:**

* For some mysterious reason, the I/V curve is rotated by +90○ Couldn’t change it to ‘textbook’ shape by either inverting X or Y or both. Please recheck connections
* Linear characteristic only up to ~ 100 Hz
* Beyond that, diode becomes non-linear. It ‘remembers’ it’s ON state even when the bias is reversed. Need different type of diodes (called fast recovery diodes) that don’t have such non-linearites

Generally good settings of DSO:

Display → XY mode

→ Use Dots

→ Pixel persistence off

Channel 1 (diode) 500 mV and Channel 2 (1k resistor) 1V scale seems to give good resolution to see 0.7V diode turn-on

Play around with connections and waveform inversion to get the characteristic ‘right side up’ !

**Resistor I-V characteristics:**

* Amplitude of input used was approximately half the maximum from FG
* Must invert one channel to get positive slope R!
* Curve becomes non-linear above ~ 5 - 10 kHz : an effect of the complex impedance (inductive wire connections depending on how the connections have been made + capacitive input impedance of the DSO) Can see the lissajous type non-linear curve change shape by merely pressing down on Part X.   
  Group 1 worked out the detailed mathematical shape of the curve using impedances X and Y – showing elliptical/circular form depending on the resistance values.
* Joule heating effect (Part C below) is very difficult to observe and interpret, hence dropped.   
  At large voltage amplitude best seen at very low frequencies ~ 0.5 – 1 Hz  
  The trace can be seen in detail moving up and down across quadrants 1 and 3: the slope is equal to the RX value near the origin, but becomes sharply higher at the extremes

**Part B)** Increase the amplitude of the function generator to maximum and reduce frequency to 1 Hz.

Redraw the observed I-V characteristic:

Joule heating can be seen by zooming into the trace in quadrants 1 and 3: near origin RX should be same as in Part A, at the extremes, slope (i.e. R­X) increases. Results vary according to the time taken to perform the experiment

Based on this new observation, deduce the value of Runknown=\_\_\_\_\_\_\_\_\_\_\_

If it is different from Part A, state a hypothesis that accounts for the difference: