with modified input 09/07/05

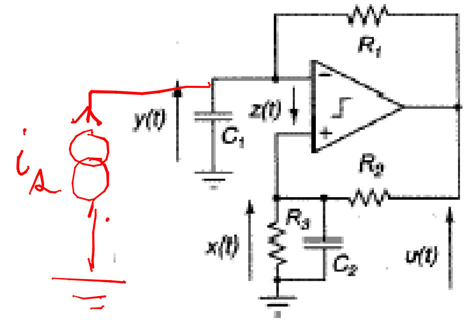
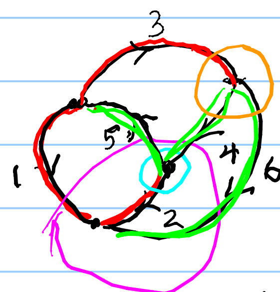


Fig. 1. Schematic of e relaxation oscillator. The comparator is assumed to be ideal.

Use KCL, KVL, laws of elements

~~tree branches~~ cotree (links) $1_3 = 1_t$



KCL

$$\begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix} = \left[\begin{array}{ccc|ccc} 1 & 0 & 0 & 1 & -1 & 1 \\ 0 & 1 & 0 & -1 & 1 & 0 \\ 0 & 0 & 1 & -1 & 0 & -1 \end{array}\right] \begin{bmatrix} i_1 \\ i_2 \\ i_3 \\ i_4 \\ i_5 \\ i_6 \end{bmatrix}$$

$0 = C i_b$ (C = cut set matrix)

t = # of tree branches

l = # of links

1_l

KVL

$$\begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix} = \left[\begin{array}{ccc|ccc} -1 & 1 & 1 & 1 & 0 & 0 \\ 1 & -1 & 0 & 0 & 1 & 0 \\ -1 & 0 & 1 & 0 & 0 & 1 \end{array}\right] \begin{bmatrix} v_1 \\ v_2 \\ v_3 \\ v_4 \\ v_6 \end{bmatrix}_b$$

$0 = T v_b$ (T = tie set matrix)

Laws of the elements, $s = d/dt$

$$\begin{bmatrix} sC_1 & 0 & 0 & 0 & 0 \\ 0 & sC_2+g_3 & 0 & 0 & 0 & 0 \\ 0 & 0 & g_1 & 0 & 0 & 0 \\ 0 & 0 & 0 & g_2 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} v_1 \\ v_2 \\ v_3 \\ v_4 \\ v_5 \\ v_6 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} i_1 \\ i_2 \\ i_3 \\ i_4 \\ i_5 \\ i_6 \end{bmatrix}$$

$v_6 = K(v_5)$ op-amp gain (nonlinear)

$v_b = \begin{bmatrix} v_t \\ v_\ell \end{bmatrix}$; $i_b = \begin{bmatrix} i_t \\ i_\ell \end{bmatrix}$

b = branch, # of branches
t = tree, # of tree branches
ℓ = links, # of links
$b = 6$, $t = 3$, $\ell = 3$. $b = t + \ell$
n = # of nodes = $t + 1$

$0 = C i_b = [1_t \mid K] \begin{bmatrix} i_t \\ i_\ell \end{bmatrix}$

transpose

$i_t = -K i_\ell$ $\qquad 0 = J v_b = [-K^T \mid 1_\ell] \begin{bmatrix} v_t \\ v_\ell \end{bmatrix}$

$v_\ell = K^T v_t$

$v_b = \begin{bmatrix} v_t \\ v_\ell \end{bmatrix} = \begin{bmatrix} 1_t \\ K^T \end{bmatrix} v_t$, $i_b = \begin{bmatrix} -K \\ \hline 1_\ell \end{bmatrix} i_\ell$

or $v_b = \mathcal{C}^T v_t$, $i_b = \mathcal{J}^T i_\ell$; $A v_{\cancel{b}} = B i_{\cancel{b}}$, $K(v_5) = v_6$

or $A\mathcal{C}^T v_t = B\mathcal{J}^T i_\ell$ + input terms $= -BJ$ $i = i_b - J$; J = input current $= [-i_s, 0 \ldots 0]^T$