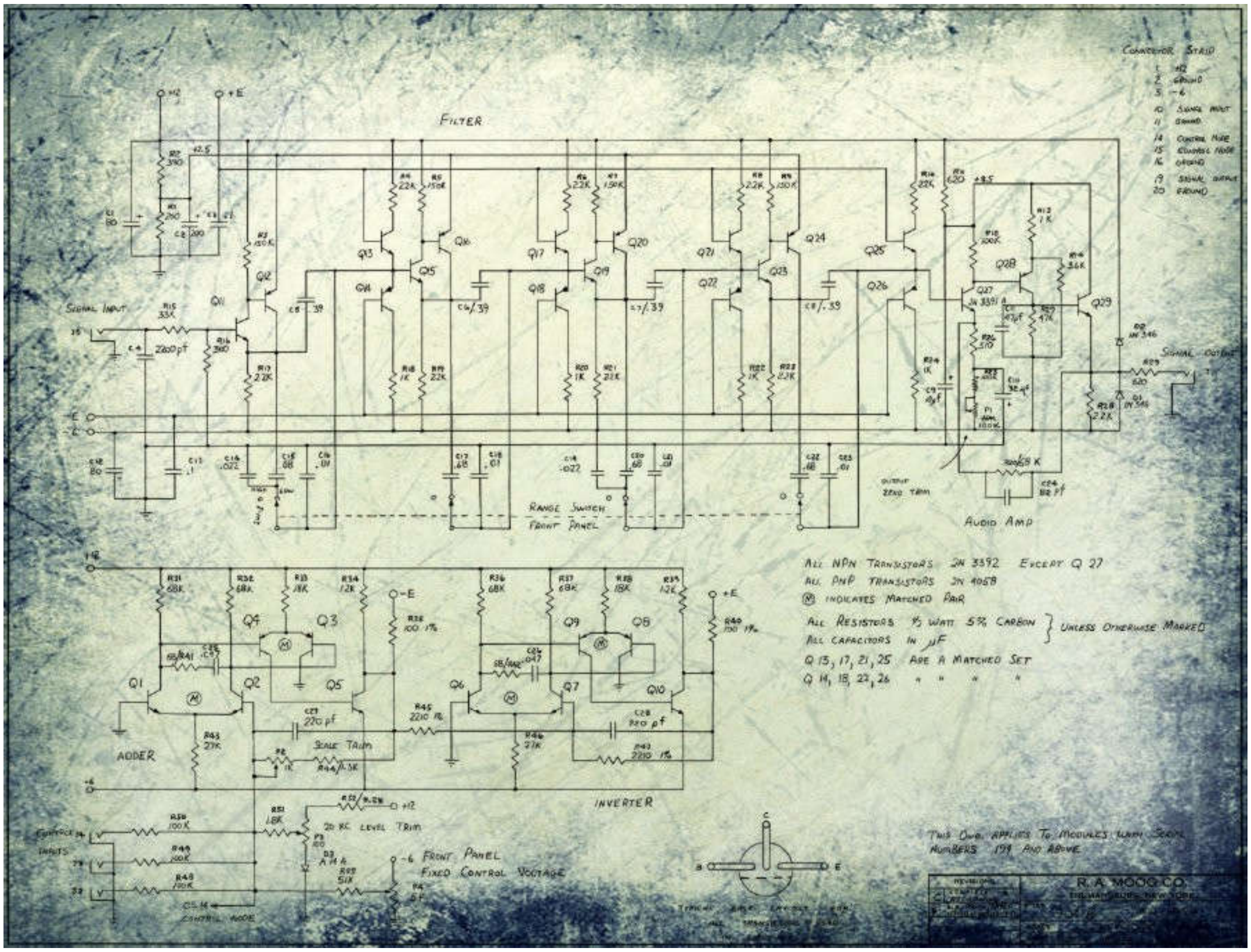

MOOG 904-B High-Pass Filter

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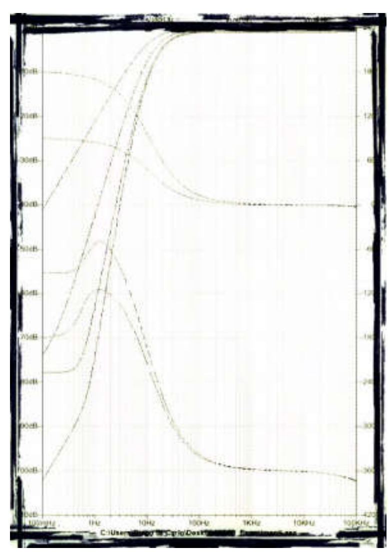
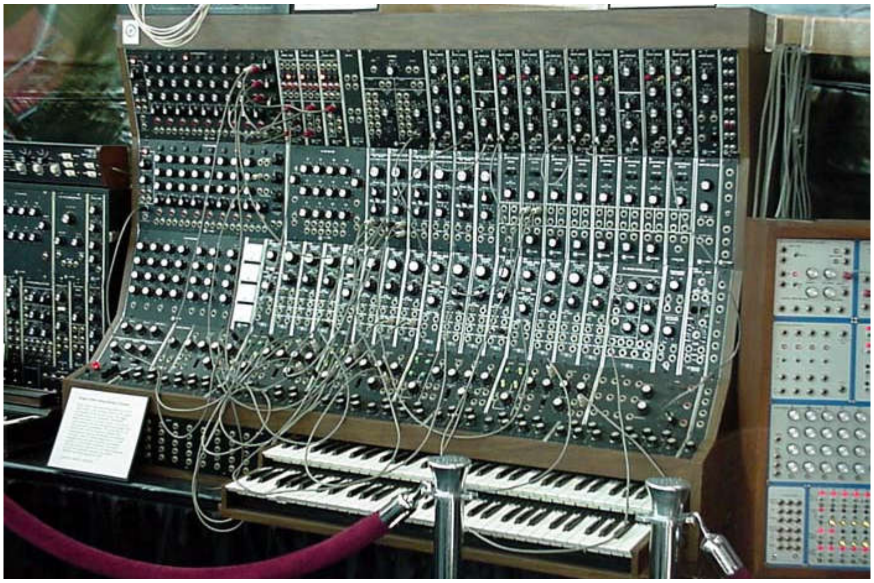
Modelling Physical System

Sound & Music Computing

Aalborg University : Copenhagen





Overview

With this project we want to analysis the original analog circuit of the MOOG 904-B, high pass filter, extract some useful and interesting information from this analysis and try to do a virtual/analog simulation.

This project was born as a collaboration between us and Stefano D'Angelo from Arturia, an electronics company and software house specialized in designing and manufacturing electronics musical instruments. This company is developing Moog modular V, a virtual emulator of Modular Moog, a famous analog synthesizer created by Robert Moog in 1964.

Moog Modular and the 904-B High Pass Filter Module

The Moog Modular system (left figure above) consists of a number of various module mounted in a cabinet. Each module perform a specific signal-generating or -modifying function, such as sound waveforms and envelopes generators, filters and spectral modulators.

The 904-B module (right figure above) is a voltage controlled high pass filter (HPF). It cames as a single module, but usually it is coupled with the others of Moog 904 Series: the 904-A Low Pass Filter (LPF) and 904-C Coupler Filter, which allows band pass filtering.

Our module features is a 4-pole voltage controlled high pass filter, featuring 24 dB/Octave (-80 db/dec) . It attenuates input signal frequencies below its cutoff frequency setting. The cutoff frequency is controlled by the control signal E, which can be any complex tone generated by other Moog's modules.

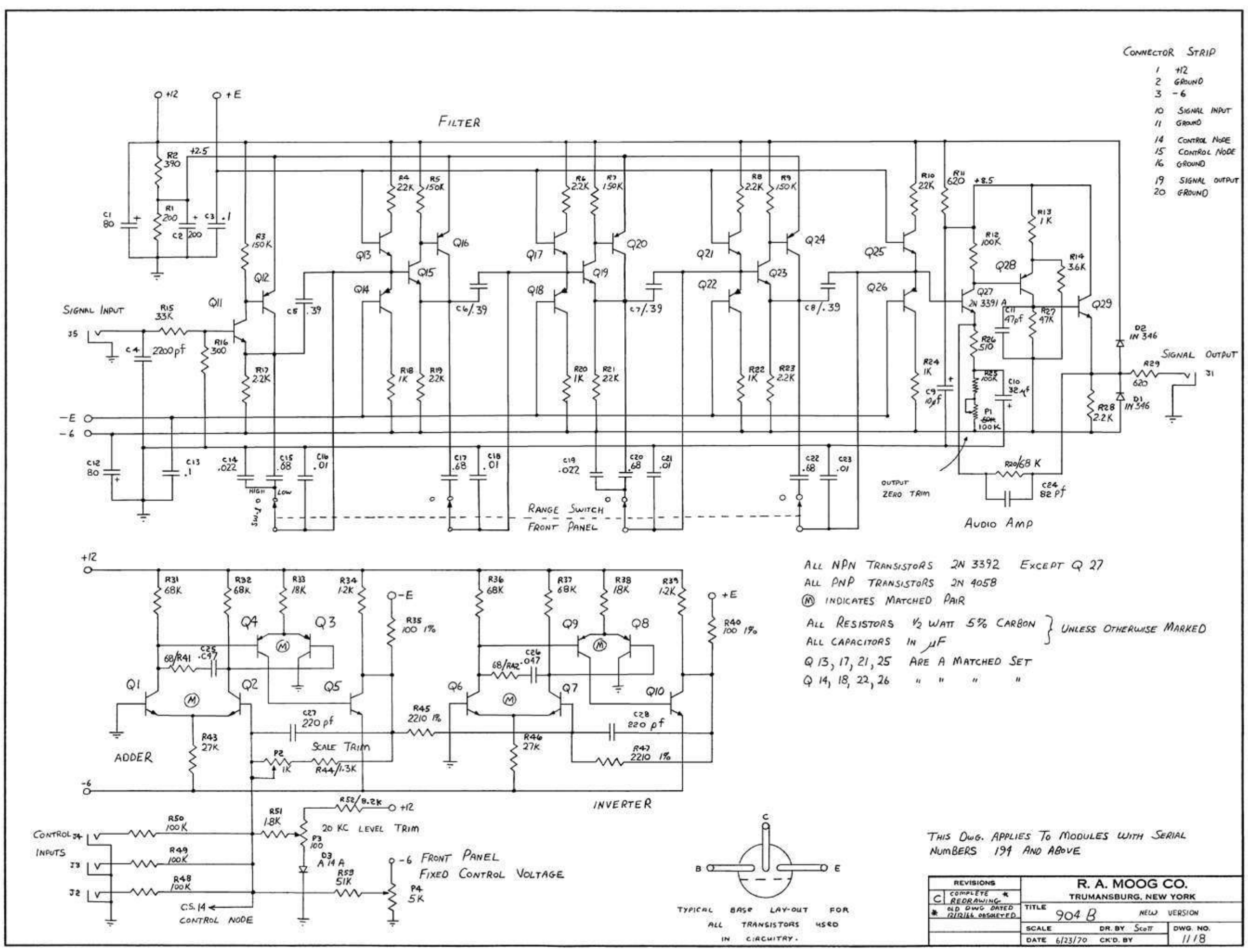
The Circuit

As show in the figure below, the circuit consists in two different parts: the lower half of the circuit consists of the control voltage mixer and a following inverter, while the upper half consists of the 4 pole voltage controlled high pass filter, which is the so-called *audio part* of the circuit.

The audio part consists in the following:

1. An attenuation stage of almost -40 dB as a voltage divider (R16 and R15)
2. 4 filter stages are passed in series. Each stage consists of a complementary Darlington cell (Sziklay pair, Q11 and Q12) and a complementary amplifier (eg. Q13 and Q14) which works as a voltage controlled resistor and forms a high pass filter in series with a capacitor set.
3. Output amplifier (Audio Amp) recreates the amplitude of the signal to the original value, that is it has an amplification factor of 42 dB.

NB: the complete module has an overall amplification of factor 2.



Goals

1. SPICE simulation of the circuit and check the independence of each stage..
2. Compute the Operating Point of the audio part of the circuit
3. Derive the (*Laplace*) transfer function related to the input/output audio signal with respect to the control signal.
4. Derive the (exact) math equation describing the filter with respect to the control signal and the cut-off frequency.
5. Derive the analytical model of the *big* signal of the audio part of the circuit with respect to control signal and the cut-off frequency
6. Implement the model in digital domain.

Milestones

With the following numbered list resumes the work done until the current status.

I. REFERENCES, TUTORIAL, LITERATURE and WORK SET-UP

Before starting with any developing and studying, we decide to set up a Trello for a better project management and we spent some day in deepening the history behind this analogue module.

Se we retrieve all the related papers, patents from official and audiophile sites, in order to get the correct informations about this projects. In fact, even if the circuit schematic is available in the patents, it seems to not be correct.

Fortunately we found that the faulty errors were not located in the audio part, although we found lot of different implementations for the audio amp stage.

Some random simulation of a simple RC circuit (HPF) has been done in order to get practice and confidence with **LTSpice**, a free multi-platform CAD program based on SPICE for circuit analysis.

II. SPICE SIMULATION and BASIC ANALYSIS

Once we get the more truthful schematics, we started to *spice* the circuit (Figure at the bottom of the next page)

Lot of time was necessary to search for the right model for the *vintage* components, such as old transistors (**2n3392** and **2n4058**) and diodes (**1N346**).

We performed some basic analysis such as check the independence of every amplification stages, that is each *pole* of the filter and the audio amplification part.

III. DC OPERATING POINTS

Performing an **DC operating point** analysis in SPICE, we have been able to figure out the voltage and current variable involved, especially around the Sziklai pairs.

IV. CIRCUIT CHECKING, DEBUGGING and BLOCK DIAGRAM

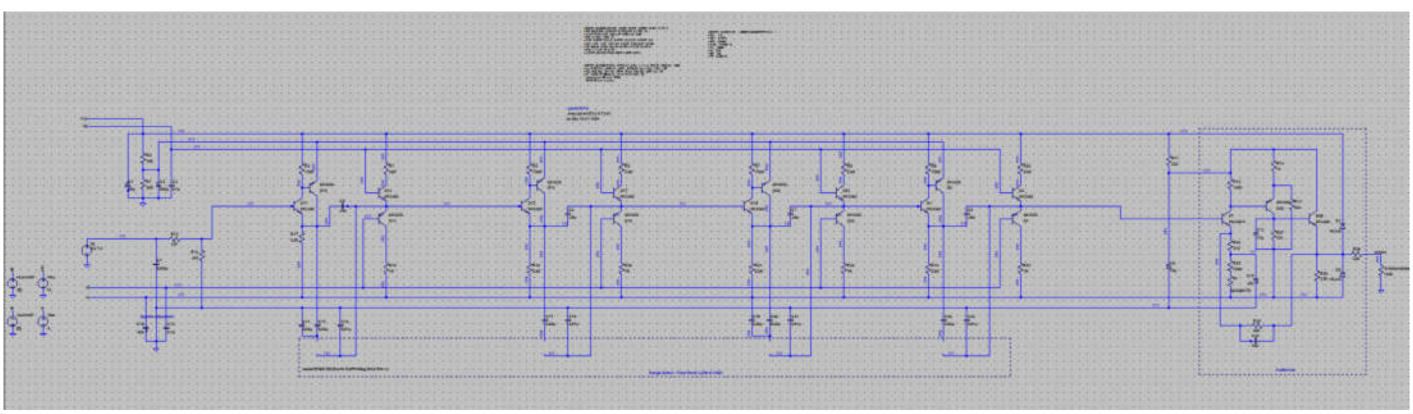
Performing some trivial **ac analysis**, we began to plot some raw *transfer functions* of every blocks of the circuit.

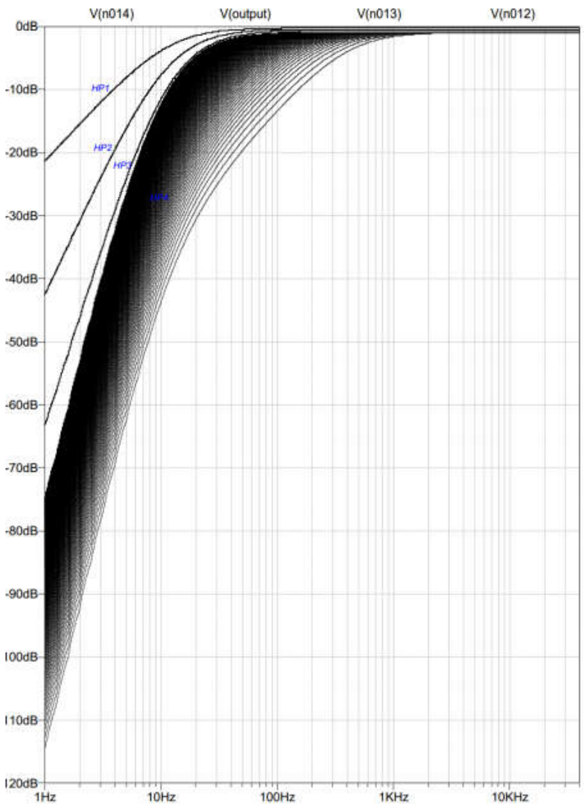
Thanks to these plots, we have been able to debug the circuit, highlight some non linear behaviours and understand its evolution with respect to different value of the control signal E.

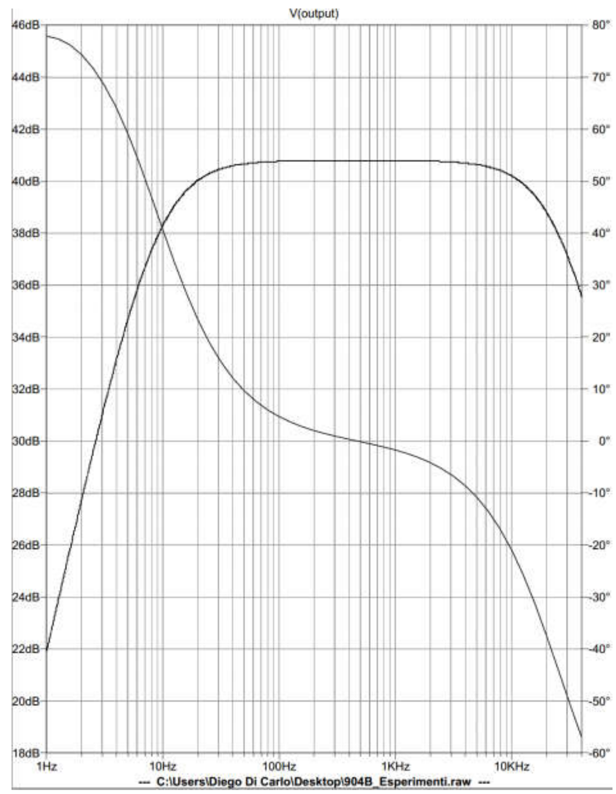
Again from these plots, we extracted the frequency response of every blocks and create a first black box model of our circuits.

Current Status

Now we are continuously dealing with the circuit inspection, more precisely on the correct value of input/output impedance of every stages. For almost all set of components we need to check if the simulation follows the analog behaviours. This will considerably simplify the further mathematical derivation of the model.







The figure above show:

- The frequency response of each (isolated) filter stage with fixed voltage control signal E. It is important to notice that only the last stage is influenced by the different values of a real *load* resistance (audio amp input impedance).
- The frequency response of (isolated) audio amp stage.

Literature

1. "Arturia - Home." Arturia - Home. Web. 12 May 2016.
2. D'angelo, Stefano, and Vesa Valimaki. "An Improved Virtual Analog Model of the Moog Ladder Filter." 2013 IEEE International Conference on Acoustics, Speech and Signal Processing (2013). Print.
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