Spire Internship Challenge

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***Scenario*—For a future satellite design, we want to outfit a satellite with a Langmuir probe for plasma measurements. Assuming you know the I-V characteristic of the probe, design a system to get sensible measurements from the sensor, and get them to a flight computer. (For the saje of this excercise, you can "choose" the flight computer being AVR, ARM, embedded Linux, FPGA, Arduino, ...).**

I. Introduction

A Langmuir probe is a device that measures a plasma's characteristics by means of generating a strong electric field that provokes electric currents due to the electrons and ions in the plasma. This currents flow to the satellite's body from the probe and could be in the order of 10^{-6}A down to 10^{-8}A[1].

A circuit that is able to read those currents was designed and is presented in the file *schematics.svg,* and a rendered image of the proposed circuit is included in *schematics.jpg.*

The diagrams for fabricating the circuit are presented in the files *schematics-F_SilkS.svg* and *schematics-B_Cu.svg*.

The code for the flight computer is available in the file *flight_computer.ino*.

The circuit is explained in the sections II and III, while section IV shortly explains what the code does.

The circuit was designed with KiCad [2] and the complete project, all the files generated by KiCad are available in GitHub[3].

II. Current to voltage converter

In order to make the measurement, the first step is to convert the electrical current into a voltage that can be measured by the flight computer. The chosen flight computer is an Arduino board with an ATmega328P microcontroller, which has a 10 bit analog to digital converter capable to read up to 5V [4]. This gives us a resolution of 4.88mV.

In order to translate that current coming from the probe into a voltage we use an operational amplifier. The negative input is connected to a bias voltage, because this voltage is what creates the electric field that the probe needs. This bias voltage tends to be extremely high, so the electronics cannot handle it, so we float the amplifier to the bias voltage, as well as its power supply, so that the amplifier only has to handle a few volts. The current flows through R_1 and dropps the voltage from V_B to $V_B - IR_1$, where I is the current to be measured. Thus, R_1 is the conversion factor and is the design parameter to be chosen. If we expect a maximum current of about $2.5\mathring{u}10^{-6}$A, as shown in Fig. 1 from [1], a resistor of 2MΩ would suffice to convert both the minimum and maximum currents into a voltage within the capabilities of the analog to digital converter. The minimum detectable current would be $2.44\mathring{u}10^{-9}$A, which is an order of magnitude smaller than the smallest expected current.

A 1MΩ resistor would reduce the range of voltages we could measure, thus having worse resolution, but it would also increase the safety factor to 2, so we could read unexpected spikes uf electrical current up to twice the maximum expected value without saturating the sensor.

An operational amplifier could have parasitic capacitances and a large resistor combined with the capacitor would act as a filter. The parasitic capacitance could be in the order of 10^{-9}F [5], so if we multiply that value by the resistance we would get a time constant for the charging of the capacitor in the order of 10^{-3}s, a value low enough that it won't disturb the measurements as long as the frequency needed is lower than that. If that were the case, we would have to reduce the value of R_1 and add a secondary amplifier to compensate for that decrease in gain.

III. Differential amplifier

The current to voltage converter has an output voltage too high for the flight computer to read, so we use a differential amplifier to reduce the voltage.

There is two inputs to the differential amplifier. One is $V_B - V_I$, where $V_I = IR_1$. The second input is V_B. We can assign temporary values to the resistors in order to write the output voltage. These values are R, $R(1-1/n)$, R/n and R' and can be seen in the schematic. The output voltage is then:

$$V_o = \frac{V_B}{n} - R(\frac{V_B - V_I - \frac{V_B}{n}}{R} - \frac{V_B}{nR'})$$

The resistors $R(1-1/n)$ and R/n create a voltage divider so that the voltage V_B is scaled to a voltage the amplifier can handle.

We want V_o to be rid of the bias voltage V_B, so we choose a value for R' that cancels out every V_B. That value is $R' = \frac{R}{n-2}$.

We can choose a value for n high enough so that we can use a wide range for the bias voltage. We need to find a suitable value for n, though, because the resistors we can buy only come in a certain set of values. We can start by assigning a value for R and find a value for n that yields a commercial value for another resistor, such as R/n. If we choose $R = 1$MΩ and $R/n = 910\Omega$, we get $n = 1098.9$, which yields $R(1-1/n) = 999089.99909\Omega$ and $R' = 911.66\Omega$. If we compare those two values with the closest commercial values we can find, there is an error of 0.091% and 0.1824% respectively, well within the 1% accuray that we can get from a commercial provider, so we will stick to those values.

IV. Flight computer software

The flight computer will process the data read by the sensor. The easiest thing to do is store it in an SD card so that the file can be read when there is a ground station available.

The output of the circuit goes into the pin A0, and is read and converted back into a voltage. This value is then sent to a function that writes it in the SD card along with a timestamp.

References

[1] J.-P. Lebreton, S. Stverak, P. Travnicek, M. Maksimovic, D. Klinge, S. Merikallio, D. Lagoutte, B. Poirier, P.-L. Blelly, Z. Kozacek *et al.*, "The isl langmuir probe experiment processing onboard demeter: Scientific objectives, description and first results," *Planetary and Space Science*, vol. 54, no. 5, pp. 472–486, 2006.

[2] "Kicad," http://kicad-pcb.org/, [Online; accessed 09-November-2015].

[3] "langmuir-probe in github," https://github.com/albertoibm/langmuir-probe, [Online; accessed 09-November-2015].

[4] *8-bit Microcontroller with 4/8/16/32K Bytes In-System Programmable Flash*, ATmel, rev. 8161DâĂŞAVRâĂŞ10/09.

[5] D. J. Dascher, "Measuring parasitic capacitance and inductance using tdr," *Hewlett Packard Journal*, vol. 47, pp. 83–96, 1996.