Electronic conception of a programmable hearing aid

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Abstract

Hearing is the feeling thanks to which, the external world is perceived by the intermediary of specialized sensors, sensitive to the sound vibrations of the air (sound waves). These waves must pass by a whole perception and transmission chain including the outer ear, the middle ear and the inner ear, to arrive finally at the auditive nerve. At each level of this chain, an embarrassment or a rupture generating a situation whose severity can go from light auditive deficiency to major deficiency can be produced. So in the most cases, the port of a hearing aid becomes required. In this paper we are interested in the electronic design of a programmable hearing aid in 0.35µm MOS technology.

Keywords: hearing aid, programmable, sub-circuit, MOS technology.

1. Introduction

The essential role of the hearing aid is not limited to a simple amplification but it must be conceived in order to be regulated according to the threshold of pain while preserving the dynamic sound wave [1]. However, the correction of deafness by amplification yields the problem of any prosthetic adaptation. It is indeed to compensate up by apparatuses a different functional deficit according to each particular case, and whose characteristics are often fluctuating and not easily definable objectively.

So the structure that we propose is made up not only of one amplification chain but also comprising filters which make it possible to adapt the prosthesis to the audiogram of the patient already drown by the audioprothesist.

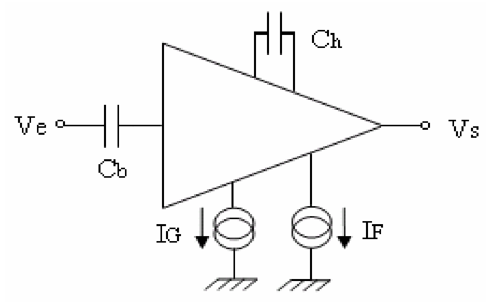

Figure 1: *Amplifying cell*

Then, the idea consists to divide the audible band, of 100 Hz to 8 KHz, in five under bands. Each sub band is treated by a cell which is controlled by two power sources I_F and I_G for the control of the gain and the frequency, respectively as shown in figure 1[2].

Each one of these five cells is composed by two amplifying cells A_{mg} and A_{mf} (Figure 2) such as:

A_{mg}: cell responsible to the adjustment of the profit controlled by I_g.

A_{fm}: cell responsible to the adjustment of the frequency controlled by I_f.

C_h: fixing capacity of the high cut-off frequency F_{ch}.

C_b: fixing capacity of the low cut-off frequency F_{cb}.

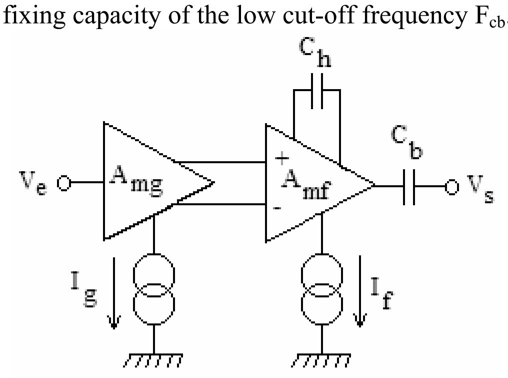

Figure 2: S*tructure of the basic cell*

This work is interested in the design of the basic amplifying cells and the improvement of their response curves in order to obtain better results.

2. Study of the structure A_{mg}

It is a structure with differential amplifier with coupled sources used in analogical designs [3]. Generally, the control processes of the profit in circuits are well known. It consists in modifying the conductance or the transconductance (the slope) of the used electronic element or both at the same time.

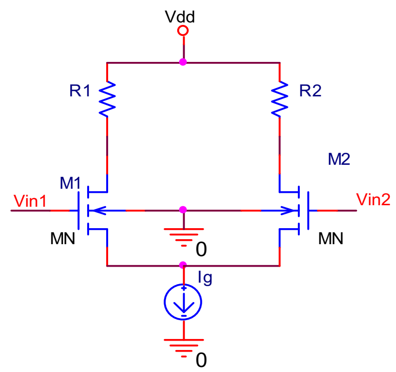

Figure 3: *Basic structure of the A_{mg} cell*

Both resistances R_1 and R_2 of figure 3 are identical and make it possible to fix the differential gain with the help of a current generator I_g which controls the transistor's slope: g_m of M_1 and M_2. In order to improve the integrated structure, each resistance is replaced by three in series P MOS transistors used in active load (Figure 4). To set a given resistance (r_{ds}) of these transistors it is required to choose a suitable polarization V_{sg}.

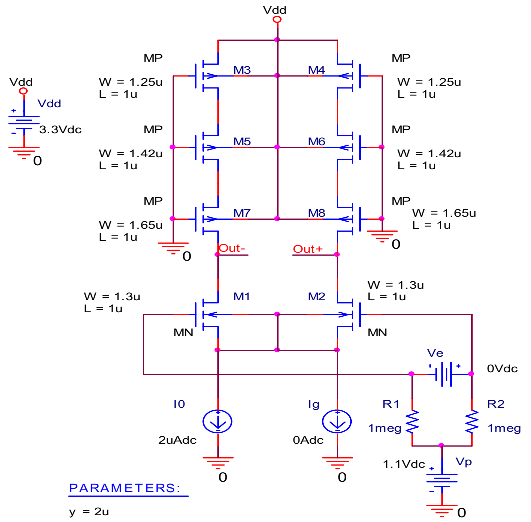

Figure 4: *Simulation diagram of the A_{mg} cell with 3 transistors active load.*

For the low values of V_{DS} (ohmic area or unsaturated area corresponding to $|V_{DS}| \leq |V_{GS}| - |V_T|$), the device is equivalent to an ohmic resistance which value depends on V_{GS}. In the case of small signals, the resistance of the channel is given by [4]:

$$r_{ds} = \frac{L}{KW(V_{sg} - V_T - V_{ds})} \quad .$$

The resistance r_{ds} will be the active load of the amplifier. This resistance should not be dependent on the polarization current I_o, or the least sensitive that possible of this one.

Resistances r_{ds} of the transistors ensuring the load (M_3- M_5- M_7 and M_4- M_6- M_8) are fixed by the polarization $V_{sg,}$ = 3.3V (V_{dd}) since their grids are placed at 0V [5].

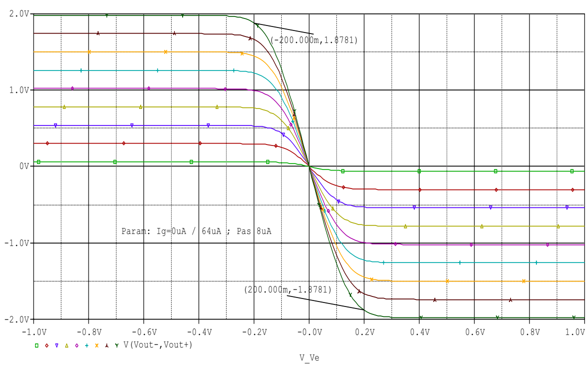

Figure 5: *Transfer Characteristics of the A_{mg} cell with activate load for different values of current I_g varying from 2µA to 64µA*

The maximum value of I_g (ordering current of the A_{mg} cell) is 64µA. It can reach different values between 0 and 64 µA with a precision equal to ΔI_g= 2µA. this leads to add a prepolarisation current, I_{go} =2µA.

The simulation results showing the transfer characteristics of the A_{mg} cell are given by figure 5.

To evaluate the variation of the differential profit, AC simulations are done for different values of current I_g varying from 2µA to 64µA. Results given by figure 6 show that the maximum gain is equal to A_{max}dB=17.2dB.

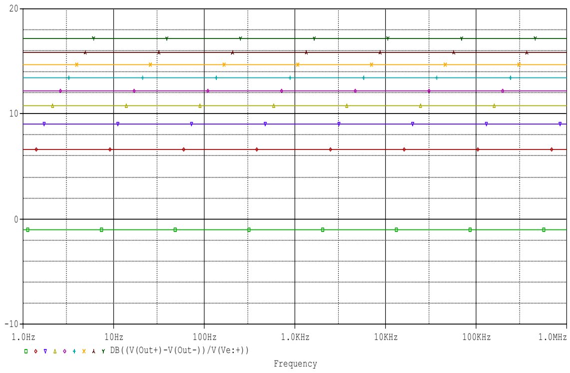

Figure 6: *Gain variations of the A_{mg} cell with an activate load for different values of current I_g varying from 2µA to 64µA*

3. Study of the structure A_{mf}

To control the band-width, we use the structure of figure 7. It is a differential pair, M_1 and M_2, with coupled sources loaded by a current mirror , consisted of the transistors M_3 and M_4 [6].

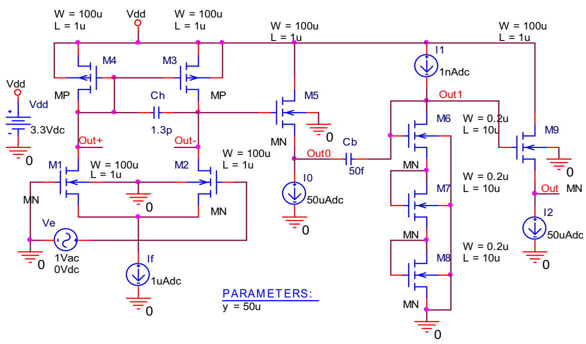

Figure 7: *Complete diagram of A_{mf} cell*

The modification of the current source by means of I_f makes it possible to control the drain's currents. In addition, while supposing that transistors M_1, M_2 and M_3, M_4 are respectively identical, and that $V_{GS1} = V_{GS2}$ and $V_{GS3} = V_{GS4}$, it comes that the drain current of M_4, as for the current source, follows rigorously the one of M_3, in the same way for the drain current of M_1 and of M_2. Then we can easily write: $I_{d1} = I_{d2}$ and $I_{d3} = I_{d4}$ [7].

The C_h capacity between the sources of the transistors M_3 and M_4 is responsible of the high cut-off frequency. In addition the C_b capacity between the sources of transistor M_5 and the drain of the transistor M_6 is responsible of the low cut-off frequency.

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The three identical transistors M_6, M_7 and M_8 placed in series and polarized by the current source I_1, ensure the impedance adaptation.
Simulation results, for the values of C_h and C_b to have the cut-off frequencies corresponding to the fifth order filter, is given by figure 8.

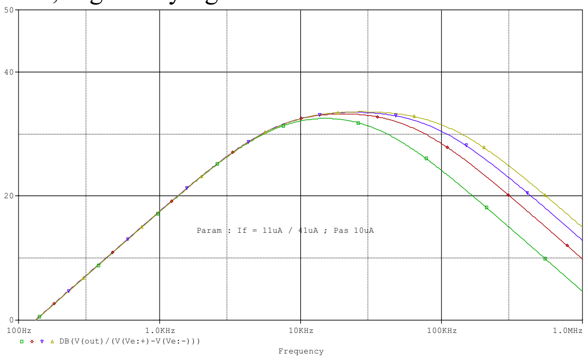

Figure 8: Frequency *response curve of* the *complete* A_{mf} *cell*

4. Improvement of the response curve

In order to obtain better performances for our hearing aid, an improvement of the frequency response curve of each filter is required.
The idea consists in letting the slope of the response curve of each cell A_{mg} and A_{mf} equal to 12dB/Octave instead of 6dB/Octave. For this, we added two other capacities C'$_h$ and C'$_b$ in the A_{mg} cell of each filter, responsible fixation of the high cut-off frequency F'$_{ch}$ and the low cut-off frequency F'$_{cb}$ respectively. Figure 9 shows the new structure of the basic cell.

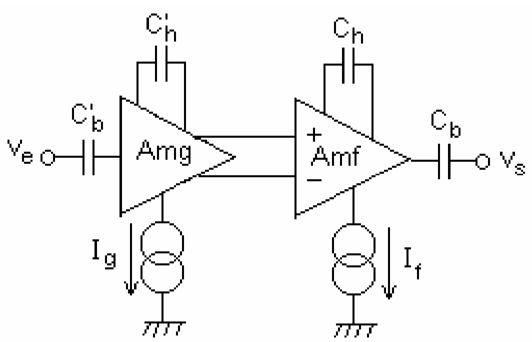

Figure 9: Improved s*tructure of the basic cell*

The values of the capacities C'$_h$ and C'$_b$ are chosen for each cell A_{mg} separately (Figure 10), and this by complying with the two following rules:

- The high cut-off frequency F'$_h$ of the A_{mg} cell must be higher than that the one of the A_{mf} cell (F_h) of the same filter.
- The low cut-off frequency F'$_b$ of the A_{mg} cell must be lower than that the one of the A_{mf} cell (F_b) of the same filter.

This operation is repeated for the five stages. Indeed, the two capacities C'$_h$ and C'$_b$ are introduced in the structure of the A_{mg} cell corresponding to the one of the five stages of the hearing aid.

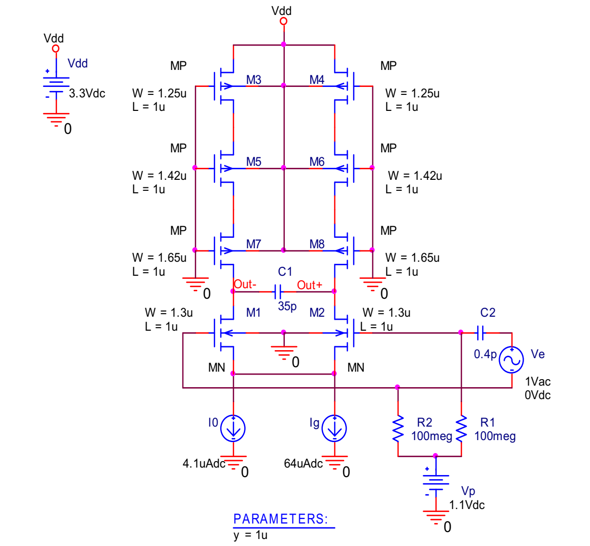

Figure 10: A_{mg} *cell with the two capacities*

Figure 11 shows the frequency response curve parameterized in I_g for the fifth stage.

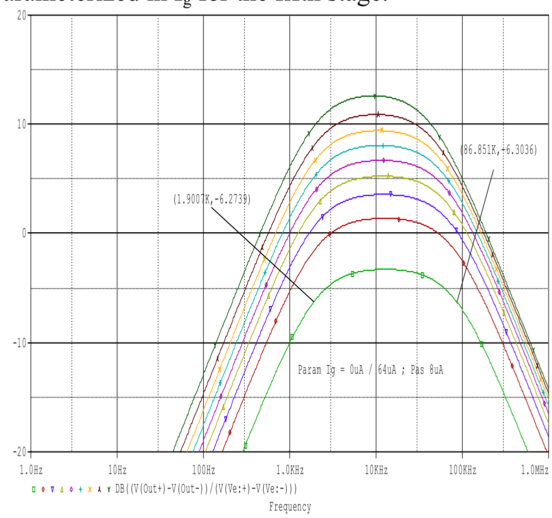

Figure 11: *Response curve of the* A_{mg} *cell with capacities*

5. Final diagram

To have the final diagram of simulation of figure 12, it is enough to use the already made sub-circuits of A_{mg} and A_{mf} cells and to fix the different missing parameters thereafter.

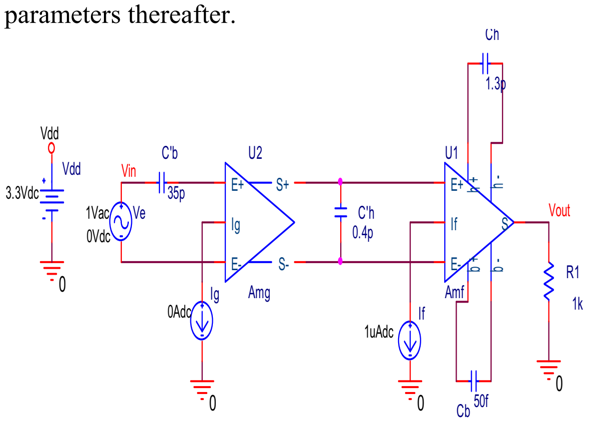

Figure 12: *Complete diagram (setting in cascade of* A_{mg}-A_{mf}*)*

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The final simulation diagram of the hearing aid is shown by figure 13.

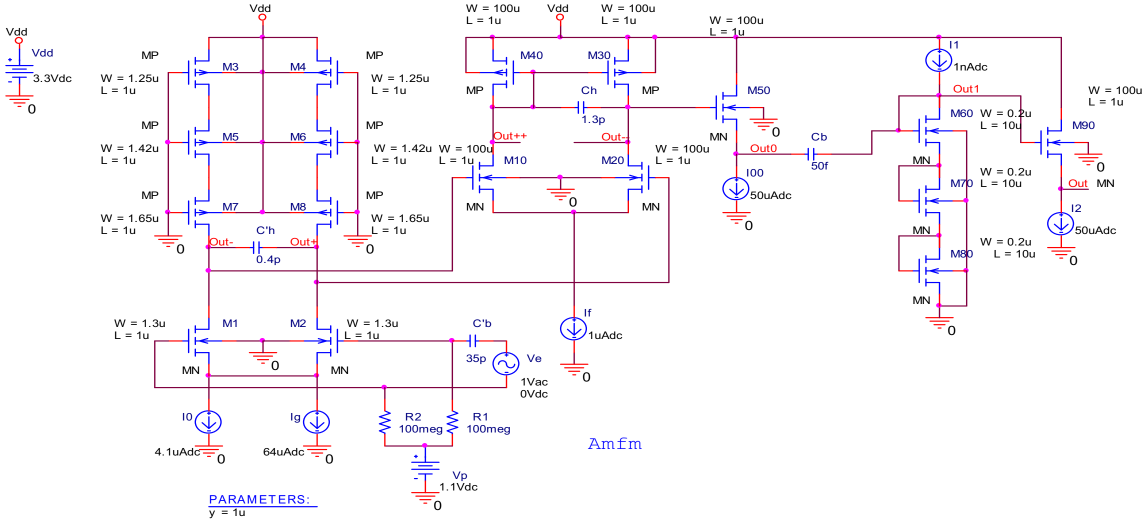

Figure 13: *Complete diagram*

Simulation results of the fifth stage are given by figure 14; the slope of the frequency response curve given by this figure is equal to 12dB/Octave.

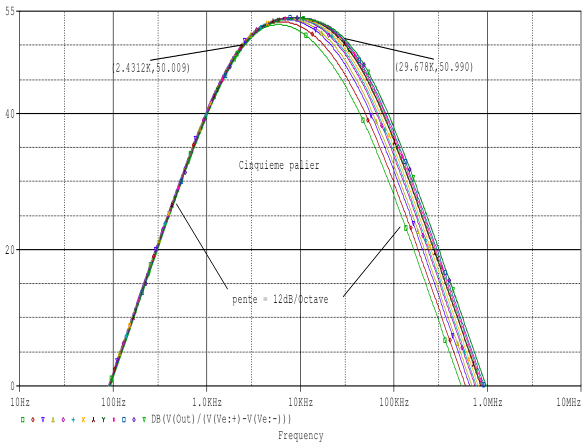

Figure 14: Frequency *response curve of the complete diagram*

6. Conclusion

We presented in this paper a programmable circuit for a hearing aid. The operating principle of operation of this hearing aid is based on the subdivision of the audible band in five sub-bands. The profit and the sub-band-width of each under band are controlled by A_{mg} and A_{mf} cells respectively which we presented their structures. These two cells are ordered respectively by current sources I_g and I_f.

Thereafter, a modification is made thereafter on these conceived structures conceived in order to have a better frequency response curve while increasing its slope and while exploiting the interior parameters of the two cells. Two cells A_{mg} and A_{mf} are thereafter put in a sub-circuit to have more use flexibility.

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