# A Procedure for Measuring the Saturation Current and Ideality Factor of a Diode, along with Measurements on various diodes

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**Quick Summary:** A schematic and operational instructions are given for a device for use in measuring Saturation Current and Ideality Factor of a diode. Measurements of various detector diodes are included.

The Saturation Current and Ideality Coefficient of a diode can be determined by measuring an applied junction voltage along with the associated current flow at two different voltages. These two data pairs are then substituted into the Shockley diode equation to create two simultaneous equations in Is and n, and then solved for Is and n. Since the equations include exponential functions, they can not be solved by ordinary algebra. Numerical methods must be used.

The **Shockley diode equation** at 25 degrees C. is: **Id = Is*(exp(Vd/(0.0256789*n))-1) Amps**. Id = Diode Current (amps), Is=Saturation Current (amps), Vd = Diode Voltage, n = Ideality Coefficient. The series resistance Rs of the diode is ignored because the measurement currents are so low that the voltage drop across Rs is negligible. Measurements have shown that Is and n of point contact germanium diodes can vary with current, but are relatively constant, down to very low currents, when the current is under six times Is. Silicon p-n junction diodes exhibit values of Is and n that vary with current. The values for Is and n of Schottky diodes are quite constant over the range of currents used in ordinary crystal radio set reception.

A convenient set of measuring currents is about 6*Is and 3*Is. Substituting Id = 6*Is, then Id = 3*Is into the Shockley and solving for Vd yields: For Id = 6*Is, Vd = 0.05000*n volts. For Id = 3*Is, Vd = 0.03561*n volts. The value of n will probably be between 1.0 and 1.2 for the type of diodes used in crystal radio sets, so use 1.1 in determining the applied voltage to use. Suggested voltages to use are about 0.055 and 0.039 volts, although other values may be used.

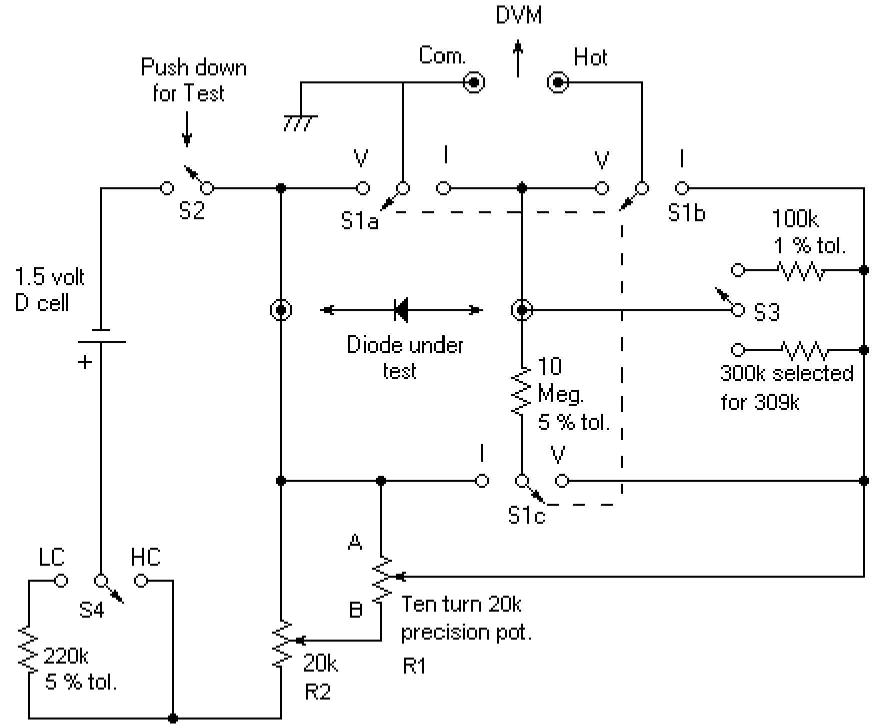


**Fig. 1 - Schematic of Device for Measuring Diode Is and n.**

S1 is a triple pole double throw switch, S2 is a push button momentary-contact SPST switch. DVM is a digital voltmeter with 10 Meg input resistance having a 200 mV range setting. S3 is a range switch that enables greater precision when using a conventional 3 1/2 digit DVM. It is also used when measuring diodes having a high Is. R2 is used for coarse setting of the diode voltage. R1 is a ten turn precision 20k pot such as part # 594-53611203 from Mouser. It is used for fine setting of the diode voltage.

## Procedure for Measuring Is and n:

1. Set S3 for 300k for diodes expected to have a low to medium Is. Set S3 to 100k if the diode is expected to have a high Is. S4 to HC and R1 to 1 about turn from point B.
2. Take Data Set #1: Set S1 to V. Push S2 and adjust R2 to obtain a reading of about 0.055 volts. Use R1 to set the voltage to the voltage desired (0.055 volts is suggested). Call this voltage V1. Set S2 to I, read the DVM and call that voltage V2.
3. Take Data set #2: Set S1 to V. Push S2 and adjust R2 to obtain a reading of about 0.039 volts. Use R1 to set the voltage to the voltage desired (0.039 is suggested). Call this voltage V3. Set S2 to I, read the DVM and call that voltage V4.
4. The diode voltage (Vd1) from Data Set #1 is V1. The diode current from Data Set #1 (Id1) is (V2/300,000)-(V1/10,000,000) or (V2/100,000)-(V1/10,000,000) Amps, depending on the setting of S3. The diode voltage (Vd2) from Data Set #2 is V3. The diode current (Id2) is (V4/300,000)-(V3/10,000,000) or (V4/100,000)-(V3/10,000,000) Amps, depending on the setting of S3.
5. The two data sets Vd1, Id1 and Vd2, Id2 must now be entered into two Shockley diode equations (shown above) in order to make two simultaneous equations in Is and n. Solving them will yield values for Is and n, measured at an average current of about 4.25 times Is.

A numerical equation solver can be used to solve the two simultaneous equations for Is and n. One is available in MathCad. If you have MathCad 5.0 or higher, go to http://www.agilent.com/. Click your way through Communications, Communications Designer Solutions, RF and Microwave, Schottky Diodes, Library, MathCad worksheets and download the file: sch_char.mcd. Execute it in MathCad, then enter your Current and Voltage values: Id1, Vd1 and Id2, Vd2 as I2, V2, I1 and V1. Pull down 'Math' and click 'Calculate Worksheet" . The program calculates Is and n. Since most crystal set operation occurs at currents so low that there is negligible voltage drop across the diodes' parasitic series resistance, there is no need to enter any new numbers for I3, 4, 5 and V3, 4, 5 on the worksheet. The program sch_char.mcd does not work in versions of MathCad earlier than 6. If you have an earlier version of MathCad, and it has a non-linear equation solver, actual entry of the Data Set will have to take place without the convenience of the sch_char program. Those who do not have MathCad but do have Microsoft Windows Word can get an unformatted view of the default data and text provided in the MathCad program by clicking here.

There is currently available on the Web, a program from Polymath Software at: http://www.polymath-software.com/. This program has many capabilities, and among them is a nonlinear equation solving capability. A free demo copy of the latest program is available for download, but is limited to 20 uses. After that, for more usage, you have to buy it.

Some programmable pocket calculators include a nonlinear equation solver. One calculator that has one is the HP 32S Scientific Calculator. A program to solve for n and Is takes only 28 steps of program memory and is here.

Mike Tuggle posted on 'The Crystal Set Radio Club' the following simple procedure for determining Is and n by using a spreadsheet. "In lieu of an equation solver package, the Schottky parameters can be solved for by simple trial-and-error. This is easily done with an ordinary spreadsheet, like Excel or Lotus. For the two measurement points, (Id1, Vd1) and (Id2, Vd2), set up the spreadsheet to calculate: Id2[exp(Vd1/0.0257n) - 1] and, Id1[exp(Vd2/0.0257n) - 1]. Then experimentally plug in different trial values of n, until the two expressions become equal. This gives the correct value of n. Now, plug this value of n into: Is = Id1 / [exp(Vd1/0.0257n) - 1] or, Is = Id2 / [exp(Vd2/0.0257n) - 1] to get the correct value of Is." An Excel spreadsheet constructed as Mike suggested is here. An example from data taken on an Agilent HBAT-5400 is entered, for reference, on line 2. Line 3 may be used for calculations using data from other diodes. Column H automatically calculates a value for Is each time n is changed. All one has to do is enter the values as described above in columns A through E and hit enter.

**Caution:** If one uses a DVM to measure the forward voltage of a diode having a high saturation current, a problem may occur. If the internal resistance of the DC source supplying the current is too high, a version of the sampling voltage waveform used in the DVM may appear at its terminals and be rectified by the diode, thus causing a false reading. One can easily check for this condition by reducing the DC source voltage to zero, thus leaving only the internal resistance of the source in parallel with the diode, connected across the terminals of the DVM. If the DVM reads more than a tenth of a millivolt or so, the problem may be said to exist. It can usually be corrected by bypassing the diode with a ceramic capacitor of between 1 and 5 nF, preferably, an NPO type. I use a 0.047 uF NPO multi-layer ceramic cap from Mouser Electronics. Connect the capacitor across the diode with very short leads, or this fix may not work.

## Tips

- If the Is of the diode under test is too high, 0.055 volts will not be attainable for V1 in step 1. The solution is to set switch S3 to 100k. The calculations for diode current then become: Id1=(V2/100,000)-(V1/10,000,000) Amps and (Id2=V4/100,000)-(V3/10,000,000) Amps.
- If the voltage readings seem to unstable, try placing the measuring setup on a ground plane and connect the common lead of the DVM to it. A sheet of household aluminum

can be used for the ground plane. Use shielded cable from the lead from the DVM to the test setup.
- The voltage readings are very sensitive to diode temperature. You can see this easily by grasping the diode body with thumb and forefinger and noting the change in the voltage reading when measuring V1 or V3. Don't take data until the readings stabilize. Saturation current is a strong function of junction temperature. For germanium and the usual (n-doped) Schottky diodes, a temperature increase of 10° Celsius results in a saturation current increase of about two times. A simple rule is: For each 1° C. increase in temperature, Is increases by 7.2%. The figures are different for zero-bias-type Schottkys. Here, a 14 degree C. (25 degree F.) change in temperature will result in approximately a two times change in Is.
- Shield glass enclosed diodes from ambient light by placing a cardboard box over the unit. Many diodes have a photo-diode response and will give an output voltage when exposed to light even if no current is applied.

Note: A simplified method of determining the Saturation Current of a diode, if the Ideality Factor is estimated in advance is shown in Section #2 of Article #4.

### Summary of measurements on some diodes:

The following charts show typical values for Is and n for diodes that might be used in crystal radio sets. One can see, for any particular diode, that Is and n do not vary by much over a moderate current range. Therefore, they may be considered to be dynamically constant when receiving a signal. Each value of n and Is is calculated from two voltage/current pairs as described above. The diode current (Id) given for each of the n, Is pairs is the geometric mean of the two currents used in the measurement. A Fluke model '89 IV' 4-1/2 digit DVM was used to enable measurements down to as low as 15 nA on some diodes. Noise problems cause some measurement error at low currents. That is the reason for the fluctuations in some of the readings. Values of n very close to 1.0 or below are obvious measurement errors. Those low values for n should have come out somewhat higher and the associated values of Is, also higher.

Note that the germanium diodes show an unexpected tendency to increased values for Is and n at the higher currents. The 1N4148 silicon p-n junction shows the expected increase of Is and n at lower currents. The Schottky diodes seem to have pretty constant values of Is and n across the current ranges measured. Experiments described in Article #27 indicate that the measured values of Is and n for silicon Schottky diodes tested here, when used as detectors, remain at the measured values at rectified currents so low that a voice signal is barely readable. This is not necessarily true for all germanium diodes.

| **Table 1 - Measured n and Is values for various diodes, over a range of currents (Id), in nA.** | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1N4148 silicon p-n junction diode** | | | **Base-emitter junction of 1N404A Ge transistor** | | | **Blue Radio Shack 1N34A Ge diode having no nomenclature** | | | **Agilent HBAT-5400 Schottky, high Is version** | | | **Infineon BAT62-03W Schottky diode** | | |
| **Id** | **n** | **Is** | **Id** | **n** | **Is** | **Id** | **n** | **Is** | **Id** | **n** | **Is** | **Id** | **n** | **Is** |
| 710k | 1.73 | 1.23 | | | | 710k | 1.71 | 3500 | | | | | | |
| | | | 570k | 1.04 | 1800 | | | | | | | | | |
| 350k | 1.75 | 1.45 | | | | 350k | 1.69 | 3200 | | | | | | |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 177k | 1.87 | 2.19 | 179k | 1.03 | 1670 | 177k | 1.61 | 2550 | | | | | | |
| 88k | 1.82 | 2.26 | | | | 88k | 1.51 | 1980 | | | | | | |
| 44k | 1.80 | 1.98 | 56k | 1.01 | 1540 | 44k | 1.39 | 1470 | | | | | | |
| 22k | 1.88 | 3.00 | 18.9k | 1.01 | 1580 | 22k | 1.28 | 1100 | | | | | | |
| 11k | 1.89 | 3.10 | | | | 11k | 1.22 | 950 | | | | | | |
| 5500 | 1.93 | 3.80 | 5700 | 1.04 | 1660 | 5500 | 1.14 | 800 | 8100 | 1.15 | 265 | | | |
| 2760 | 1.94 | 3.90 | 1790 | 0.98 | 1730 | 2760 | 1.10 | 750 | | | | 2600* | 1.06 | 248 |
| 1380 | 2.02 | 4.90 | | | | 1380 | 1.05 | 680 | | | | | | |
| 690 | 1.98 | 4.40 | 620 | 0.99 | 1740 | 690 | 1.20 | 830 | 990 | 1.15 | 248 | 970 | 1.04 | 240 |
| 343 | 2.06 | 5.30 | | | | 343 | 1.01 | 670 | 360 | 1.15 | 265 | 341 | 1.04 | 236 |
| 170 | 2.18 | 6.70 | | | | 170 | 1.08 | 720 | 160 | 1.15 | 255 | 133 | 1.04 | 236 |
| | | | | | | | | | 76 | 1.15 | 254 | 87 | 1.04 | 236 |
| | | | | | | | | | | | | 59 | 1.01 | 228 |
| | | | | | | | | | 40 | 1.15 | 261 | 39 | 1.06 | 233 |

* This Infineon diode has an unusually high series resistance of 130 ohms. The voltage drop across this resistance is low enough in all the measurements to be ignored, except for the highest current one. There, a correction for the voltage drop was made.

## Table 2 - Measured n and Is values for various diodes, over a range of currents (Id), in nA.

| Radio Shack Ge 1N34A diode marked 12101-3PT | | | Agilent HBAT-5400 Schottky diode (low Is version) | | | Agilent HSMS-282M quad Schottky, all four diodes in parallel | | | Agilent HSMS-286L triple Schottky, all three diodes in parallel | | | One diode of Infineon BAT62-08S triple diode Schottky | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Id** | **n** | **Is** | **Id** | **n** | **Is** | **Id** | **n** | **Is** | **Id** | **n** | **Is** | **Id** | **n** | **Is** |
| 47k | 1.28 | 230 | | | | | | | | | | | | |
| 17k | 1.18 | 188 | | | | | | | | | | | | |
| 9.5k | 1.16 | 174 | | | | | | | | | | | | |
| | | | 6.7k | 1.03 | 102 | | | | | | | 4650 | 1.03 | 143 |
| 2.8k | 1.13 | 160 | | | | | | | | | | | | |
| | | | | | | 1140 | 1.03 | 47 | 1750 | 1.04 | 76 | | | |
| 630 | 1.15 | 162 | 510 | 1.03 | 104 | 470 | 1.02 | 41 | | | | 700 | 1.02 | 142 |
| | | | | | | | | | 360 | 1.04 | 76 | | | |
| 205 | 1.15 | 166 | | | | 203 | 1.02 | 41 | | | | 222 | 1.02 | 136 |
| | | | 151 | 1.03 | 103 | 108 | 0.98 | 40 | 117 | 1.02 | 72 | | | |
| 81 | 1.14 | 161 | | | | | | | | | | 99 | 1.01 | 134 |
| | | | 59 | 1.01 | 102 | 59 | 0.99 | 39 | | | | 47 | 1.02 | 138 |
| 37 | 1.13 | 160 | | | | 36 | 1.00 | 39 | 53 | 1.03 | 73 | | | |
| | | | 26.4 | 1.02 | 100 | 23.1 | 0.98 | 39 | 24.5 | 1.02 | 72 | 23.6 | 1.01 | 135 |
| | | | 13 | 1.03 | 102 | 15.3 | 1.02 | 40 | | | | | | |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 10.2 | 1.00 | 39 | 12.6 | 1.06 | 76 | | | |
| | | | | | | 6.3 | 1.08 | 42 | | | | | | |
| | | | | | | 4.4 | 1.04 | 42 | | | | | | |

A rare germanium diode that seems to be ideal for many crystal radio set designs is the FO 215, branded ITT. A search of the Internet has not turned up a manufacturer's datasheet. ITT is not in the germanium diode business anymore, but from the Internet search it appears that the original company was a German company named ITT Intermetall. Some of their semiconductor business became ITT Semiconductors. This was later sold, around 1997 to General Semiconductor Industries. That business was later sold to Vishay. One source indicated that General Instruments was also one of the intermediate owners. Averages of measurements on three samples of the FO 215 are: Is=109 nA and n=1.02. These measurements were made at an average current of about 250 nA. Interesting note: The average Is of the FO 215 diodes is about equal to the geometric mean of that of the Agilent 5082-2835 and a typical 1N34A. I obtained my FO 215 diodes from Mike Peebles at: http://www.peeblesoriginals.com/ .

Article #27 shows detector measurements of how diodes having different values of Is and n perform as weak signal detectors when impedance matched at both input and out put.

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