RF section design note

The probe antenna

In order to measure the microcontroller activity through its current consumption, a magnetic coupled probe has been selected as it offers galvanic isolation, no DC bias and the lowest sensitivity to other sources of EM (electromagnetic) noise. The literature shows that magnetic loop antennas are less sensitive to the ambient EM noise.
To selectively pick-up the power supply current variations, the probe antenna must be located close to the microcontroller power supply, between the IC die and the decoupling capacitor and have a physical size similar to twice the pitch of the pins. On the other hand, the sensitivity of the probe increases with the number of turns.

This is expressed in the well known equation : $U=L\frac{di}{dt}$

where U is the voltage at the probe output, L the inductance of the probe and i the current circulating in the probe.

For an air coil, the inductance is given by : $L=\mu_0\frac{N^2A}{l}$

where $\mu_0=4\pi 10^{-7}$ is the permeability of free space, N the number of turns, A the area of the coil cross-section and l the coil length.

Engineering is a matter of compromises, in this case, between inductance and physical size.
As the Arduino Uno features a DIL (dual in-line) device, the probe antenna must be located close to one of the power pins (e.g. pin 7).

Here are the characteristics of the probe:

- air coil (winding on a plastic core)
- diameter : ~ 6.4 mm
- length : 2.5 mm
- number of turns : 20
- measured inductance at 1 MHz : 620 nH

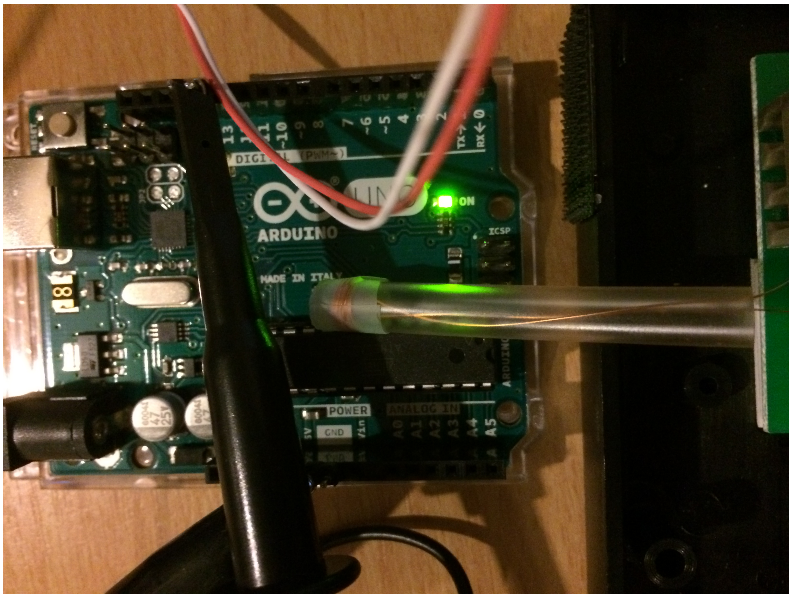

fig 1: probe antenna close-up

The differential pre-amplifier

To further improve rejection of other sources of electromagnetic noise, a differential pre-amplifier topology has been selected as a companion of the probe antenna.
A wide band amplifier was selected in order to be able to experiment with different algorithms in different frequency bands, such as baseband noise analysis or amplitude modulation of the current at the clock frequency.
This one can be easily realized using commonly available small signal transistors and its schematic is shown in figure 2. As one can easily see, a pair of complementary bipolar transistors provides the voltage gain in amplifying only the voltage difference at the input. The third transistor is a voltage follower that lowers the output impedance.

Here are the main characteristics of the pre-amplifier: (see also figure 3)

- bandwidth (-3 dB) : 27 MHz
- differential gain : 33 dB
- common mode rejection ratio (CMMR) : 30 dB

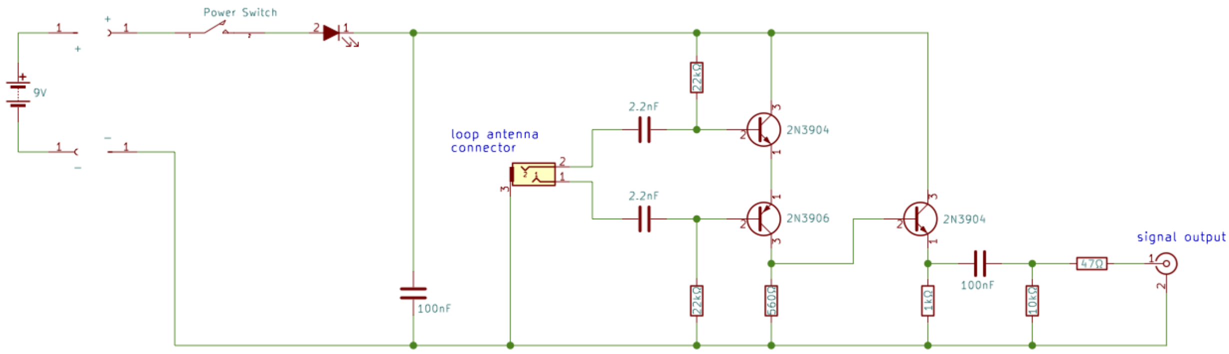

fig 2: differential pre-amplifier schematic

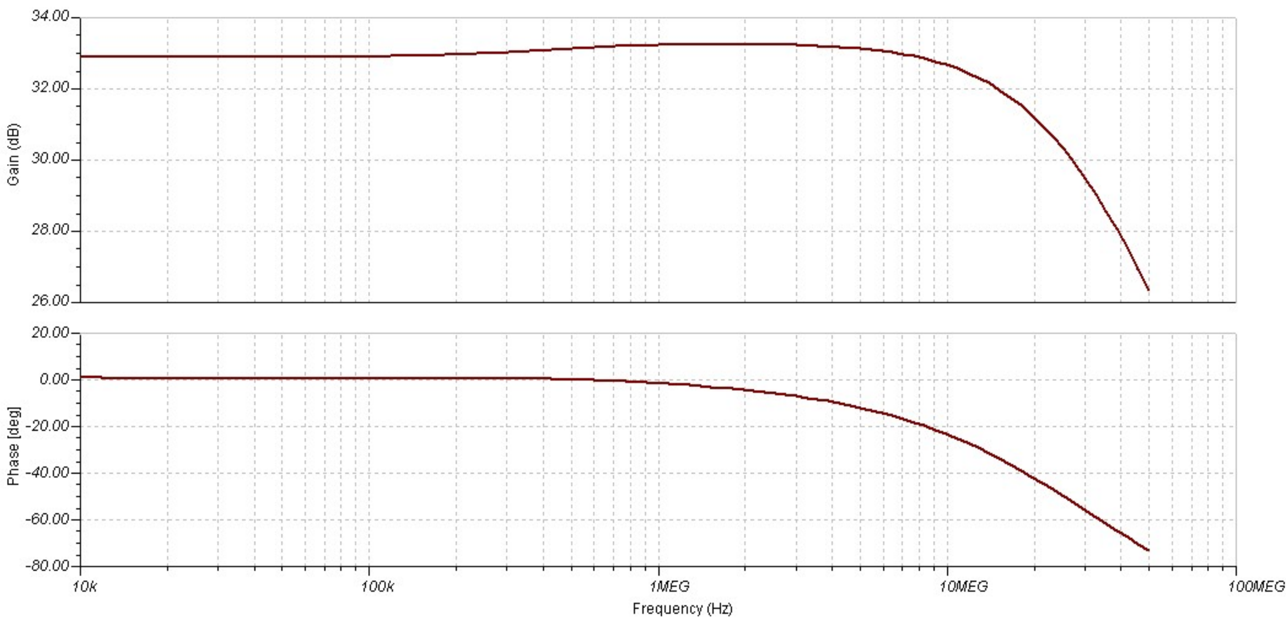

fig 3: differential pre-amplifier frequency response (TINA-TI SPICE simulation)

Notes :

1. The purpose of the 10 kΩ resistor between the output capacitor and the ground is to avoid that the capacitor discharges its DC component through the connected instrument (e.g. Red Pitaya).
2. Design trade-off: increasing the current in the transistors (decreasing the values of the 560 Ω and 1 kΩ resistors) increases the bandwidth at the price of a reduced autonomy when running of battery. The maximum achievable bandwidth is close to 50 MHz.

We can see from figure 3 that this simple pre-amplifier provides enough bandwidth to measure signals from low frequencies up to above the processor clock frequency.

Connecting the probe to the pre-amplifier

To achieve the best possible performance the following rules must be applied:

- the connecting wires should be as short as possible (typ. < 20 cm),
- twisted wires allows to avoid picking unwanted noise sources,

The following figure show the global transfer function from a wire near to the probe antenna to the output of the pre-amplifier. The conversion gain is about 3 V/A at 1 MHz.

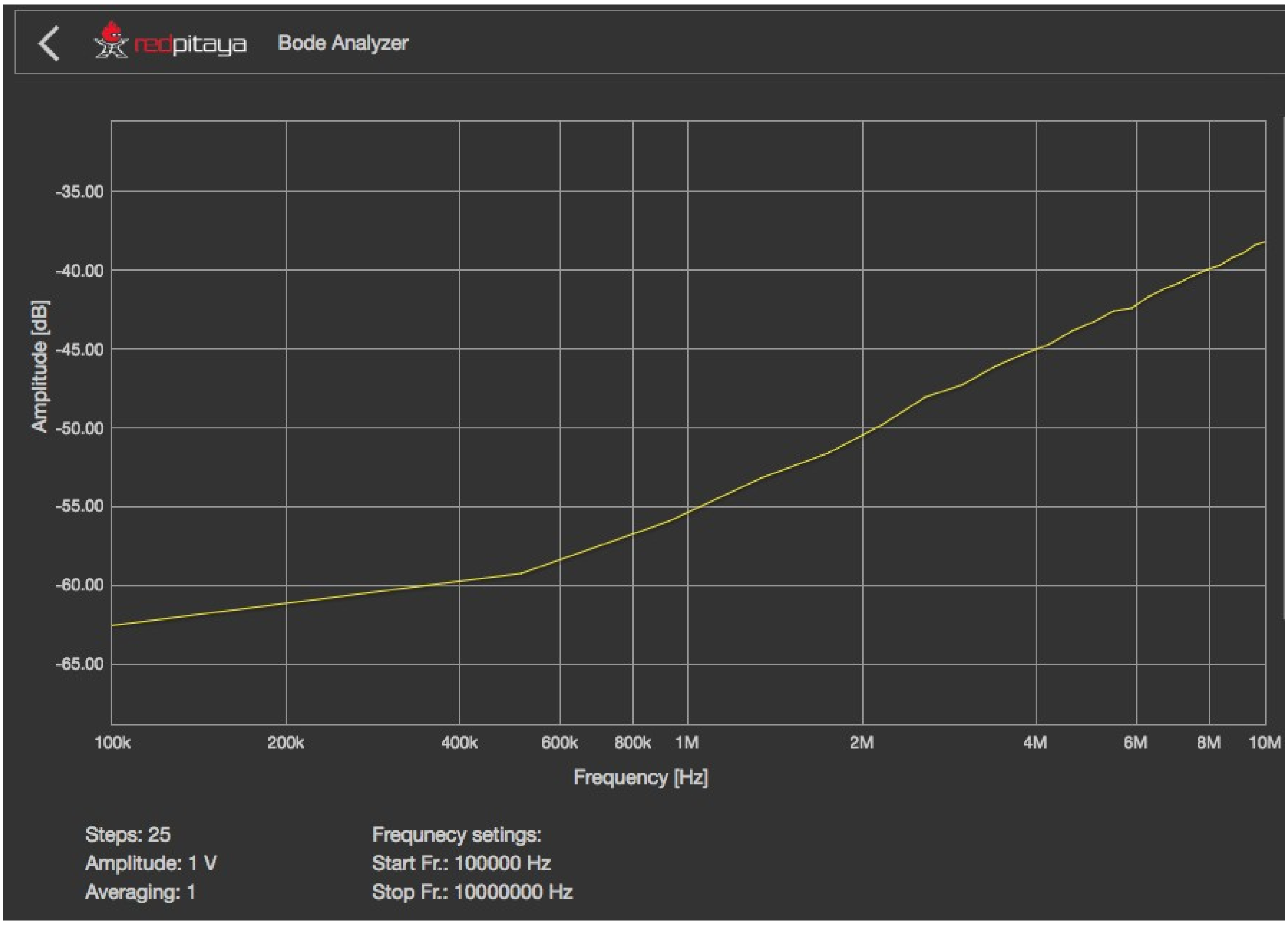

fig 4: overall transfer function