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SOME CONCLUSIONS ABOUT FILTERS IN NUCLEAR PULSE AMPLIFIERS

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The most usual circuits employed as filters in nuclear pulse amplifiers are analyzed in different situations.

1. Introduction

It is known that for valves as well as for transistors, the noise can be represented as produced by two resistors placed at the input of the amplifier, as indicated in fig. 1.

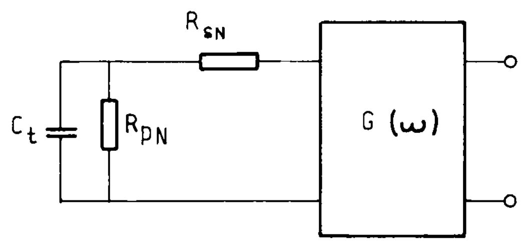

Fig. 1. Equivalent noise circuit.

R_{sn} depends fundamentally, on the input element of the amplifier; instead R_{pn} depends also on the detector[1]).

In accordance with this representation of the noise, the total noise power-spectral density at the input, can be represented by the expression :

$$\overline{\rho_{nT}^2} = 2\,(kT/\pi)\,[R_{sn} + 1/(\omega^2\, C_t^2\, R_{pn})]\,.$$

Supposing that $G(\omega)$ is the filter characteristic as a function of frequency, the total mean square noise voltage at the output will be :

$$\overline{V_{snT}^2} = 2\,(kT/\pi) \int_0^\infty [R_{sn} + 1/(\omega^2\, C_t^2\, R_{pn})]\,|G(\omega)|^2\, d\omega.$$

If H is the maximum value of the unit step response of the filter, the peak amplitude at the output produced by a charge Q_{in} will be:

$$V_{0\,max} = (Q_{in}/C_t)\, H.$$

It is understood that the effective noise charge is that charge which produces a peak voltage amplitude equal to the rms value of the noise:

$$Q_{eff} = (C_t/H)\,(\overline{V_{snT}^2})^{\frac{1}{2}}\,.$$

This effective noise charge indicates the quality of the circuit and therefore our interest in minimizing it. The reduction of Q_{eff} may be obtained by means of the filter transfer function, $G(\omega)$ and step function response (H).

The most usual circuits employed as filters are:

1. Simple integration and differentiation.
2. Double integration and simple differentiation.
3. Simple delay line shaping and simple integration.

In this paper it is proposed to analyze the results obtained with these circuits in different situations and to make evident their various advantages and disadvantages.

2. Simple integration and differentiation

It is known that the best conditions are obtained when the integration and differentiation time constants are equal[2]). If τ is the time constant we have the following expression for the effective charge:

$$Q_{eff} = e\,(\tfrac{1}{2}\, kT/\pi)^{\frac{1}{2}}\,(R_{sn}\, C_t^2/\tau + \tau/R_{pn})^{\frac{1}{2}}\,.$$

If τ_{op} is the time constant that makes minimum the effective charge, we may write:

$$\tau_{op} = C_t\, R_{pn}\,(R_{sn}/R_{pn})^{\frac{1}{2}}\,. \qquad (1)$$

For the minimum effective charge, we have the relation:

$$Q_{eff\,min} = e\,(kT\,C_t)^{\frac{1}{2}}\,(R_{sn}/R_{pn})^{\frac{1}{4}}\,. \qquad (2)$$

If t_p, resolution time, is the time taken by the response to decay down to P percentage of its maximum response and $k = t_p/\tau$ we have[3]) :

$$100\, k/P = e^{k-1}.$$

Curve (a) of fig. 2 shows k vs P.

Another expression of interest is the one of Q_{eff} when $\tau < \tau_{op}$ (a condition that may result when for reasons of resolution it is impossible to work with τ_{op}), in this case:

$$Q_{eff} \simeq e\, C_t\,(\tfrac{1}{2}\, kT)^{\frac{1}{2}}\,(R_{sn}/\tau)^{\frac{1}{2}}\,. \qquad (3)$$

The expressions of interest for comparison with the other cases are: (1), (2) and (3), and therefore we may write them in the following form:

$$\tau_{op} = K_1\, C_t\, R_{pn}, \tag{1a}$$

$$Q_{eff\,min} = K_2 \sqrt{C_t}, \tag{2a}$$

$$Q_{eff} \simeq K_3\, C_t\, (R_{sn})^{\frac{1}{4}}, \tag{3a}$$

where

$K_1 = (R_{sn}/R_{pn})^{\frac{1}{2}}$; $K_2 = e\,(kT)^{\frac{1}{2}}\,(R_{sn}/R_{pn})^{\frac{1}{4}}$;

$K_3 = e\,(\frac{1}{2}\,kT/\tau)^{\frac{1}{2}}$.

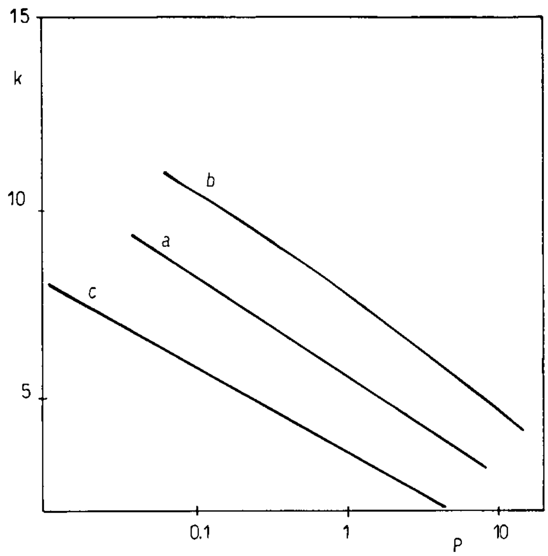

Fig. 2. Percentage of maximum response vs k.
a. Simple integration and differentiation.
b. Double integration and simple differentiation.
c. Simple delay line shaping and simple integration.

3. Double integration and simple differentiation

It is known that the optimum conditions are obtained when the two integration time constants are equal and when the relation between the differentiation constant and the integration one is equal[4]) to 1.06. As the difference is negligible the time constants may be taken as equal. Then we have:

$$\tau_{op} = \tfrac{1}{3}\, K_1\, C_t\, R_{pn} \sqrt{3}, \tag{1b}$$

$$Q_{eff\,min} = \tfrac{1}{4}\, e\,(3)^{\frac{1}{4}}\, K_2 \sqrt{C_t}, \tag{2b}$$

$$Q_{eff} \simeq \tfrac{1}{4}\, e\, K_3\, C_t\, (R_{sn})^{\frac{1}{4}}. \tag{3b}$$

The resolution time defined as before is determined by the relation

$$\tfrac{1}{4}\,(100\,k^2/P) = e^{k-2}.$$

Curve (b) of fig. 2 shows k vs P.

4. Simple delay line shaping and simple integration

In this case the optimum condition[4]) is obtained when the relation between the delay and the integration constant is 1.036. As before it will be taken for the relation the value 1 and the equivalent equations are:

$$\tau_{op} = (e-1)^{\frac{1}{2}}\, K_1\, C_t\, R_{pn}, \tag{1c}$$

$$Q_{eff\,min} = [2\,(e-1)^{\frac{1}{4}}/\{(e-1)\,e^{\frac{1}{2}}\}]\, K_2 \sqrt{C_t}, \tag{2c}$$

$$Q_{eff} \simeq [2/\{e\,(e-1)\}^{\frac{1}{2}}]\, K_3\, C_t\, (R_{sn})^{\frac{1}{4}}. \tag{3c}$$

For this case the factor k is given by the expression[3])

$$k = \ln(100/P) + 1.$$

Curve (c) of fig. 2 gives k vs P.

TABLE 1

Summary of comparative values.

	$\frac{\tau_{op}}{K_1\, C_t\, R_{pn}}$	$\frac{Q_{eff\,min}}{K_2 \sqrt{C_t}}$	$\frac{Q_{eff}}{K_3\, C_t \sqrt{R_{sn}}}$	k for $P = 0.1$	$\frac{t_p}{K_1\, C_t\, R_{pn}}$ $P = 0.1, \tau = \tau_{op}$
Simple integration Simple differentiation	1	1	1	10.2	10.2
Double integration Simple differentiation	0.578	0.894	0.68	12.5	7.22
Simple delay line shaping Simple integration	1.31	0.81	0.928	7.8	10.2

5. Conclusions

With the help of eq. (1), (2) and (3) describing the three cases once normalized, table 1 can be built. In this same table the factor k for $P = 0.1$ and t_p for $P = 0.1$ and $\tau = \tau_{op}$ have also been represented.

It is observed from the table that the simple delay line shaping and integration is the one that gives the minimum $Q_{\text{eff min}}$.

With respect to $Q_{\text{eff min}}$ this delay line shaping method is 10% better than the double integration and simple differentiation. On the other hand the double integration and simple differentiation method is the one that behaves best with respect to the resolution time and the relation Q_{eff}/C_t. The improvement here is more pronounced.

As a conclusion it may be said that considering the small complication that one more integration represents, a double integration should always be used instead of a simple one and unless optimum resolution is of greater interest (conditions permitting) the double integration and simple differentiation should be preferred to the simple delay line and integration.

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