

BASIC CIRCUIT FOR SILICON COCHLEA

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Summary Cochlear implants restore partial hearing to people with severe to profound sensorineural deafness. Low-power wide-dynamic-range systems are hard to build. The biological cochlea is one of the most awesome examples of such system. It can sense sounds over 12 orders of magnitude in intensity with power dissipation of few tens of microwatts. In this paper, an analog band pass filter is implemented in AMS 0.35 μ m CMOS technology. We used the Sallen-Key topology in the filter.

1. INTRODUCTION

The human ear transduces airborne sounds into a neural signal which is subsequently processed by a large variety of neurons in the brainstem before being passed on to higher levels of neural processing. The cochlear implant is a device that bypasses a nonfunctional inner ear and stimulates the hearing nerves with patterns of electrical currents so that speech and other sounds can be experienced by profoundly deaf people [1]. They mimic the function of the ear in stimulating neurons in the cochlea as the response to sound.

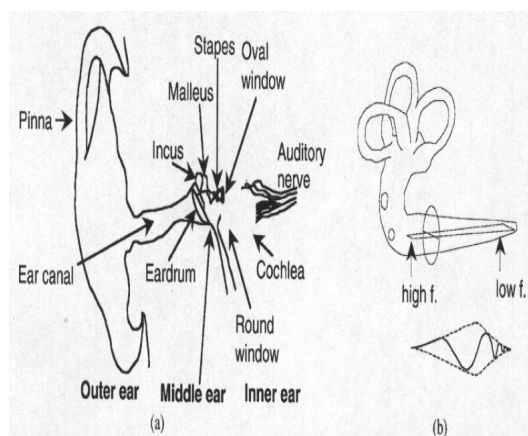


Fig. 1: (a) The human ear. (b) The uncoiled cochlea with the basilar membrane and an exaggerated, schematic representation of the membrane displacement due to a pure tone of a relatively low frequency. The dashed lines represent the maximum displacement of the basilar membrane and the solid line is a snapshot. [2]

Human ears hear only sounds with frequencies between 10Hz and 20 kHz. But human speech can be recognized just by hearing sounds with frequencies in much smaller interval, from 1 kHz to 5 kHz. Therefore we will use a band pass filter that will pass only frequencies from this interval.

2. BAND PASS FILTER IN ELECTRONIC COCHLEA

Three stages transduce the sound into voltage spikes on the auditory nerve fibers. The first structure of importance is the cochlea, a fluid-filled, coiled, bony structure in the inner ear. The cochlea is divided in two by basilar membrane. Sound creates pressure waves in the fluids of the cochlea and the cochlea filters this wave, so that different sound frequencies will cause different parts of the basilar membrane to vibrate most. The second stage in the transduction process consists of an array of inner hair cells, which sense the vibration of the basilar membrane along the membrane. The third stage in the transduction process is implemented by the spiral ganglion cells which make synaptic contacts with inner hair cells and whose axons form the auditory nerve.

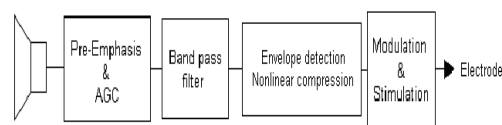


Fig. 2: Bionic ear overview.

Fig. 2 shows an overview of a common signal-processing chain. Sound is first sensed by a microphone. Pre-emphasis and gain control are then performed on the input path. Band pass filters then divide the sound into different frequency bands. The envelope of each channel is then detected. The dynamic range of each channel is compressed to fit into the patient's dynamic range. Finally, the signal from each channel are modulated and sent to the electrodes to stimulate the remaining neurons of the patient [4].

Current systems use a DSP-based processor that may be worn as a pack on the belt or as a Behind-The-Ear unit. The challenge now is to move to designs that can be fully implanted. Reducing the power of the bionic ear is one of the keys to moving to a fully implanted system and provides an important motivation for this work.

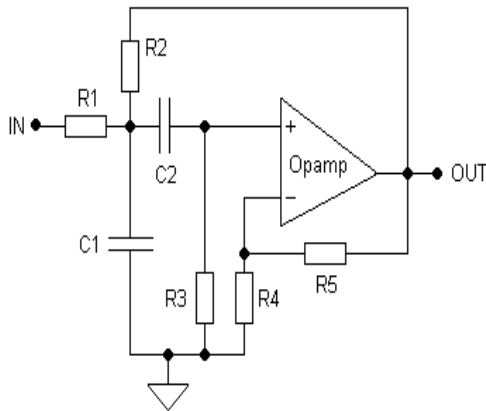


Fig. 3: Sallen-Key band pass filter.

The Sallen-Key filter is a popular filter due to its versatility and ease of design. The Sallen-Key band pass filter (fig. 3) was designed in AMS 0.35 μm CMOS technology. Devices R1 and C1 represent a low pass filter and devices C2 and R2 represent a high pass filter. Resistors R4 and R5 sets the gain of the two stage operational amplifier. The circuit was simulated by the CADENCE tools. The transfer function of the band pass filter is the following [5]:

$$H_{BP}(s) = \frac{G \left(\frac{w_0}{Q} \right)}{s^2 + \left(\frac{w_0}{Q} \right) s + w_0^2}$$

We readily identify the following expressions for the three parameters:

$$w_0 = \sqrt{\frac{R_1 + R_2}{R_1 R_2 R_3 C_1 C_2}},$$

$$Q = \frac{\sqrt{\frac{R_1 + R_2}{R_1 R_2 R_3 C_1 C_2}}}{\frac{1}{R_1 C_1} + \frac{1}{R_3 C_2} + \frac{1}{R_3 C_1} + \frac{1 - \mu}{R_2 C_1}},$$

$$G = \frac{\frac{\mu}{R_1 C_1}}{\frac{1}{R_1 C_1} + \frac{1}{R_3 C_2} + \frac{1}{R_3 C_1} + \frac{1 - \mu}{R_2 C_1}}.$$

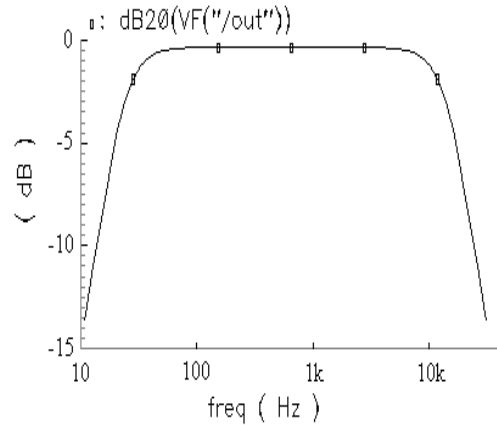


Fig. 4: The output response of the designed filter.

Fig. 4 show the frequency characteristic of the designed band pass filter. You can see that we oriented on the region about 3.5 kHz, what is frequency band corresponding with the human speech. We used a transient analysis. We applied a rectangle pulse on the input pin of the filter and we observe the voltage on the output pin.

3. CONCLUSION

Moving bionic ears from systems that are partially worn outside the body to true implants that are fully embedded inside the body requires overcoming a number of technical obstacles. One important obstacle involves ways to substantially lower the power of the signal processing. A first step in that direction is exploring and customizing filter technologies. These filters have to operate with large dynamic range and use minimal power. A functionally simple, analog filter for electronic cochlea was presented. The band pass filter was designed and implemented in AMS 0.35 μm CMOS technology. The future work is adding switched capacitor elements to the schematic and fabricates the chip.

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