A Hysteretic Neural-Type Pulse Oscillator

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Abstract

An op-amp RC, hysteresis, neural-type pulse oscillator is presented. Design constraints are given of a first order module for its realization with experimental verification indicating the practicality of the circuit and important factors to be considered.

I. Introduction

Neural-type microsystems are electronic systems which realize the pulse handling characteristics of biological neural systems in a form suitable for integrated circuit construction [1]. To date research efforts have been concentrated upon the generation and propagation of action-potential-type pulses in neurister structures [2]. However, recently some efforts have investigated signal mixing systems [3]-[5]. In our studies on neural-type microsystems, hysteresis was found to occur naturally in such systems [6]. This motivated us to investigate the hysteresis phenomenon [7], its use in neural-type systems [8], and the design of a hysteretic triggered neural pulse generator [9]. In this paper we develop these ideas further and give the means to design a hysteretic neural-type op-amp-RC pulse oscillator.

II. The Hysteretic Neural-Type Module

We begin with the basic first order state-variable like equations [8] written in a form most useful for our circuit

$$K\dot{x} = -\alpha x - \beta H(x) - \gamma u \qquad (1a)$$

$$y = x$$

here u = input, y = output, x = internal (state-like) variable; α, ,γ,K are nonnegative constants and H(•) is the multivalued binary hysteresis function

$$H(x) = \begin{cases} H_+ & x > x_+ \\ \{H_+, -H_-\}, & -x_- < x < x_+ \\ -H_-, & -x_- < x \end{cases} \qquad (2)$$

(where $\{H_+, -H_-\}$ is the two element set comprised of H_+ and H_-). We have (using $G_i = \frac{1}{R_i}$, $i = x,H,u$)

$$K = C,\ \alpha = G_x,\ \beta = G_H,\ \gamma = G_u \qquad (3)$$

The lower portion of Fig. 1 shows an op-amp means of realizing a suitable hysteresis functions H(.) [9]. To determine further the characterization of H(.) we consider the op-amp characteristic as that given by the set function

$$K(v_i) = \begin{cases} V_+ & , \quad 0 < v_i \\ [-V_-, V_+], & 0 = v_i \\ -V_- & , \quad v_i < 0 \end{cases} \qquad (4)$$

where $[-V_-,V_+]$ is the interval of numbers between $-V_-$ and V_+ ; V_+ = positive saturation voltage, $-V_-$ negative saturation voltage. According to Fig. 1, the op-amp characteristic is subject to the load line

$$K(v_i) = -\left(\frac{R_f}{R_i}\right) x + \left(1 + \frac{R_f}{R_i}\right) v_i \qquad (5)$$

Drawing this load line on the op-amp curve shows that the x-intercepts of $H(v_i)$, x_- and x_+, are determined by the lines going through b-c and g-h respectively. Using

$$K(0_+) = V_+ = H_+ , \quad K(0_-) = -V_- = -H_- \qquad (6a)$$

in (5) gives

$$x_- = \left(\frac{R_i}{R_f}\right) H_+ , \quad x_+ = \left(\frac{R_i}{R_f}\right) H_- \qquad (6b)$$

The four parameters in H(•) of (2) are consequently fixed by the op-amp saturation voltages and the resistances of Fig. 1. It should be noted that the two member set value of H(•) is really a three member set value --- we ignore the third value as it is dynamically of little importance to our theory giving an unstable equilibrium point.

Returning to (1) we next look at equilibrium points, these being the value of x for which $\dot{x}$=0. For this let us note (1) when $\dot{x}$=0 and define the load line L(x,u) by

$$L(x,u) = -\frac{\alpha}{\beta} x - \frac{\gamma}{\beta} u \qquad (7a)$$

Then if the input assumes a constant resting value

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u_R and x_E is the corresponding equilibrium state

$$H(x_E) = L(x_E, u_R) \tag{7b}$$

is the equation determining x_E, as illustrated in Fig. 2.

III. Neural Pulse Oscillator

In the case of an oscillator the load line of Fig. 2 does not intersect either of the horizontal portions of the hysteresis curve. Therefore, for the constant input u_R we have

$$-H_- < L(x_+, u_R) < L(-x_-, u_R) < H_+ \tag{8a}$$

Evaluated in terms of circuit elements, using (3) & (6b), these are

$$-H_- < -\frac{G_x}{G_H} \cdot \frac{G_f}{G_i} H_- - \frac{G_u}{G_H} u_R < \frac{G_x}{G_H} \cdot \frac{G_f}{G_i} H_+ - \frac{G_u}{G_H} u_R < H_+ \tag{8b}$$

The inequalities of (8b) give the design constraints necessary for the circuit to be an oscillator.

As seen by (1), transitionings are complicated but something like increasing exponential in form, $\exp(t/R_{eq}C)$, and hence are faster for smaller C's; in a time $R_{eq}C$ the response "increases" by a factor approximating e.

IV. Experimental Results

Measurements were made on Fig. 1 using an MC 1458CP dual operational amplifier package for the two op-amps (with pin numbering as shown in the figure). When fed by sine waves (as for the recording of the hysteresis loop) a Tektronix FG 502 Function Generator was used. All oscilloscope displays presented were recorded on a Tektronix 561A oscilloscope (with a faulty retrace which shows up on the photograph).

Figure 3 shows the self-oscillations obtained when C=0.01 f and the input is kept at a constant (dc) value of u_R=1.3V. In order to hold to the design values of $H_+ = H_- = 4$v, as obtained in Figure 4, it was necessary to apply op-amp biases $V_{B+} = 4.6$v and $V_{B-} = 6.0$V. The values $R_f = R_H = 2R_i = R_x = R_u = 20$K were used. The oscillations are seen to be at 1.1KHZ (which is of the order of $1/R_xC$ = 5KHZ but differing due to the hysteresis effects).

V. Discussion

In section II we have presented a design procedure leading to a working op-amp RC neural-type circuit. This design is based upon the use of hysteresis which is biased into unstable regions for the generation of self-excited oscillations. This circuit gives a first order oscillator. Clearly, by various modifications other characteristics can be obtained; for example, variation of x_+ and/or x_- allows for modulation.

The circuit studied here has shown us a high degree of robustness in that reasonable variations in parameters have still allowed it to work essentially as designed. Consequently, we believe the use of hysteresis, which has allowed a simple first order circuit to result, seems to hold considerable promise for the field of neural-type microsystems.

V. References

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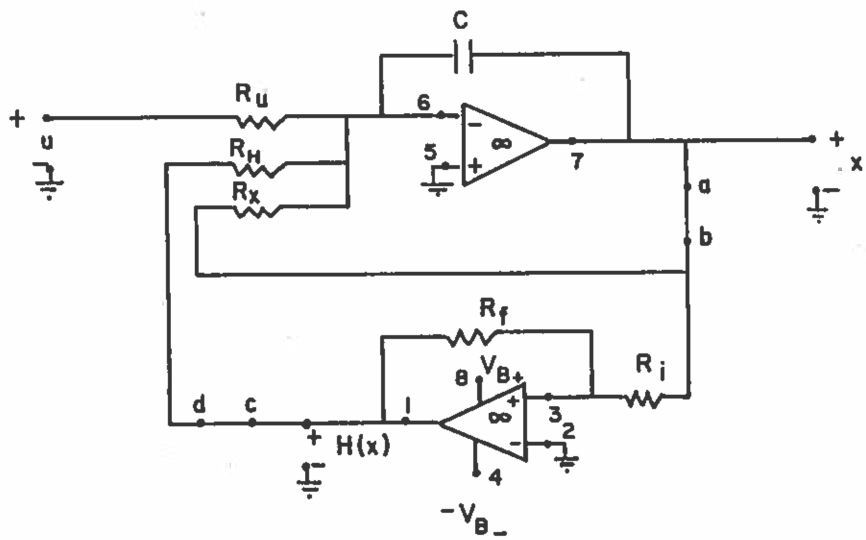

Figure 1. Op-Amp, Hysteresis, Neural-Type Circuit

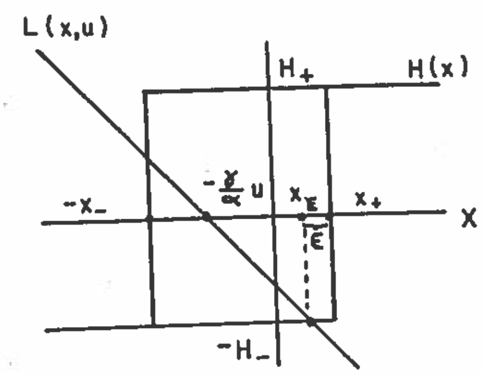

Figure 2. Resting Point Determination

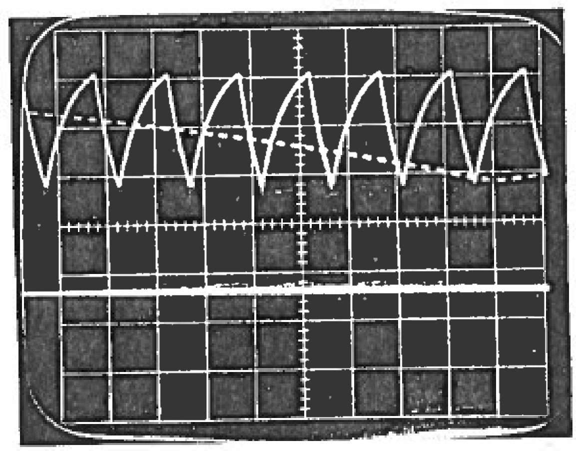

Figure 3. Self-Oscillations. $C=0.01\mu f$, u = 1.3 vdc.
Scales: 2v/div and 0.5 m sec/div
Upper trace = x, 0 on second line down
Lower trace = u, 0 on second line up.

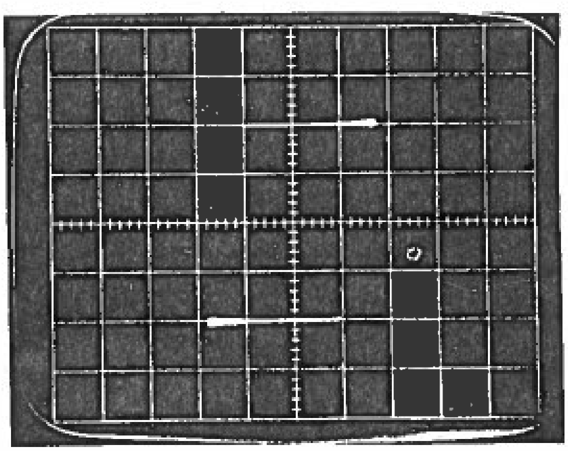

Figure 4. Measured In-Place Hysteresis
$R_x = R_f = R_H = R_u = 2R_i = 20\ K\Omega$
Scales: 2v/div, (0, 0) at center
Horizontal = x
Vertical = H(x)
$V_{B+} = 4.6v$, $V_{B-} = 6.0v$.

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