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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.

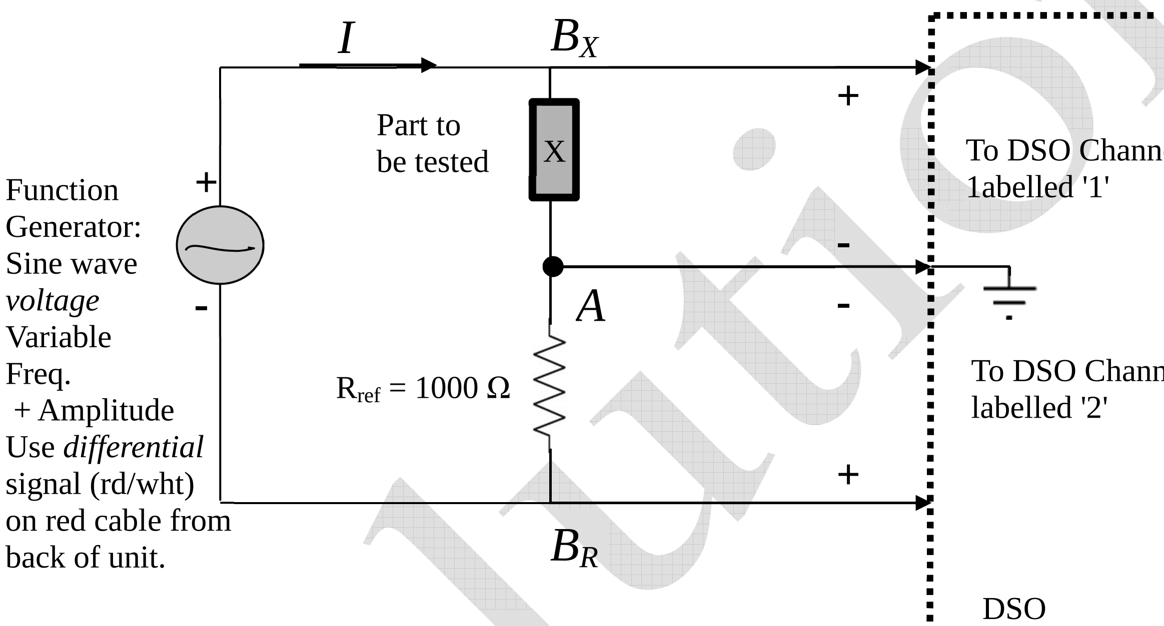

Fig 1: Setup for Assignment 3

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.

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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.

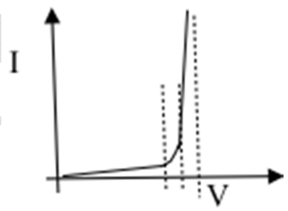
Observe and note the following:

1. From the markings on the DSO probe, what is the input resistance seen by the points *(B_X-A)* i.e. device X and *(B_R-A)* i.e R_{ref} looking into the DSO? ______~ 1 MΩ || pF
2. Based (1), what is the path of current *I* at the junction A? _____through X and R_{ref} (no I into DSO)
3. Accordingly, what does channel 1 measure? ____________________V_X
4. What does channel 2 measure? ______________________________V_{Rref}

Using Ohm's law and the above information, assuming R_{ref} is a perfect resistor, one axis of the X-Y measurement plot can be simply converted into a different quantity

5. What is this quantity? _____________________________________I_X

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 R_{ref} 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.

6. What is the voltage at which the diode just starts conducting? ____________________
7. 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.

Answer: At high frequency, heat dissipation in the diode (which appears like an equivalent series resistor) and *capacitive* effects, cause the observed characteristic to become non-linear. The diode has a certain delay time in going from forward to reverse bias. At high frequency, the common diode used in our lab cannot switch fast enough, and acts like a capacitor in the lower left part of the characteristic. It never really 'turns off'. So the characteristic looks somewhat like an apostrophe '
For applications where high frequency switching of diodes is important, special diodes called Schottky diodes are typically used.

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.

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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 $R_{unknown}$ 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 $R_{unknown}$

Based on your observations, determine $R_{unknown}$=____________________

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 $(R + 1/j\omega C + j\omega L)$. In this measurement, at high frequencies the complex term is non-negligible and different for the two devices. $(R_X + 1/j\omega C_X + j\omega L_X)$ and
$(R_{ref} + 1/j\omega C_{ref} + L_{ref})$. This causes the elliptical 'Lissajous' type curve observation.

In principle, from the observed major and minor axes of the ellipse, L_X and L_{ref} can be derived.

Observations made by PSarin in testing the setup with DSO on Aug 16, 2012-08-16 (and during the lab)

1.A	1.B	2.A	2.B.1	2.B.2	Total
/6	/2+2	/3	/1	/1	/15

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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 R_X 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 R_X should be same as in Part A, at the extremes, slope (i.e. R_X) increases. Results vary according to the time taken to perform the experiment

Based on this new observation, deduce the value of $R_{unknown}$=____________
If it is different from Part A, state a hypothesis that accounts for the difference: