FUZZY CONTROL OF A DC MOTOR

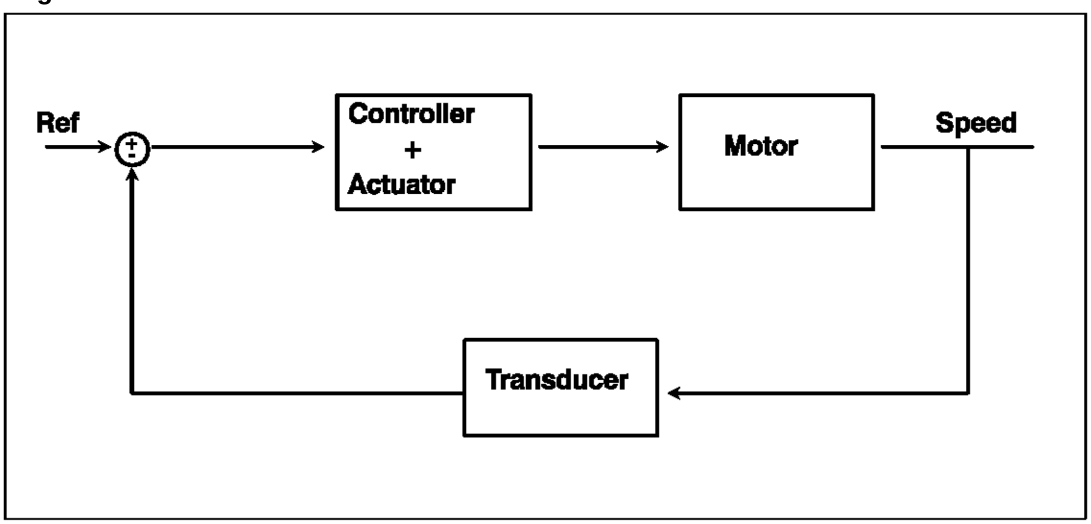
The application has the aim to control the rotation speed of a small DC motor with permanent magnet having the following specs:

- Nominal tension 12 V
- No-load speed 3800 ± 10% revolution per minute
- No-load current < 1 A
- Power output 37 W

The block diagram shown in figure 1 represents the closed-loop model.

- The transducer provides a voltage directly proportional to the angular speed of the motor which is compared with the reference one.
- The controller takes the result of this comparison and drives the motor speed by providing (by means of the actuator) the right voltage to reach the reference speed (Ref).

Figure 1: Scheme of the controller



SYSTEM MODELLING

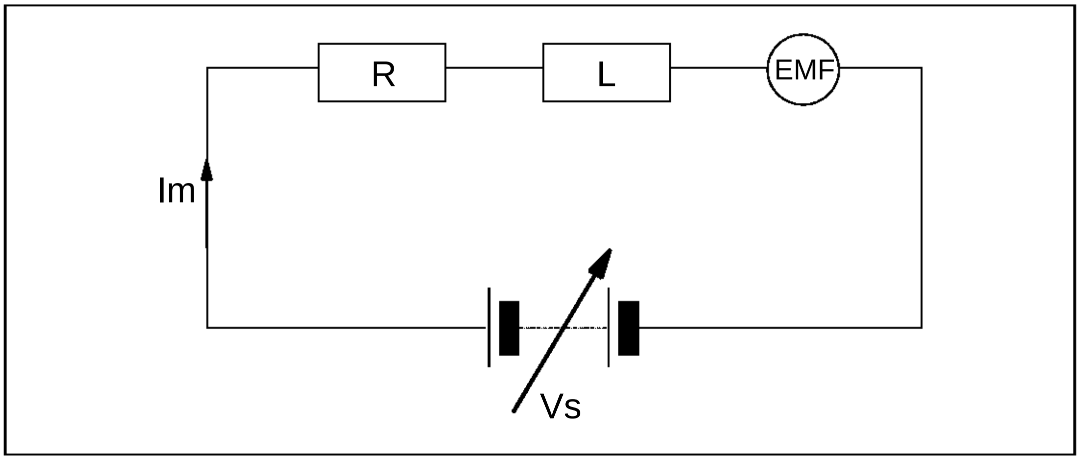
Motor

The considered DC motor can be modelled by using a first order model (see figure 2) , where:

- R is the rotor winding resistance ($R=29\Omega$),
- L is the rotor winding inductance ($L=0.5mH$)
- EMF is the electromotive force at the extremities of the ideal motor (with null internal resistance), directly proportional to the motor speed.

It is then possible to express the motor couple C_m and the electromotive force EMF as functions of the field current I_m and of the angular speed ω.

Figure 2. Model of the motor.



The following relations are obtained:

$C_m = K_m * I_m$

$EMF = K_b * \omega$

with K_m and K_b the characteristic constants of the motor and taking the same value (around 0.03 Volt *sec/rad) when for C_m and ω units of measurements are chosen to have their product equal to the watt (newton * meter and rad/sec).

Transducer

The transducer is represented by another DC motor used as a generator.

By fitting the transducer on the same drive shaft of the motor to be controlled, the electromotive force provided by the transducer will be proportional to the angular speed ω (by a constant $K'_b = 0.003 Volt * sec/rad$).

This technique gives a feedback voltage influenced by the discontinuity of the dragging contact between the brushes and the rotating collector.

Actuator

The actuator must provide the proper voltage and current for the bidirectional speed control.

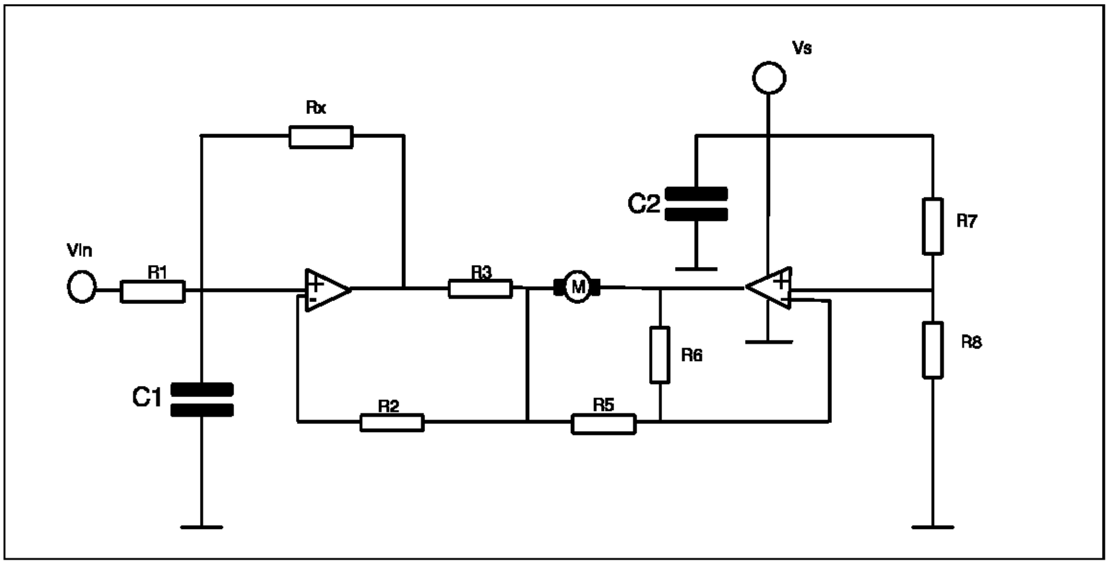
Operational power amplifiers are used as voltage level translaters.

The voltage V_m is disposable at the extremities of the motor when the input voltage (which is the voltage provided by the controller) is V_{in} and the power voltage of operationals is Vs, so obtaining (see figure 3):

$V_m = 2(V_{in} - V_s/2) + R_o * I_m$

$R_o = 2R3 * R1/R_x$

Figure 3. Model of the actuator



FUZZY CONTROL

Aim of the controller is to force the motor to reach any rotation speed represented by a reference voltage value.

One of the inputs is given by the ”error” variable defined as

$$err(t) = rif(t) - V_{out}(t)$$

where V_{out} is the voltage given by the tachometer generator.

To take in account the dynamic of the system a second input representing the derivative of the error (d_{err}) is given.

At the output, the controller is incrementally designed so that the value of the control voltage at the instant K is

$$V_{in}(K) = V_{in}(K - 1) + \Delta V_{in}(K)$$

The above relation represents the sum of the control voltage at the instant K-1 and the value obtained by the fuzzy inference.

The inputs err and d_{err} are computed at the instant K.

The link of the W.A.R.P. digital device with the analog system is realized by using proper A/D and D/A converters interfaced with W.A.R.P. through handshaking signals.

The figure 4 depictes a block diagram of the system. An apposite W.A.R.P. BOARD implementation is reported in the APPENDIX A - W.A.R.P. BOARD SCHEMATICS at the end of this application note.

The error between Ref and V_{out} is computed at the input and then sent to the A/D converter along with its derivative.

The A/D conversion begins when the SC command arrives, meanwhile indicating the completion of a fuzzy inference (End Process signal) by W.A.R.P., which remains in stand-by until the arrival of the EOC(End Of Conversion) command indicating the readiness of data and the capability to start a new computation (TRG).

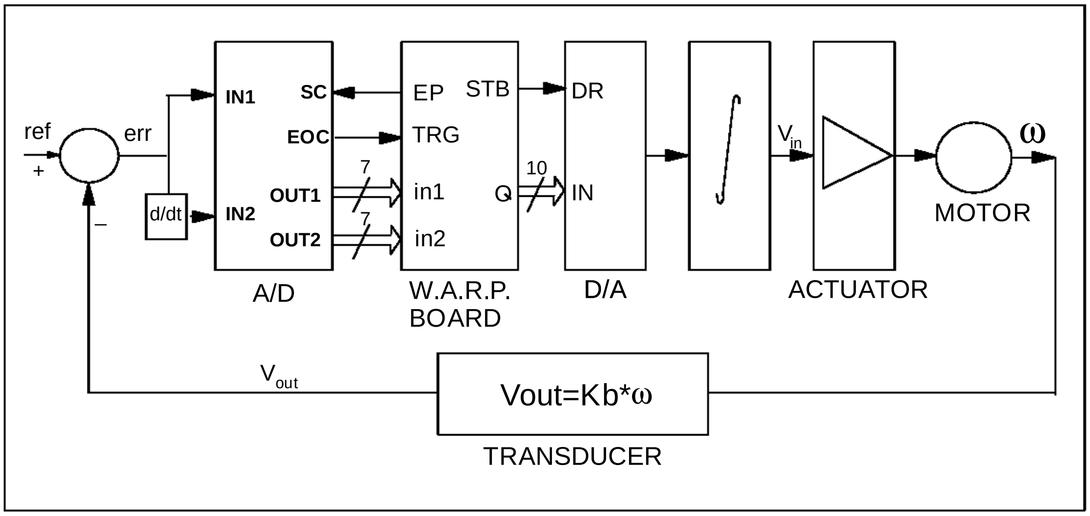
It is to be considered that W.A.R.P. accepts as inputs for each channel 7-bits digital data only.

If a converter having an 8-bits resolution is used, the less important bit is to be eliminated in order to have less precision without changing the range of the voltage to be converted (generally ranging from 0 to 5 V).

Result of the fuzzy computing is a 10-bits digital output. When the signal of data ready (STB) is set one the result is converted in analog voltage by using a proper D/A and then sent to the integrating block.

The obtained voltage value drives the power actuator by providing the motor with the field current in order to reach the reference speed.

Figure 4: Block diagram of the system



SYNTHESIS OF THE CONTROLLER

The Universe of Discourse for the err variable is set ranging between [-1, 1], while only the speed variations ranging between [-0.01, 0.01] (which represent the error variations d_{err}) have been taken in account.

Three Membership Functions are used for each input by following empirical rules regarding incremental controllers.

By using all possible combinations of input Membership Functions sets it is possible to build a fuzzy controller having 9 rules.

To individuate the shape of each antecedent MF the general criterium chosen is to overlap the respective Universe of Discourse in order to avoid divisions by zero during the defuzzification phase.

By tracking the MFs as depicted in the below figure, the Universe of Discourse of the inputs has to be divided in three parts respectively having the following meanings: negative (n), zero (z) and positive (p).

Consider then the set of rules obtained by combining the above depicted MFs:

IF err IS p AND d_{err} IS p THEN dv IS pp

IF err IS p AND d_{err} IS z THEN dv IS pz

IF err IS p AND d_{err} IS n THEN dv IS pn

IF err IS z AND d_{err} IS p THEN dv IS zp

IF err IS z AND d_{err} IS z THEN dv IS zz

IF err IS z AND d_{err} IS n THEN dv IS zn

IF err IS n AND d_{err} IS p THEN dv IS np

IF err IS n AND d_{err} IS z THEN dv IS nz

IF err IS n AND d_{err} IS n THEN dv IS nn

To obtain the incremental fuzzy controller the MF of the consequent part of each rule must force the output voltage in the correct direction, i.e. towards the void-state error.

It is to be taken in account that the W.A.R.P. device uses the centroyds defuzzification method.

The desired results are obtained by considering crisp output MFs centered on the value to be given to the output variable in order to provide the voltage increment.

Figure 5: MFs of the error (err) input variable

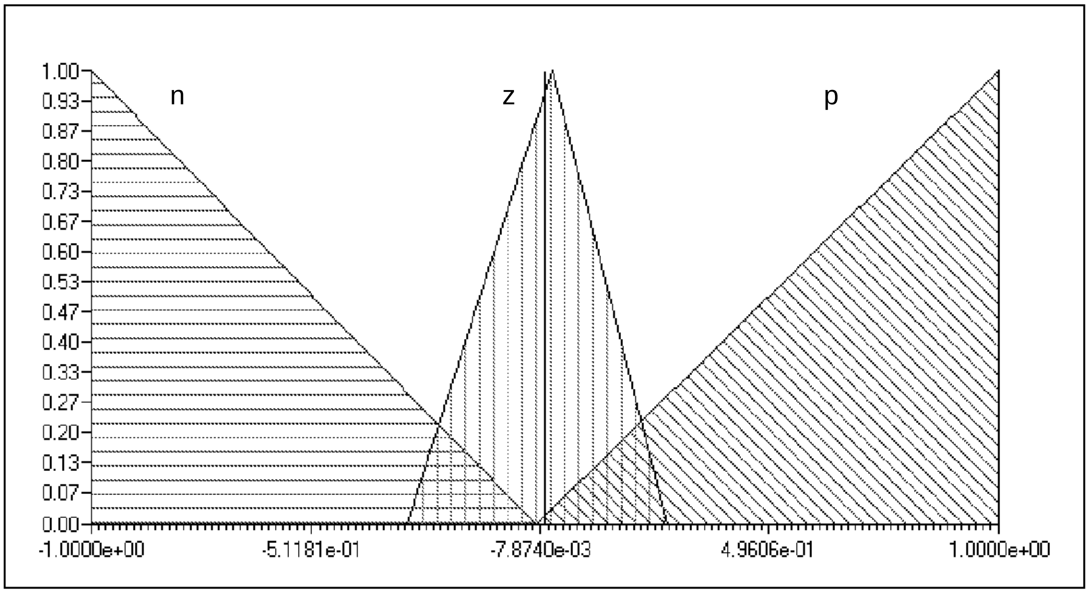
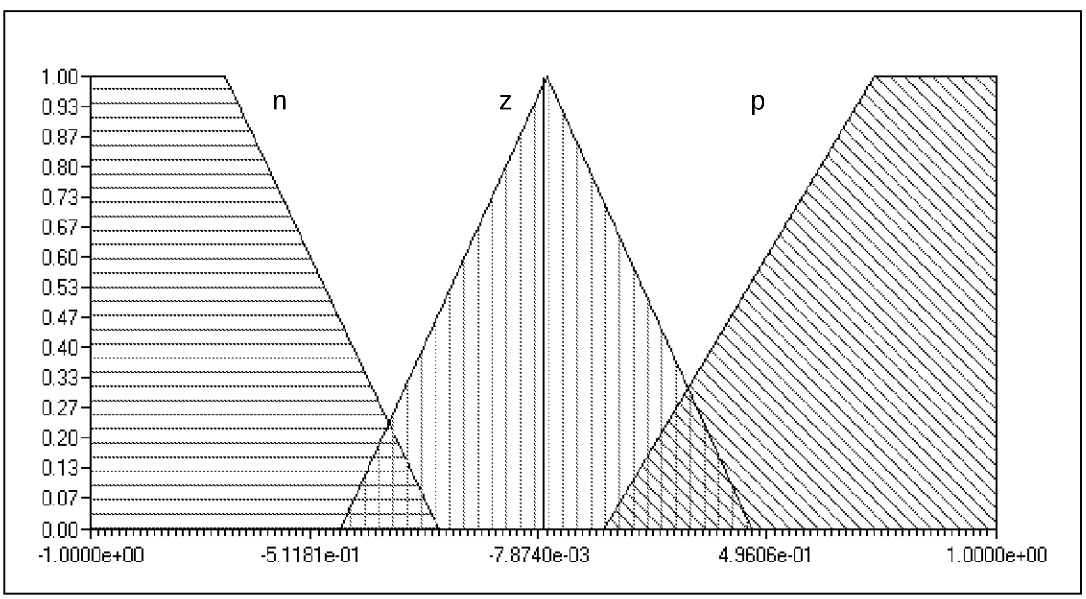


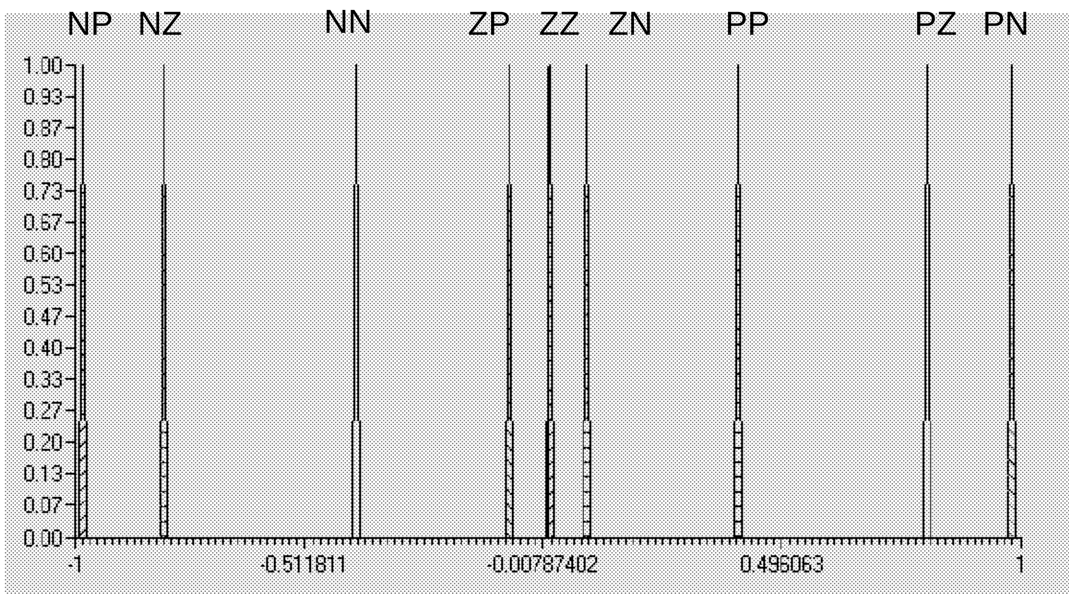
Figure 6: MFs of the error variation (derr) input variable



As a matter of fact, by using output MFs having equal areas, in the defuzzification formula used by W.A.R.P. , $y = \frac{\sum i\, Ai\theta i Xi}{\sum i\, Ai\theta i}$, these areas are simplified.

Consequently, the value of the output depends only on the barycentre of the MFs.

Figure 7: MFs of the output variable incremental voltage (dv)



The actuator has to force the motor to the desired speed.

For example, consider the case in which the error (err) is negative and its variation (d_{err}) is positive.

Since err = rif - $V_{out,}$ it means that the motor is running at a higher speed than the reference one and it is accelerating (derr positive). To contrast this trend, the control voltage is to be decremented by centering the corresponding output MF (np) at a very negative value.

Likewise, when err = 0 and d_{err} = 0, the motor has reached the desired speed and no contribution is to be given to the actuator (e.g. zz).

Results and conclusions

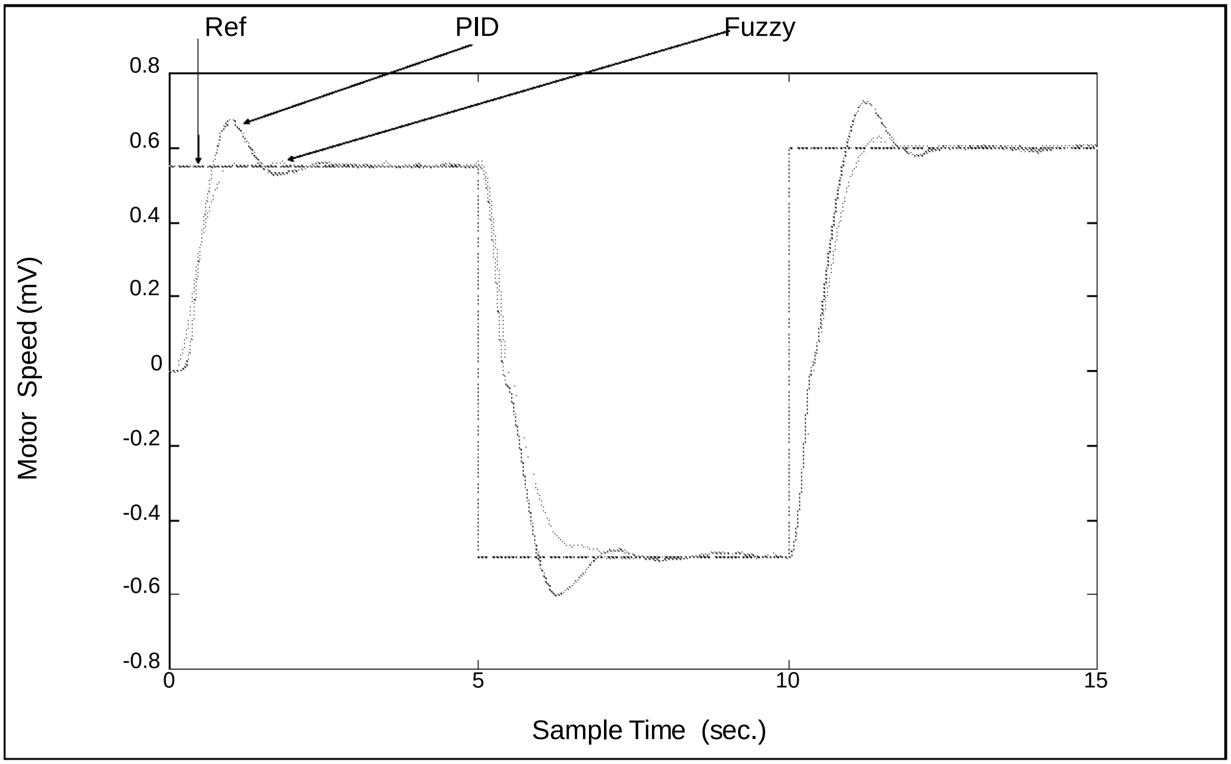
To confirm the validity of the implemented model comparative closed-chain attempts have been made between the fuzzy control through W.A.R.P. and a traditional PID controller.

The testing consists of the tracking of a speed having rotating inversions.

In the below figure the results obtained in function of the iteration number are reported.

Under the same sampling time (at around 250 µsec.) the fuzzy controller performs more efficiently for both the rise time and the overshoot.

The control through the W.A.R.P. is also more insensible to the parametric variations of the system.

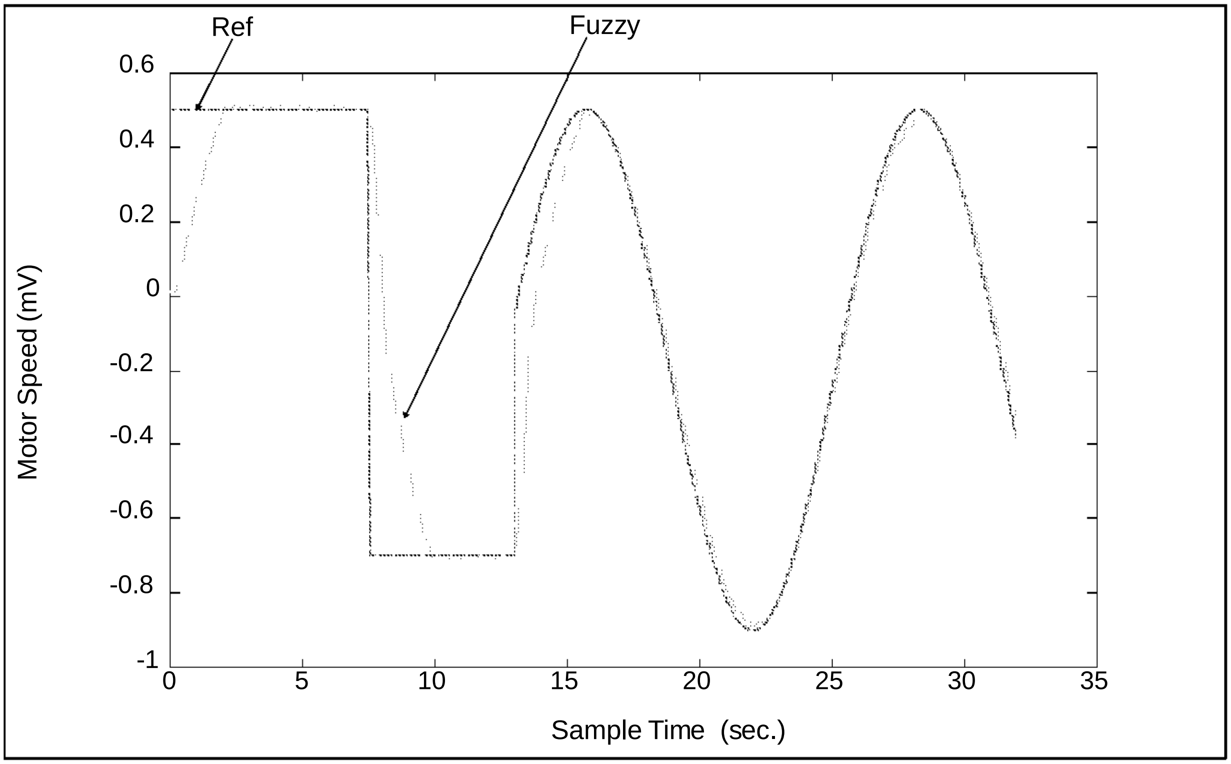


The goodness of the controller can be verified also through the response of the system to a reference composed of opposite levels (having different absolute values) and of a synusoid centered at zero.

It shows the capability of the system to control the motor at low speed.

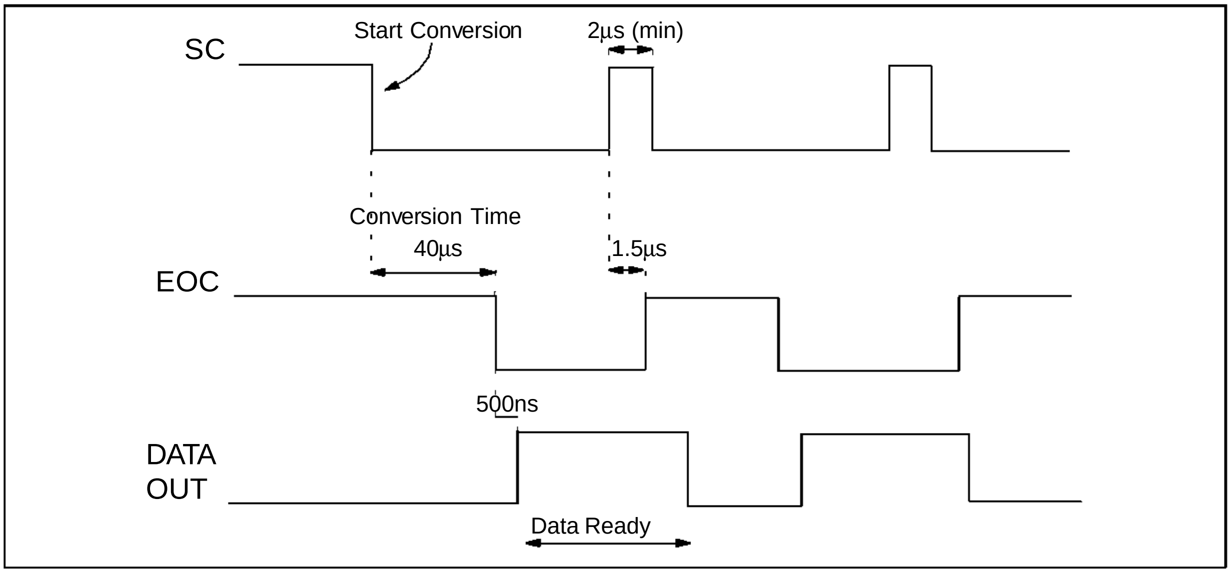
It is to notice the robustness of the fuzzy control with respect to the disturbs.

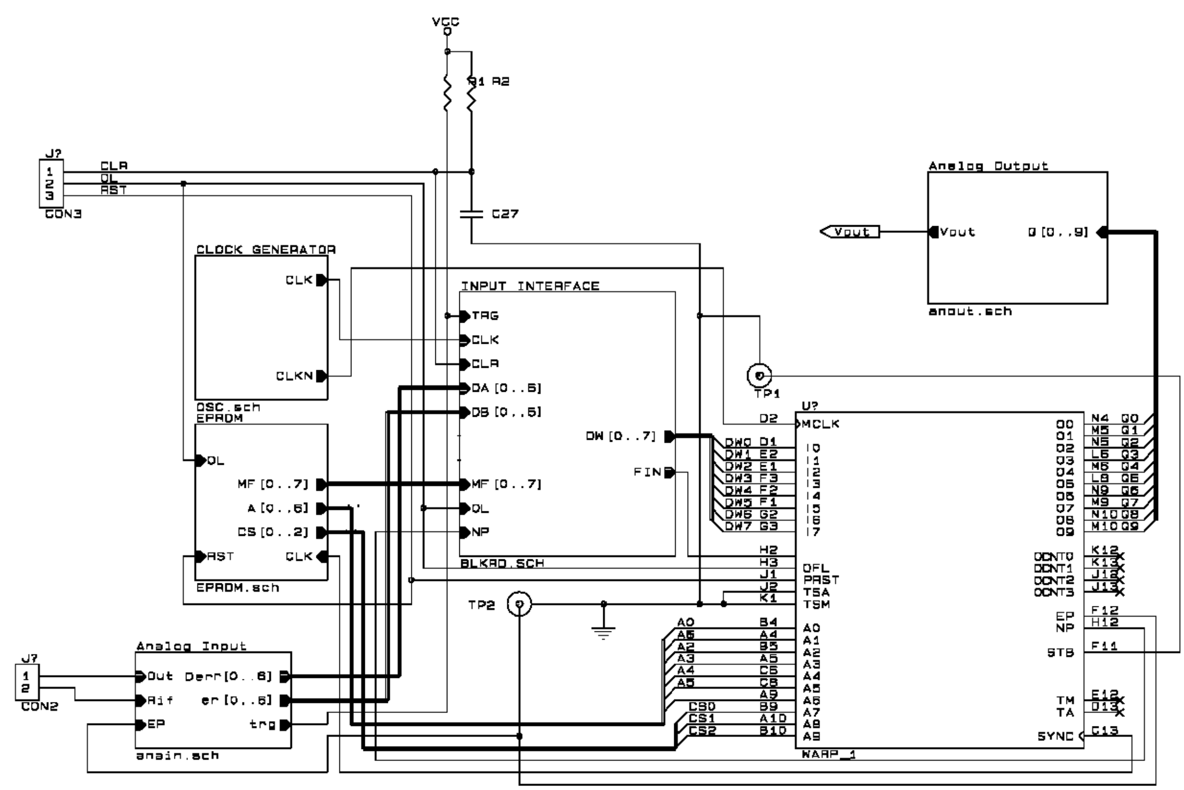
In the below figure can be easily observed that the motor reaches the steady-state speed in despite of the the brushes noise affecting the voltage coming from the transducer (on the reaction shaft).


Ref
Fuzzy
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
Motor Speed (mV)
0
5
10
15
20
25
30
35
Sample Time (sec.)

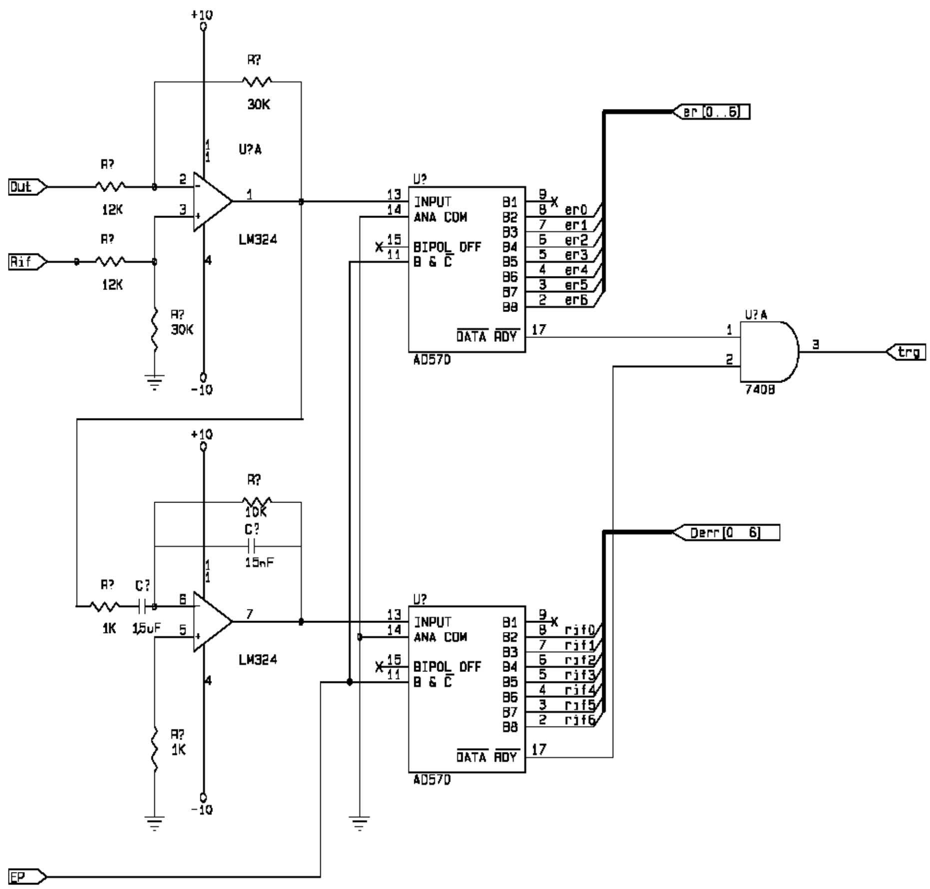
APPENDIX A - W.A.R.P. BOARD SCHEMATICS

Analog Input Timing.

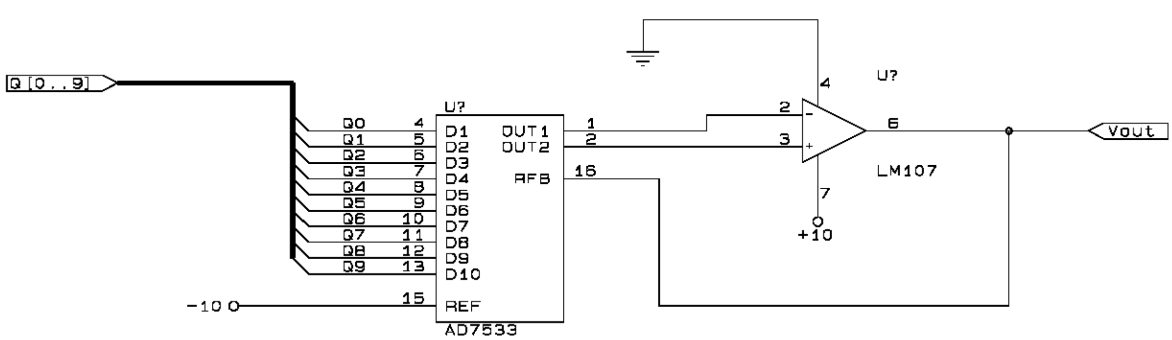




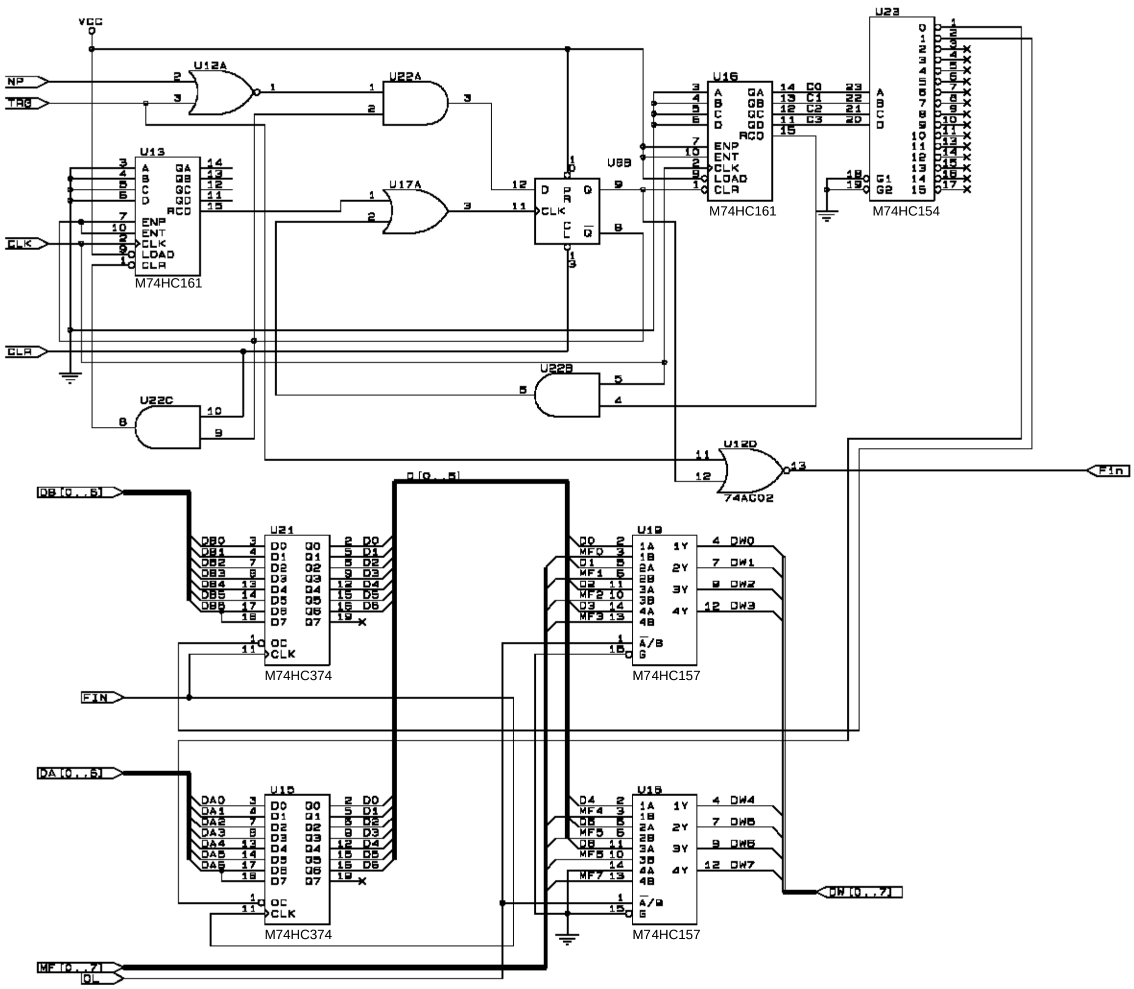
W.A.R.P.-BOARD BLOCK DIAGRAM



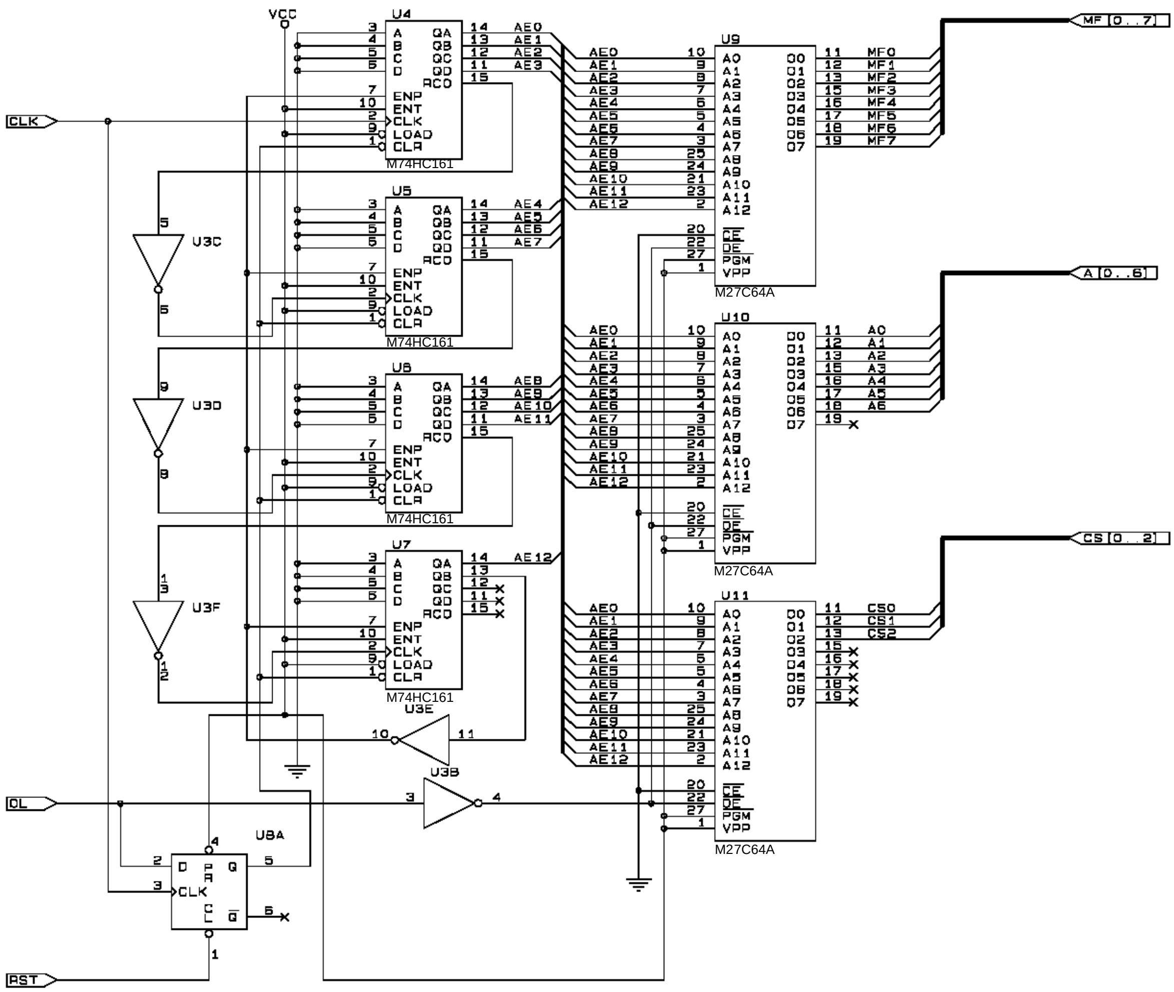
ANALOG INPUT



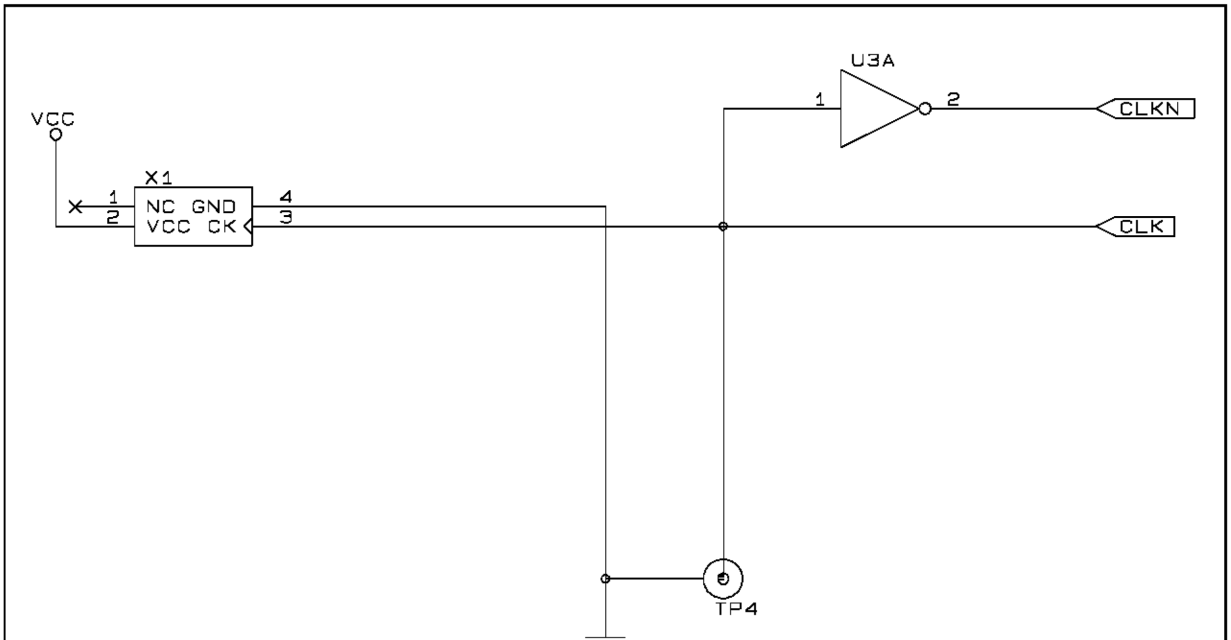
ANALOG OUTPUT



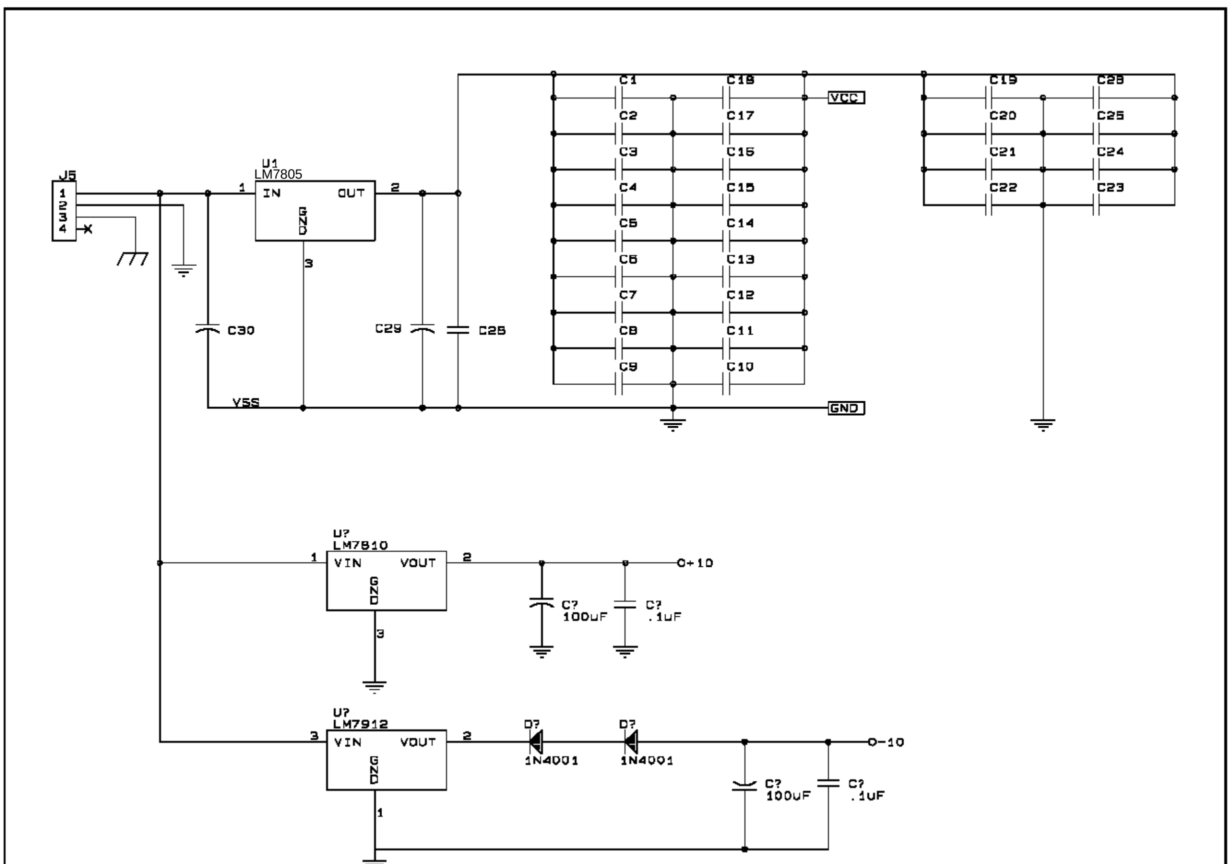
INPUT INTERFACE



EPROMs BLOCK



OSCILLATOR



POWER CIRCUIT