REALIZATION OF EYES AS LOW PASS FILTER

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Abstract

Eyes can be shown as passive low pass filter, basically RC low pass filter, in this paper we have proved eyes as LPF and obtained some beautiful hypothetical results. And we made a proper linkage between analogue electronics and biology.

Introduction

A low-pass filter is a filter that passes signals with a frequency lower than a selected cut-off frequency and attenuates signals with frequencies higher than the cut-off frequency. We are considering passive ideal low pass in this paper. An ideal low pass filter completely eliminates all frequencies above the cut-off frequency while allow those below unchanged. And if the gain of the filter is not unity, It will attenuates or amplify the input signal passing through it irrespective of changing its characteristics.

Figure- 1.0

The figure-1.0 depicts the frequency response of ideal low pass filter with cut-off frequency of B. similarly we can also show that the impulse response of low-pass filter will be a *sinc function*

Transfer function of ideal first order low pass filter is given as $\frac{\text{output}}{\text{input}} = k \frac{1}{1+sT}$

where, k is the gain of the filter in passband, s is the laplace variable and T is the time constant of the circuit

Now we can deduce clearly that, if the frequency of signal is more than cut-off frequency of the filter then it will fall on stop band region hence will not pass through the filter. **This similar phenomenon occurs in human eyes.** We can prove given statement in three different ways. Now let's move to describe the practical low pass filter, which will suits best in real life rather than an ideal one.

Figure-1.2

Figure-1.2 represents the frequency response of practical 1st order low pass filter of cut-off frequency f_H , in which there is no sudden change in gain between pass band region and stop band region.

Circuit diagram of **RC** 1st order low pass filter provided below-

Figure- 1.3

Where C is ideal capacitor with zero internal resistance, R is resistance in series with capacitor. $V(i)$ is input voltage $V(out)$ is output voltage.

Observations

- The optical system of the eye acts as a low-pass filter removing all frequencies more than ~ 60 cycles deg^{-1} , so from the sampling theorem that the retinal image can be fully represented by sampling at a frequency of 120 cycles deg^{-1} , as of Nyquist rate of sampling which is also approximately that of the receptor mosaic. When the light modulated information of an image enters into human eyes, it passes through the optical lens of the eye and is captured by photoreceptors in the retina. One of the functions of photoreceptors is to sample the continuous spatial variation of the image discretely. The cone signals are further processed through the horizontal cells, bipolar cells, amacrine cells, and ganglion cells with some re-sampling. From an image processing point of view, the effects of optical lens, sampling, and re-sampling in the retinal mosaic are **low-pass filtering**, moreover in the retina of human eyes there are much less number of cone cells present with respect to rod cells. The cone cells are responsible for colour vision; these cells are packed in the fovea (centre of the retina) at

a density of approximately 120 cones per degree of arc subtended in the field of vision. The density of cones falls off rapidly outside a circle of 1 degree radius from the fovea and the pupil of the eye acts as an aperture, and therefore acts as a low pass filter.

- Let's prove human eye is a low pass filter by contradiction, firstly assume, eyes allow signals of any range of wavelength to pass through the optic nerve (ON), then by Parseval's theorem we can get any amount of energy in frequency band and since optic nerve is acting like a channel that contains signal from eyes to brain must have some finite channel capacity and moreover fibre tracts should use space and energy efficiently, because both resources are constrained in neural computations. So, we conclude that only fixed range of bandwidth of signal passes through human vision system that must be less than the channel capacity of optic nerve.
- All matter exhibits wave-like behaviour however by de Broglie's principle due to huge mass of matters the wavelength is too small to have a practical impact on daily life. Hence matter wave emitted from a basketball or human beings doesn't seem relevant.

By special theory of relativity, we have a formula for relativistic momentum and relativistic mass energy given as-

$$\vec{p} = \gamma m_0 \vec{v}$$

$$E = mc^2 = \gamma m_0 c^2$$

From the above equation we can deduce that-

$$\lambda = \frac{h}{\gamma m_0 v} = \frac{h}{m_0 v} \sqrt{1 - \frac{v^2}{c^2}} \quad \text{equation 1}$$

$$f = \frac{\gamma m_0 c^2}{h} = \frac{m_0 c^2}{h} \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}} \quad \text{equation 2}$$

Where, m_0 denotes particle rest mass.

V =velocity,

γ is Lorentz factor

f = frequency

And c is speed of light in a vacuum.

From equation 2 we can conclude that as the velocity of matter increases the frequency associated with its matter wave also increases. And according to theoretical studies, if a ball (soccer) to be invisible, it would need to cross 70 meters in 1/250th of a second. That's 17500 meters every second or 38146 mph. i.e. much faster than the speed of sound.

The whole conclusion of the above point is that the human visual system has similar characteristics like a Low pass filter, as when the frequency of signal is very high (more than cut-off frequency), it attenuates the output.

- Human vision system is static system, as it only depends upon present input

Hypothesis concluded

If an eye is low pass filter, then it must obey the characteristics of it, that means we can comment on the signal that eyes send to optic nerve, i.e. in case of ideal low pass filter we get total DC (constant signal) value of input as output (across capacitor). If we compare it with eye and assume eyes as ideal or practical low pass filter then also the DC (constant part) value of

input signal will majorly reflected in output part. Thus, with this hypothesis we got to know about the nature of the signal that visual system send to optic nerve.

Now, if the **frequency of wave is enough, such that it can activate photoreceptors** in the eye, then we can equalize the anatomical human eye model with this illustrated electronic circuitry below.

FUNCTIONING OF EYE

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