Amplificazione e formatura del segnale

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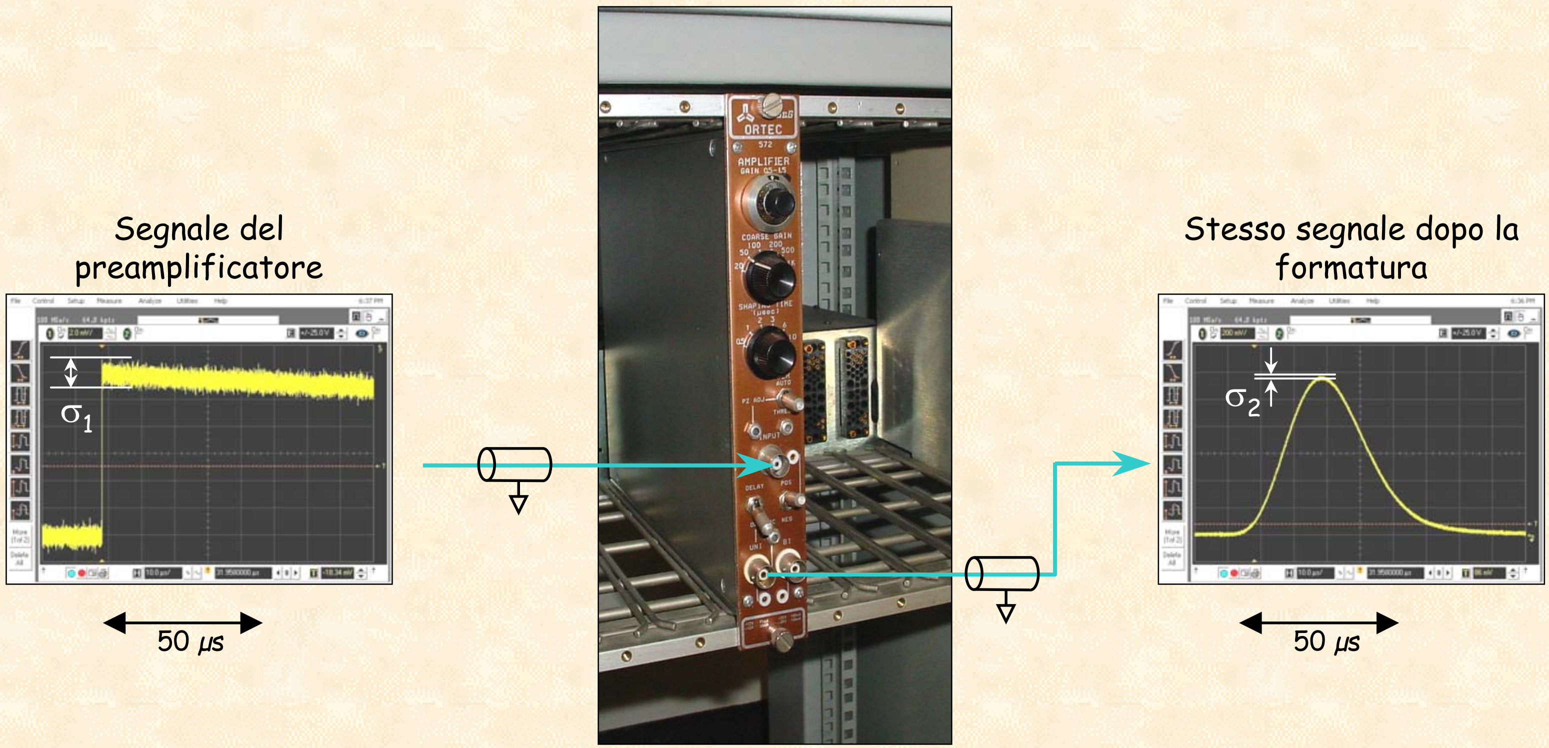
Perchè “formare” (o filtrare) il segnale ?

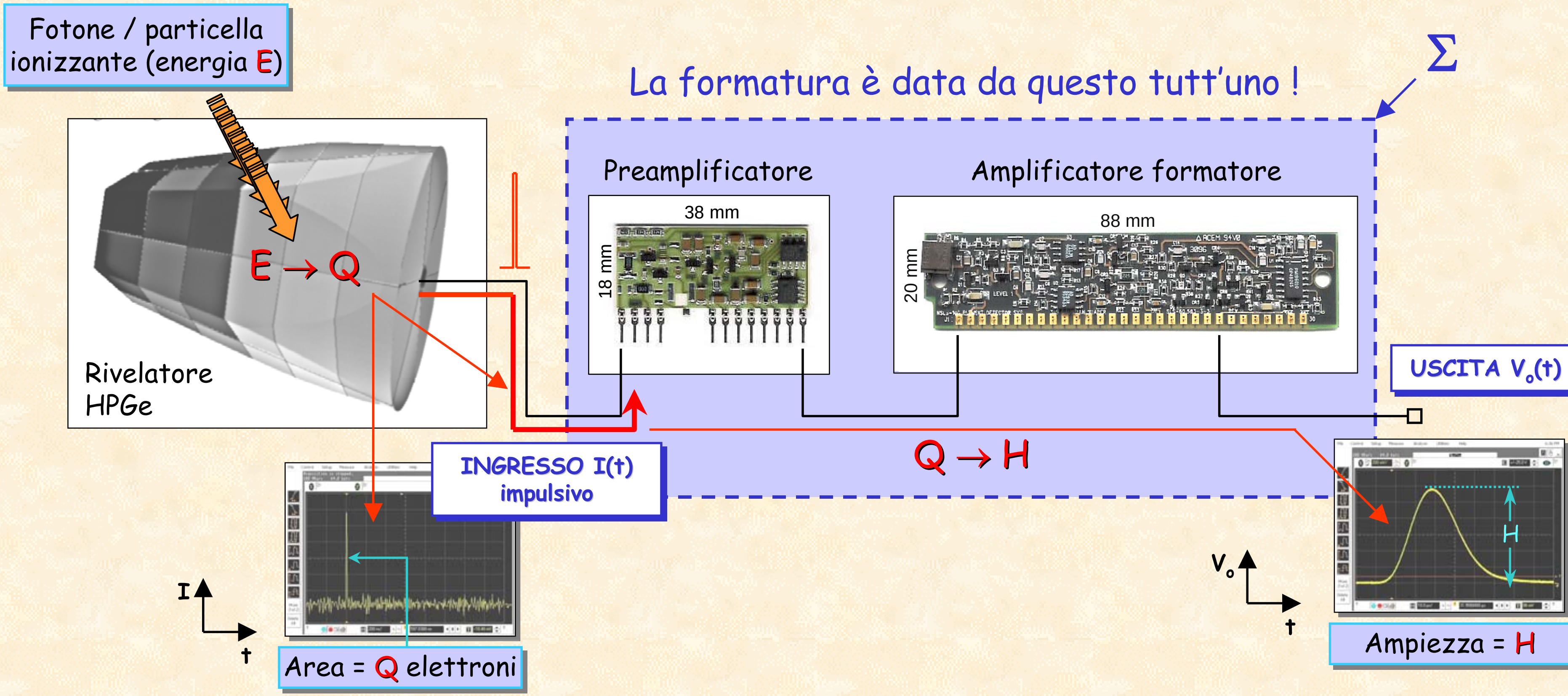


Amplificatore formatore analogico quasi Gaussiano (*spectroscopy amplifier* ORTEC mod. 572)

$\sigma_2 \ll \sigma_1$: la formatura abbatte il rumore elettronico !

L'amplificatore formatore modifica la forma del segnale del preamplificatore per ridurre il rumore elettronico.

Ingresso, uscita e ENC



Segnale:

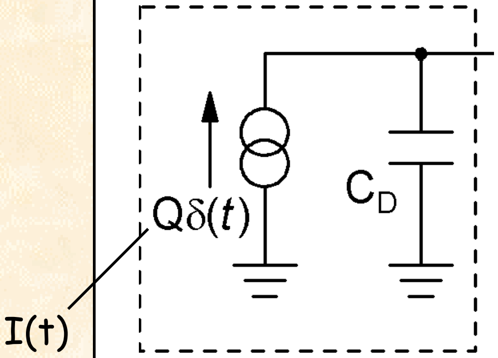
Dalla misura di H (a basso rumore) si ricavano a ritroso Q ed E.

Rumore:

Il rumore visto all'uscita dell'amplificatore formatore va anch'esso riferito all'ingresso dividendolo per il guadagno H/Q della catena elettronica Σ.

ENC = Equivalent Noise Charge (Rumore della misura di H espresso in carica rms all'ingresso)

Schematizzazione sistema

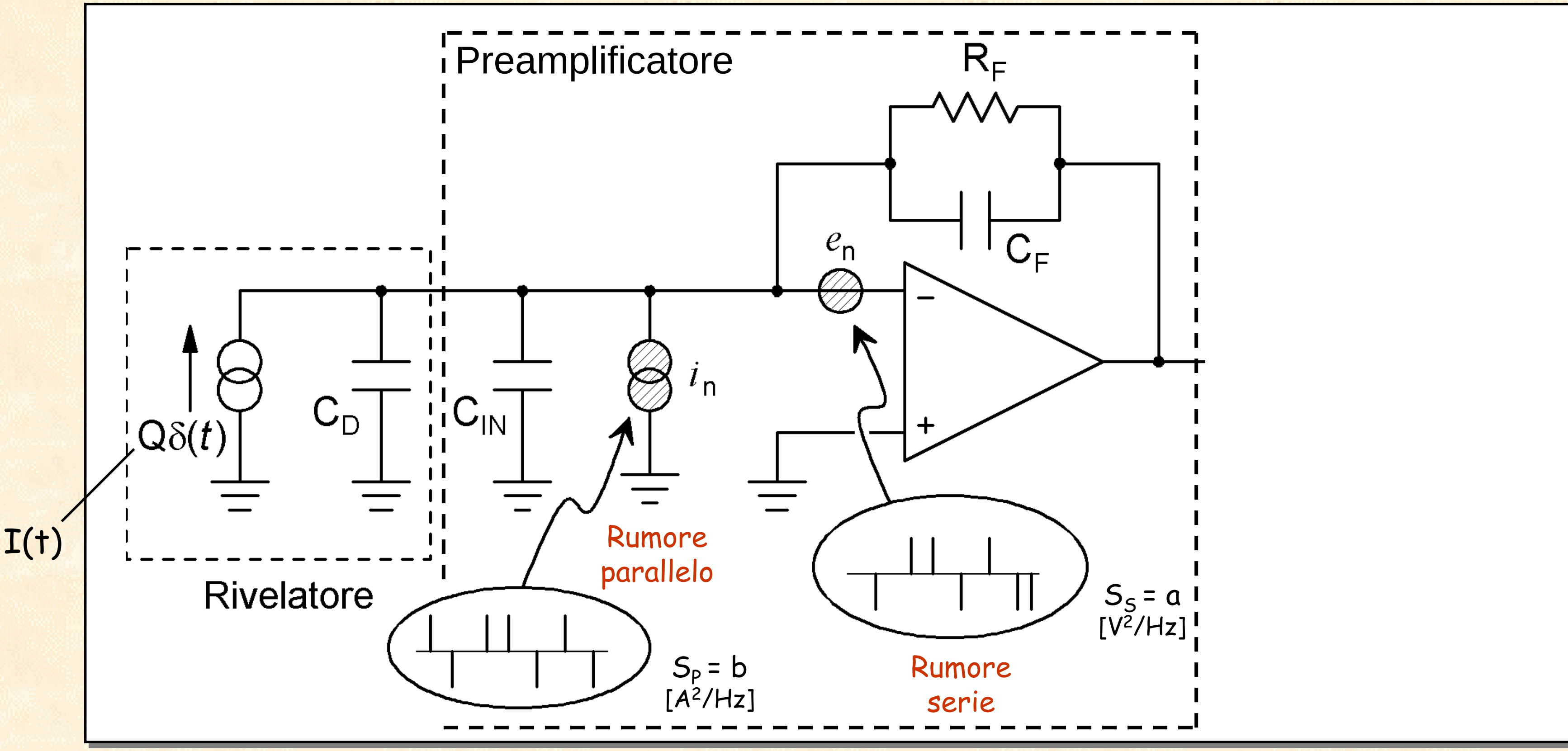


Rivelatore

(strip, pixel, fotodiodo,
a drift, a fili, HPGe, ...)

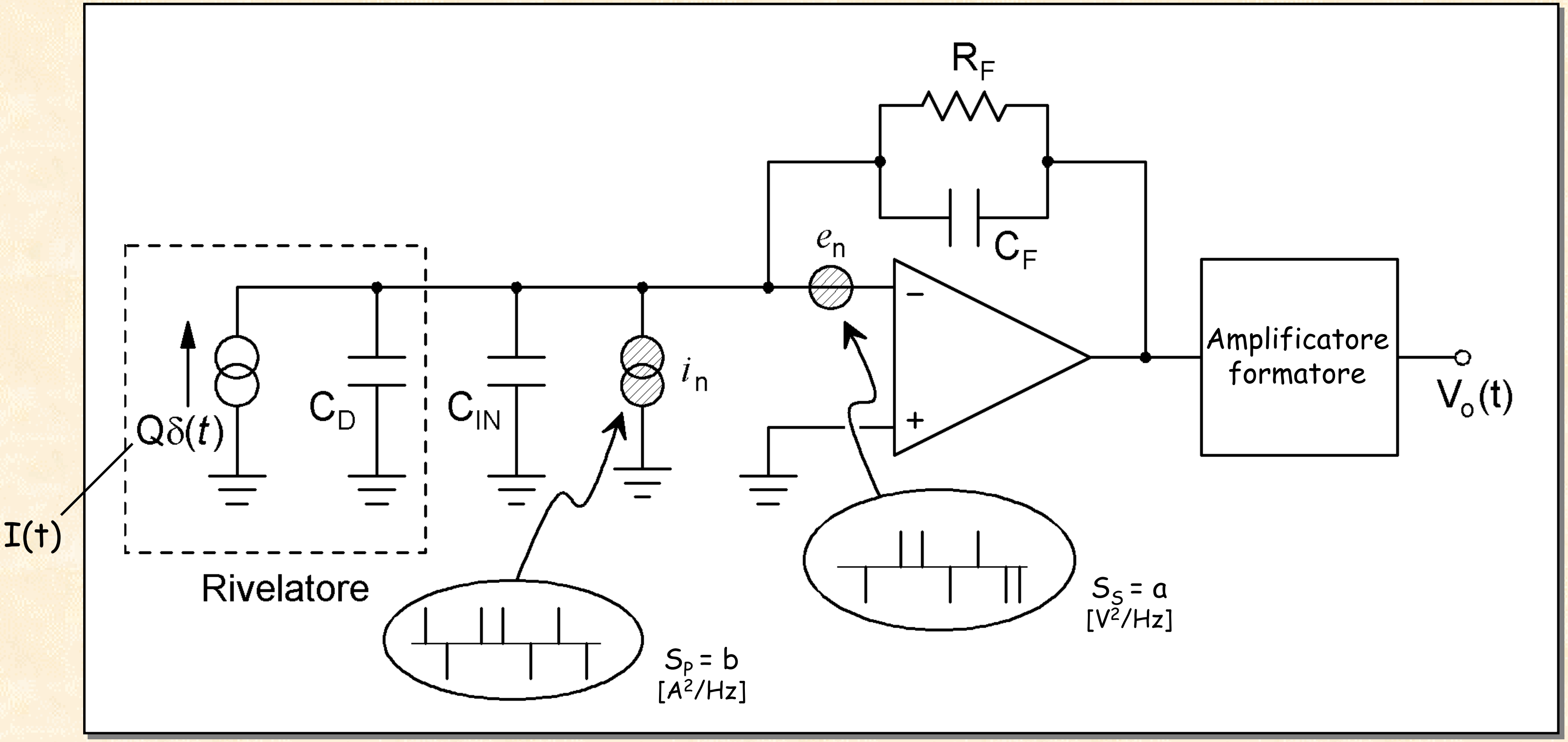
Rifs. Rad1, Pul1

Schematizzazione sistema



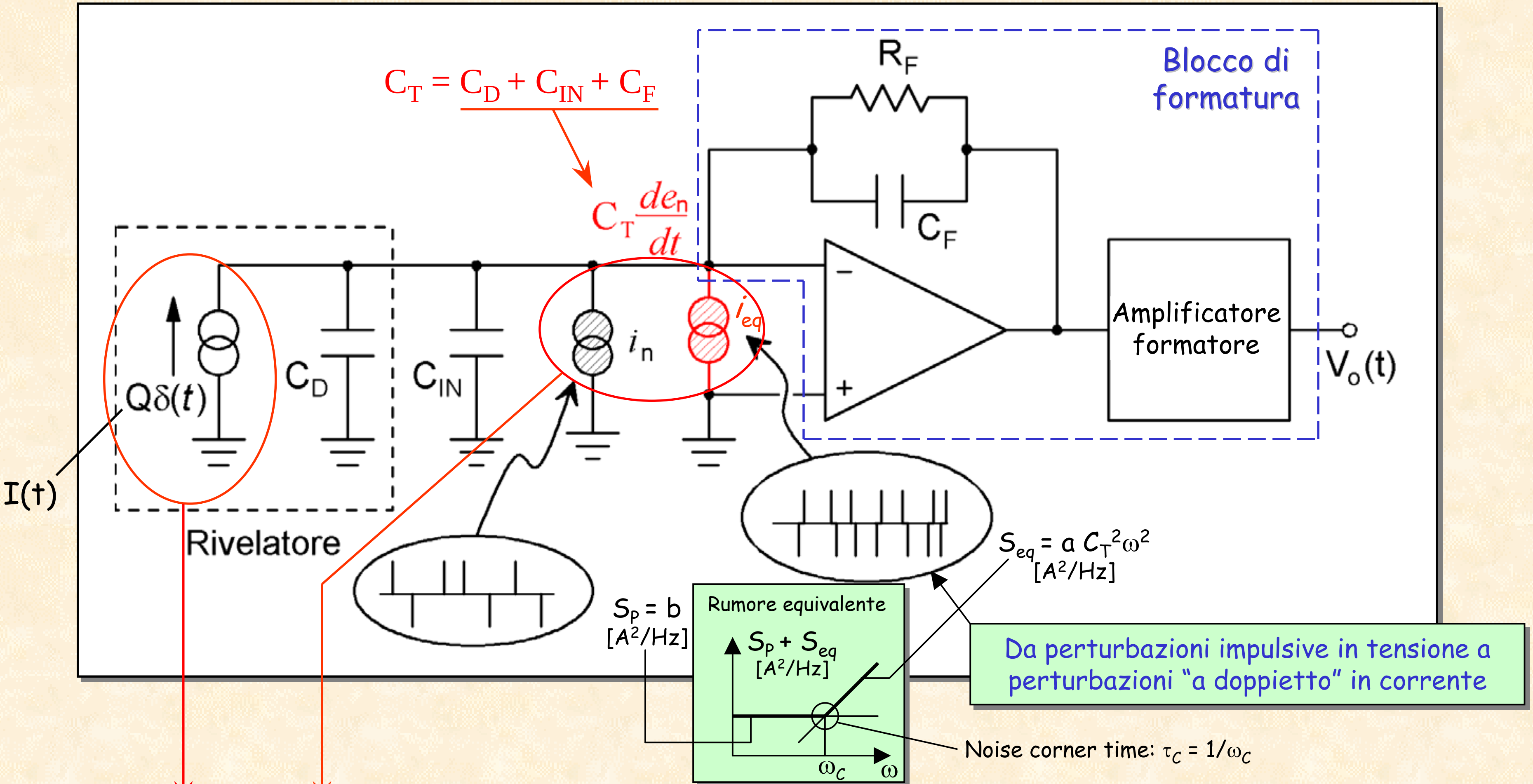
Rifs. Rad1, Pul1

Schematizzazione sistema



Rifs. Rad1, Pul1

Schematizzazione sistema



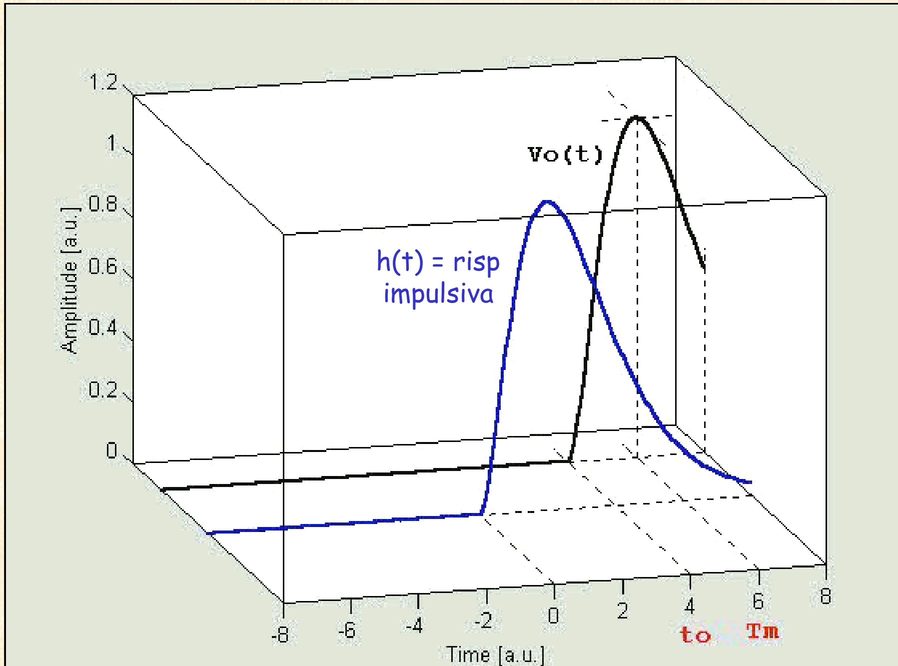
Segnale e rumore sono tutti ricondotti in termini di corrente di ingresso I(t)

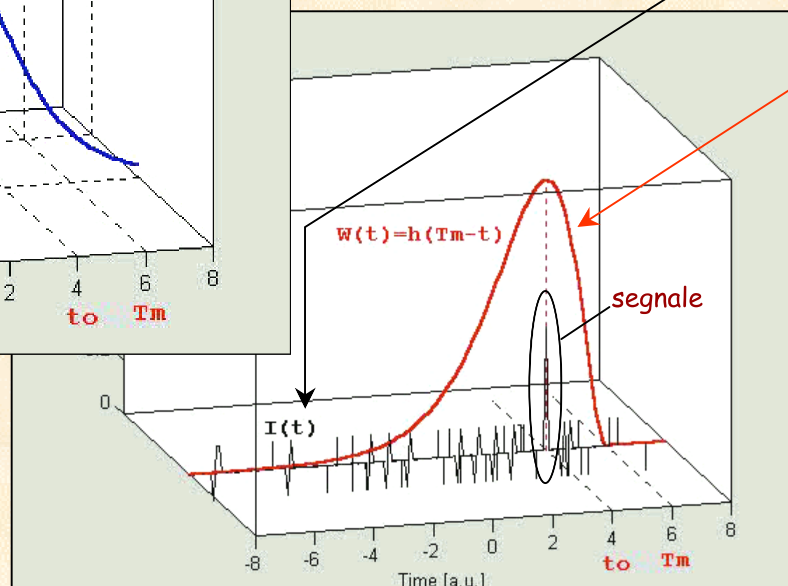
Rifs. Rad1, Pul1

Da I(t) a $V_o(t)$: funzione peso

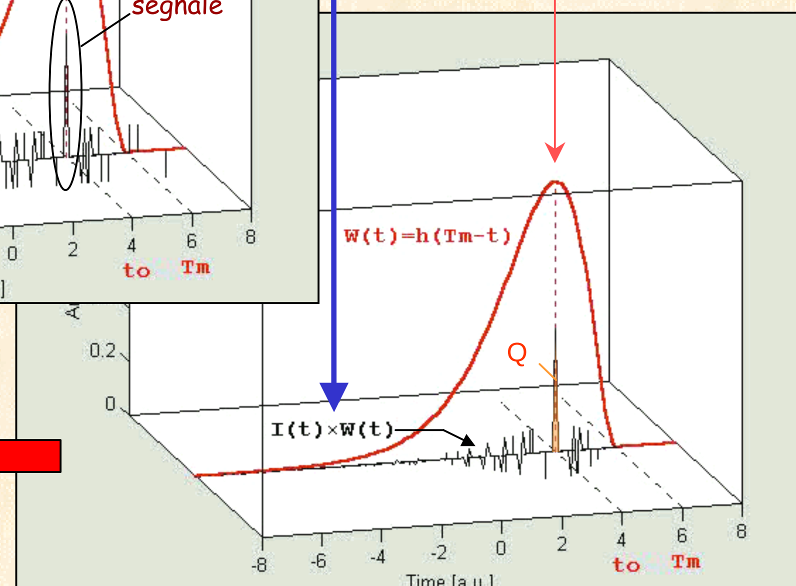
$$V_o(T_m) = \int_{-\infty}^{\infty} I(t)\, W(t)\, dt$$

$h(T_m - t)$ (teorema di convoluzione)



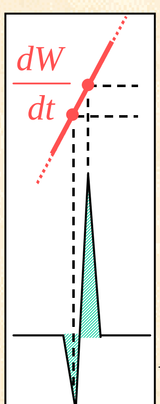


Normalizzando W ad 1 si ottiene la carica Q anziché la tensione $V_o(T_m)$



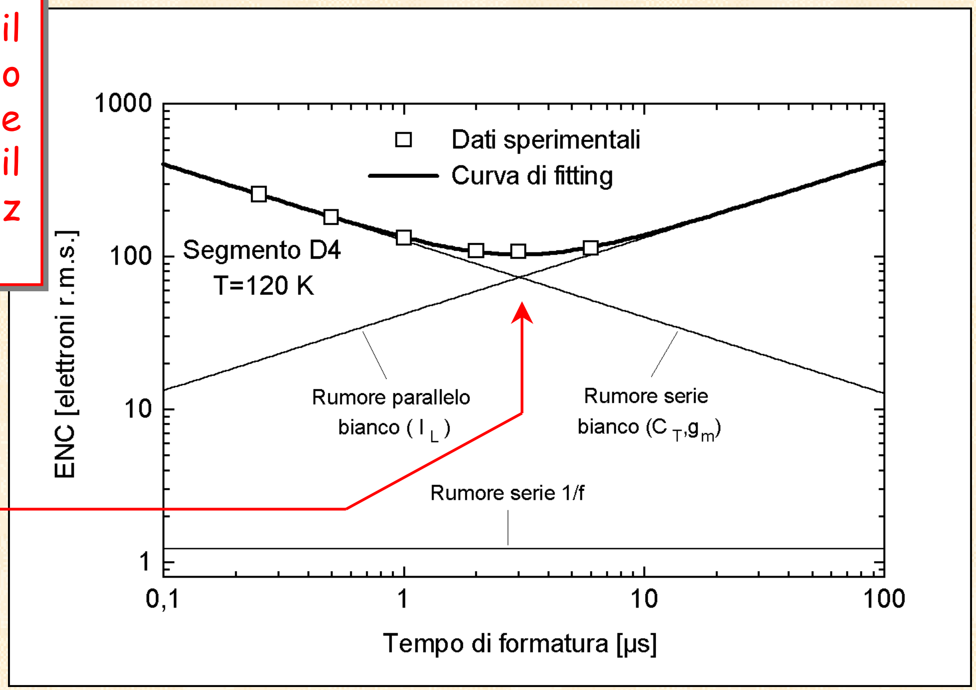
Per minimizzare il rumore a "delte" (parallelo bianco) → fz peso stretta

Per minimizzare il rumore a "doppietti" (serie bianco) → fz peso "morbida", larga



Tempo di formatura

Esiste un tempo di formatura ottimo dove il rumore è minimo. E' il giusto compromesso per il rumore a delte (fz peso stretta) e il rumore a doppietti (fz peso larga).



Per tempi di formatura crescenti $V_o(t)$ si allarga ma non cambia di forma

Formature sub-ottime

Rumore serie bianco

Rum 1/f

Rumore par bianco

$$ENC^2 = C_T\, a\,\frac{A_1}{\tau} + k A_2 + b A_3 \tau$$

$$\int_{-\infty}^{\infty}\left(\frac{dh}{dt}\right)^2 dt$$

$$\int_{-\infty}^{\infty} h(t)^2\, dt$$

$$\int_{-\infty}^{\infty}\left(\frac{d^{1/2}h}{dt^{1/2}}\right)^2 dt$$

Rif. Pul3

$$\tau_C = C\sqrt{\frac{a}{b}}$$

$$\tau_{opt} = \sqrt{\frac{A_1}{A_3}}\,\tau_C$$

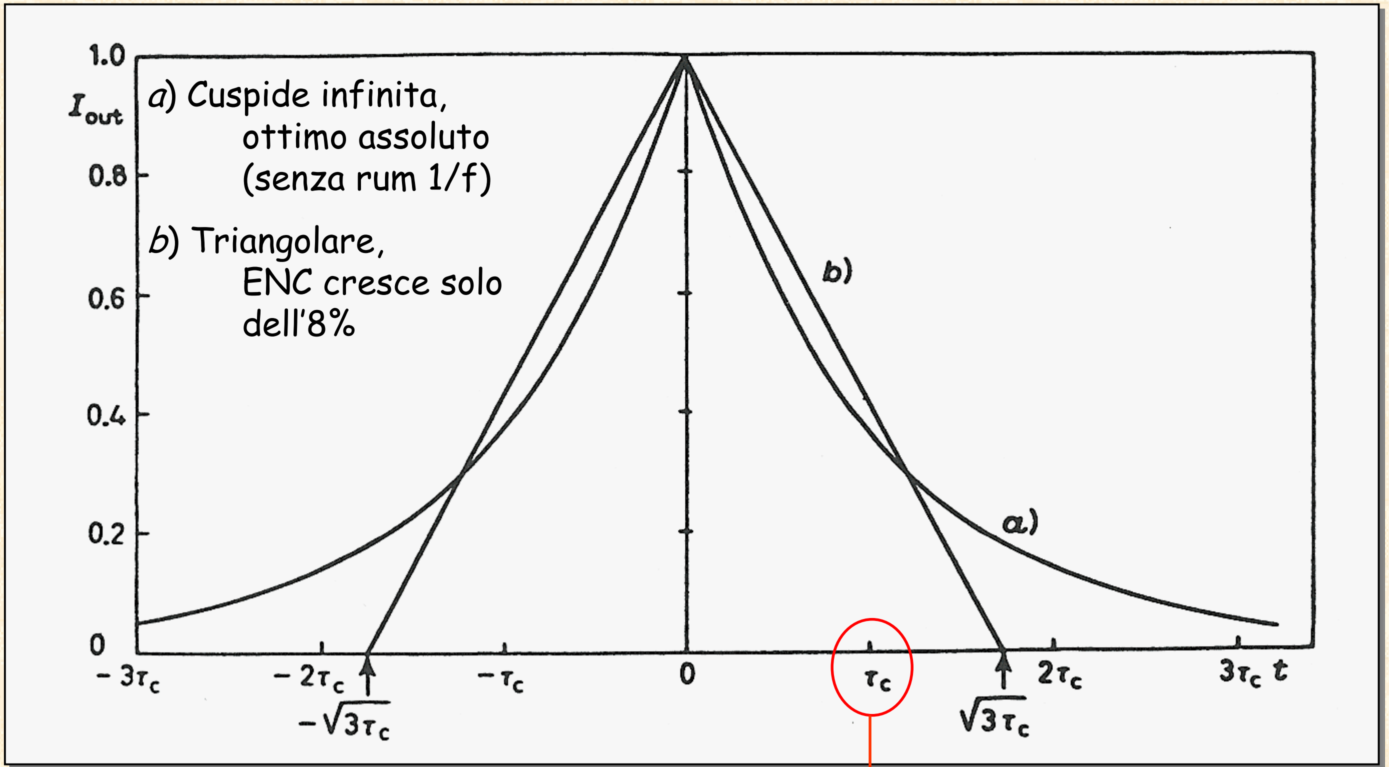
$$\frac{ENC^2_{opt}}{ENC^2_{\infty}} = \sqrt{A_1 A_3}$$

(senza rumore 1/f)

Rif. Man1

	Shaping	h (t) Function		A_2	$\sqrt{A_1A_3}$	$\frac{A_2}{\sqrt{A_1A_3}}$	A_1	A_3	$\sqrt{\frac{A_1}{A_3}}$
1	indefinite cusp	e^{t/τ_C} e^{-t/τ_C} O		0.64 $\left(\frac{2}{\pi}\right)$	1	0.64	1	1	1
2	truncated cusp	$k = \tau'/\tau$ −τ' −τ O τ τ'	k=1	0.77	1.04	0.74	2.16	0.51	2.06
			k=2	0.70	1.01	0.69	1.31	0.78	1.30
			k=3	0.67	1	0.67	1.10	0.91	1.10
3	triangular	O τ 2τ		0.88 $\left(\frac{4}{\pi}\ln 2\right)$	1.15 $\left(\frac{2}{\sqrt{3}}\right)$	0.76	2	0.67 $\left(\frac{2}{3}\right)$	1.73
4	trapezoidal	O τ 2τ 3τ		1.38	1.83	0.76	2	1.67	1.09
5	piecewise parabolic	O τ 2τ		1.15	1.43	0.80	2.67	0.77	1.86
6	sinusoidal lobe	O τ 2τ		1.22	1.57	0.78	2.47	1	1.57
7	RC-CR	O τ		1.18	1.85	0.64	1.85	1.85	1
8	semigaussian (n = 4)	O 4τ		1.04	1.35	0.77	0.51	3.58	0.38
9	gaussian	$e^{-1/2(t/\tau)^2}$ O		1	1.26	0.79	0.89	1.77	0.71
10	clipped approximate integrator	O 0.5τ		0.85	1.34	0.63	2.54	0.71	1.89
11	bipolar triangular	O τ 2τ		2	2.31	0.87	4	1.33	1.73

Funzione peso ottima "a cuspide"

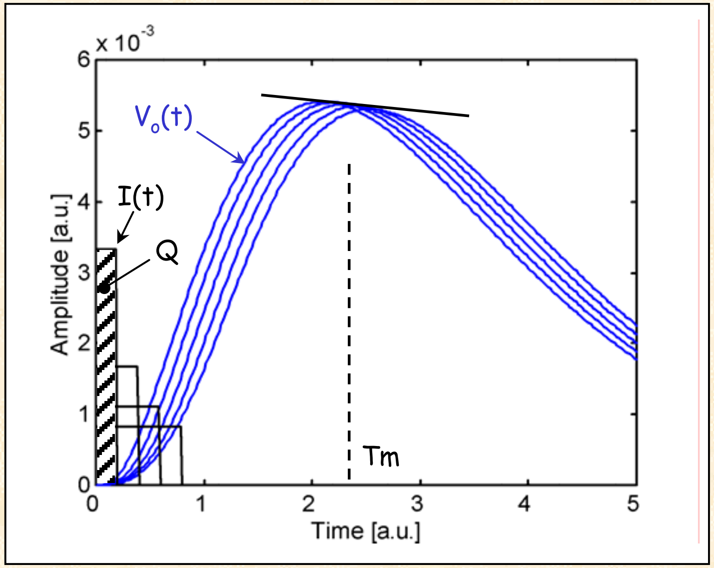


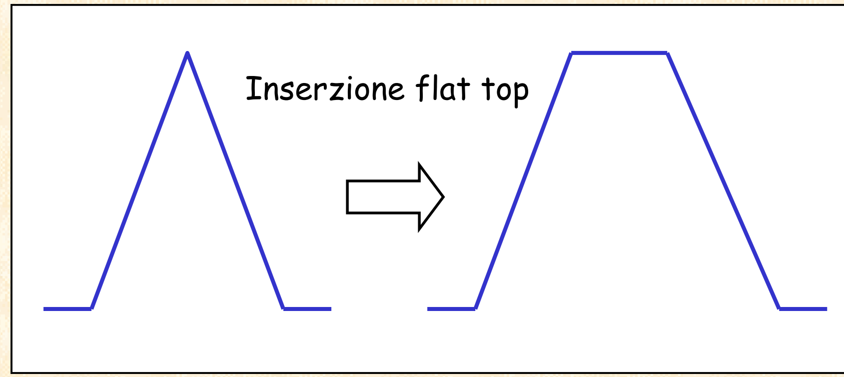
Rif. Rad2

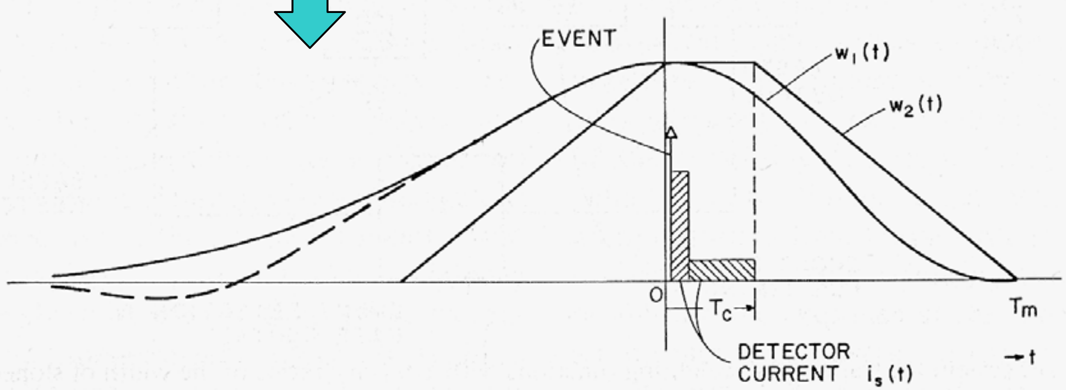
$$\tau_C = C\sqrt{\frac{a}{b}}$$

Per ridurre il *pileup*, cioè la sovrapposizione di più segnali si può utilizzare una fz peso tempo limitata (ad es. triangolare).

Deficit balistico / *flat top*



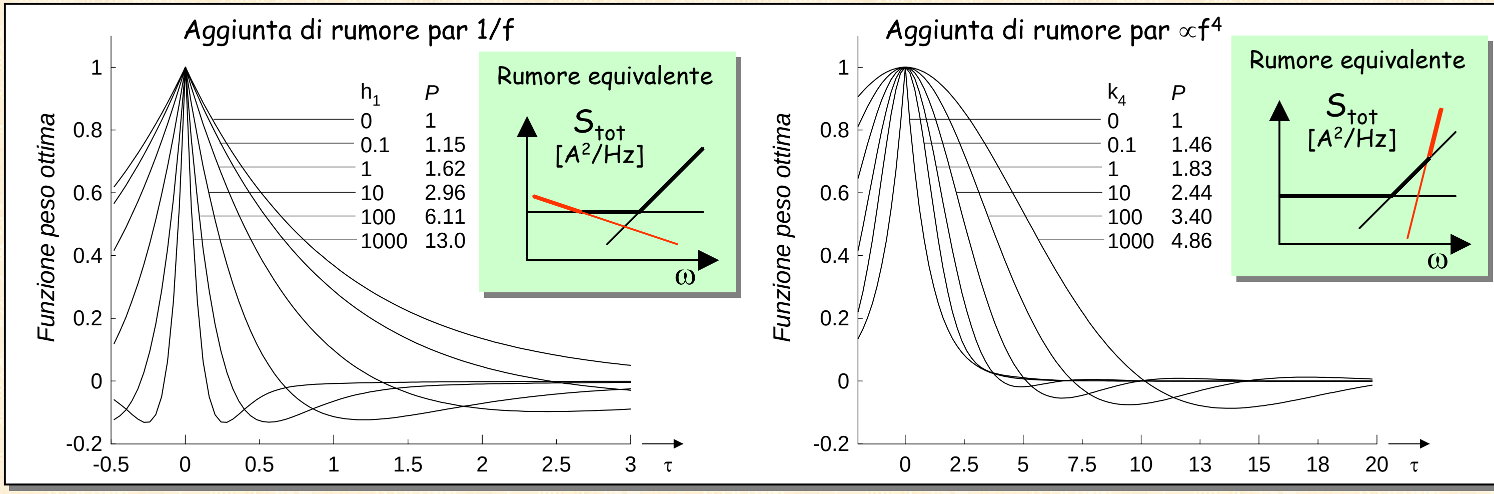




Rif. Rad3

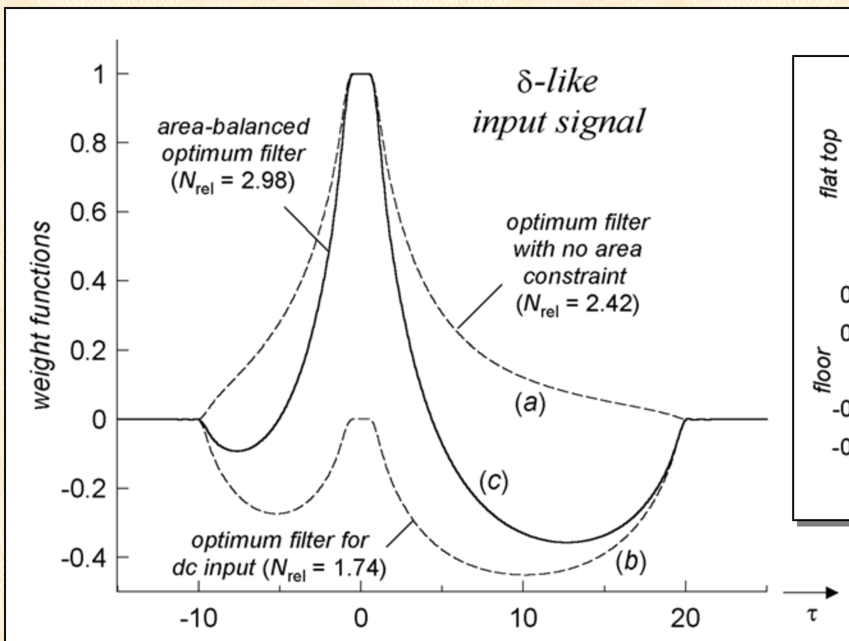
Formatura ottima (filtro) *matched* con vincoli

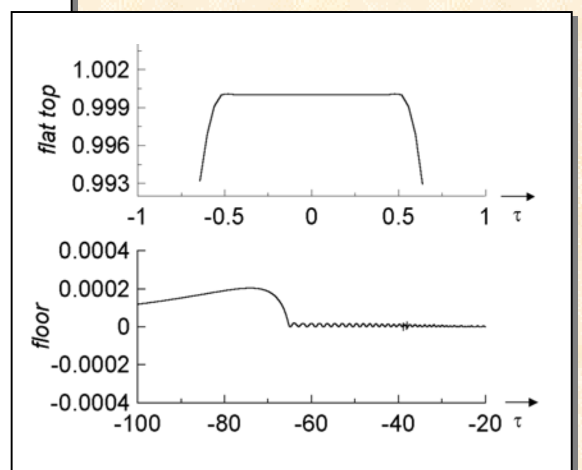
Forme ottime
senza vincoli per
diverse densità di
rumore



Inserzione di vincoli
(flat top, durata finita)
per sovrapposizione

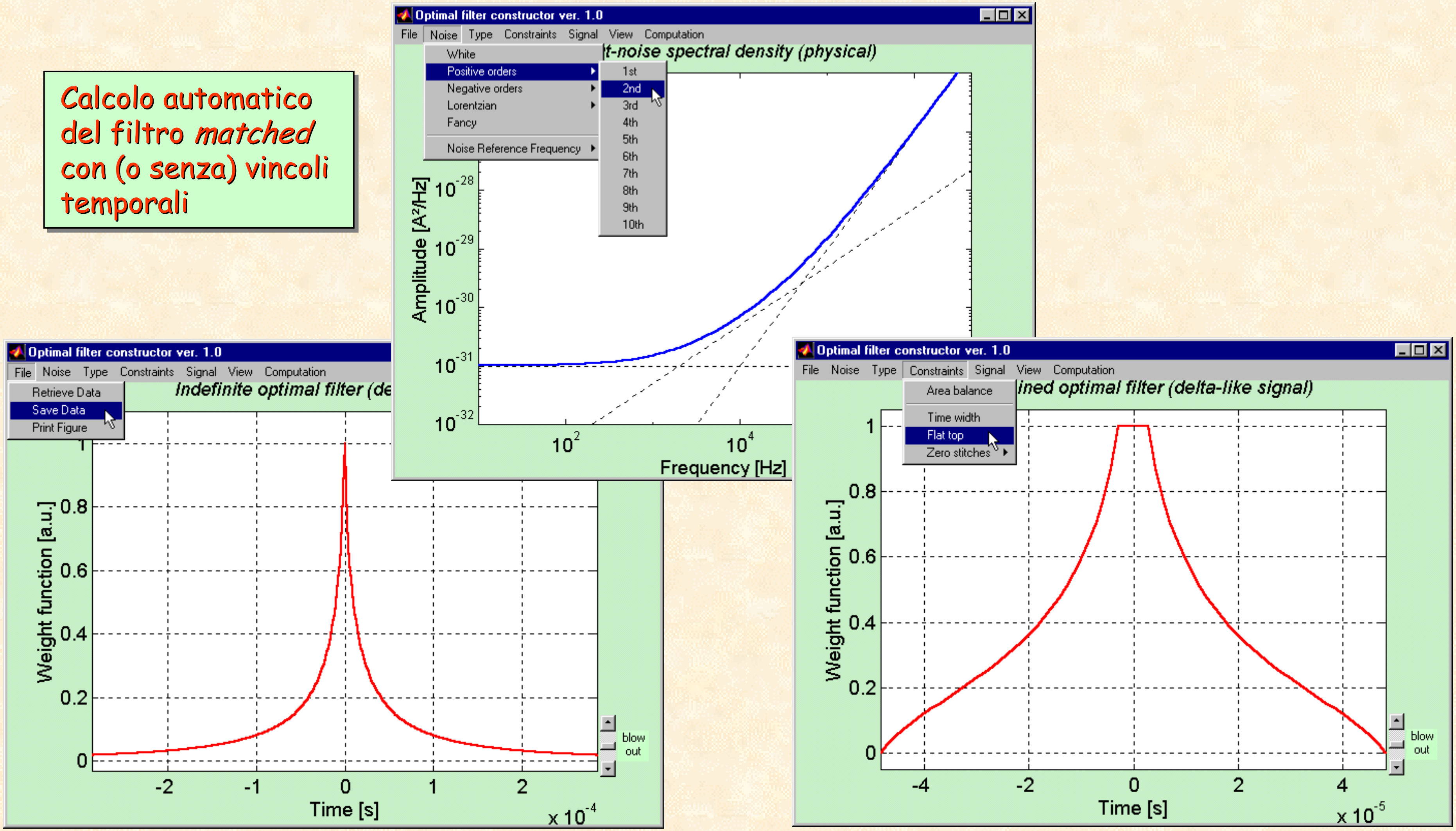
Rif. Pul2





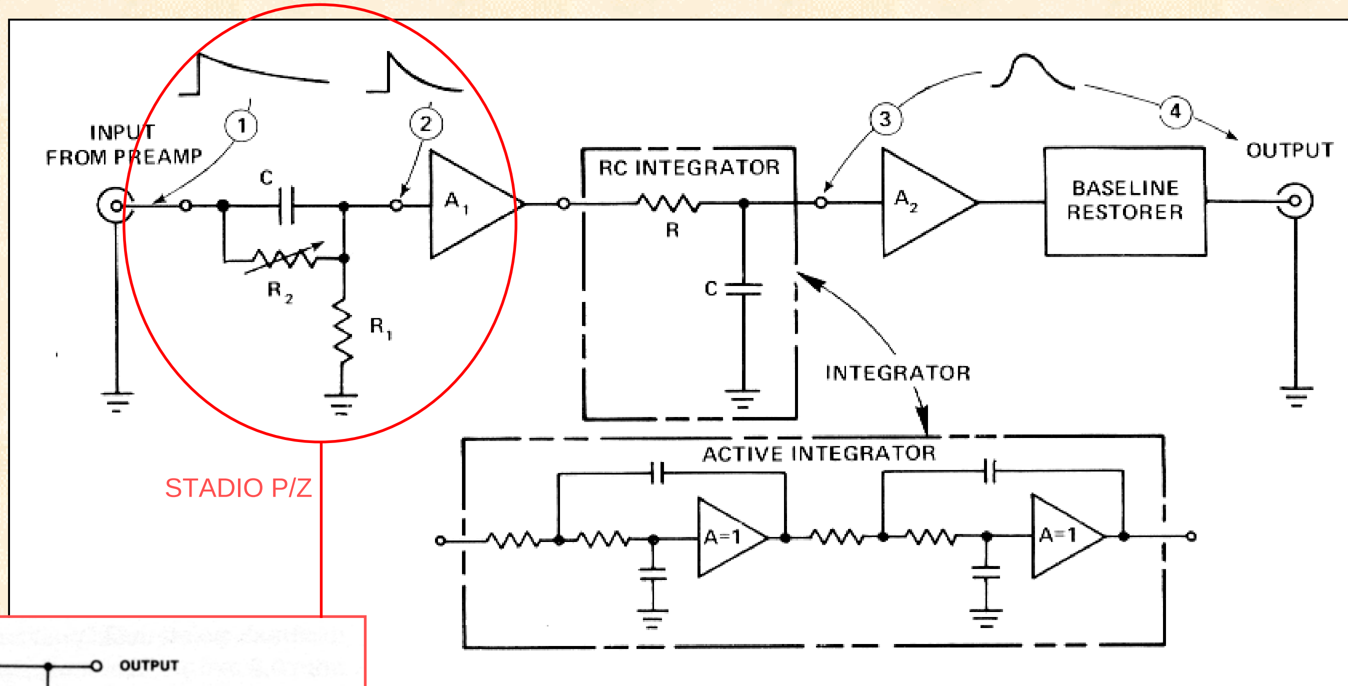
Software di calcolo filtro *matched* con vincoli

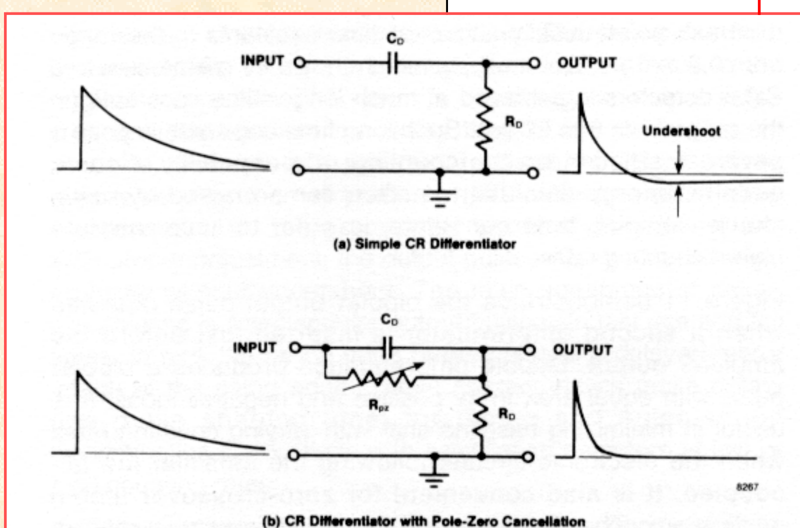
Calcolo automatico del filtro *matched* con (o senza) vincoli temporali



Formatori quasi-Gaussiani

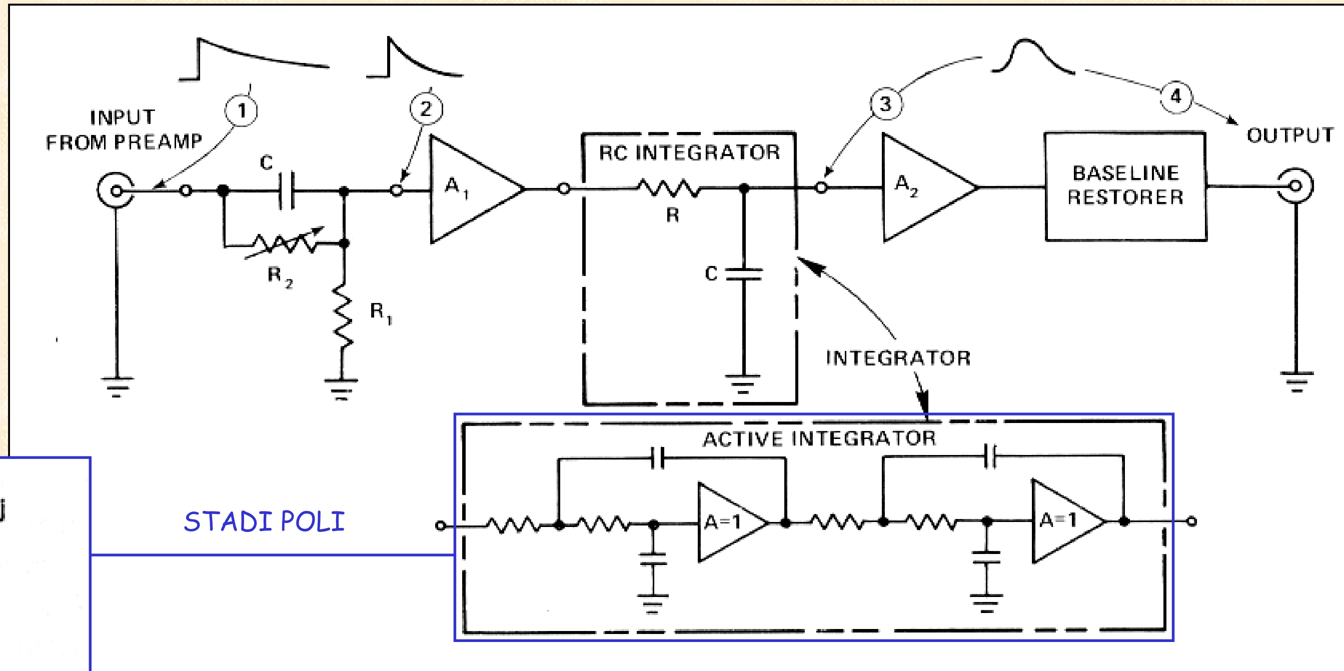
Rif. Ortec1

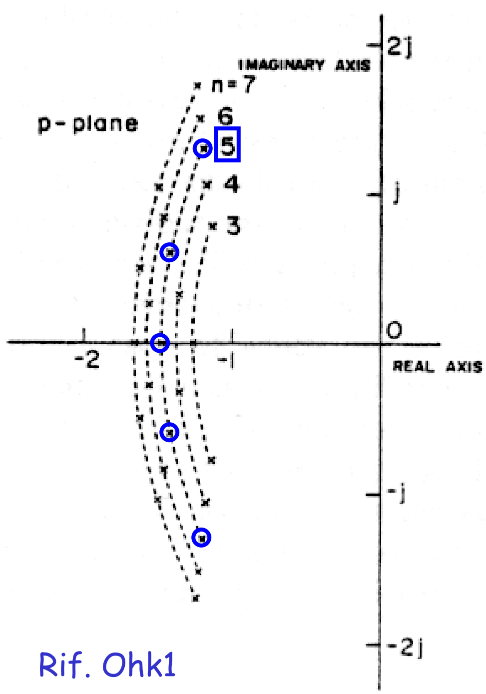




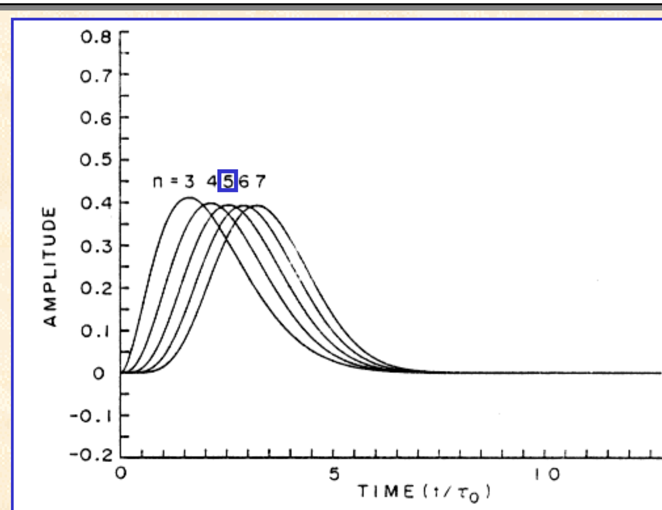
Formatori quasi-Gaussiani

Rif. Ortec1





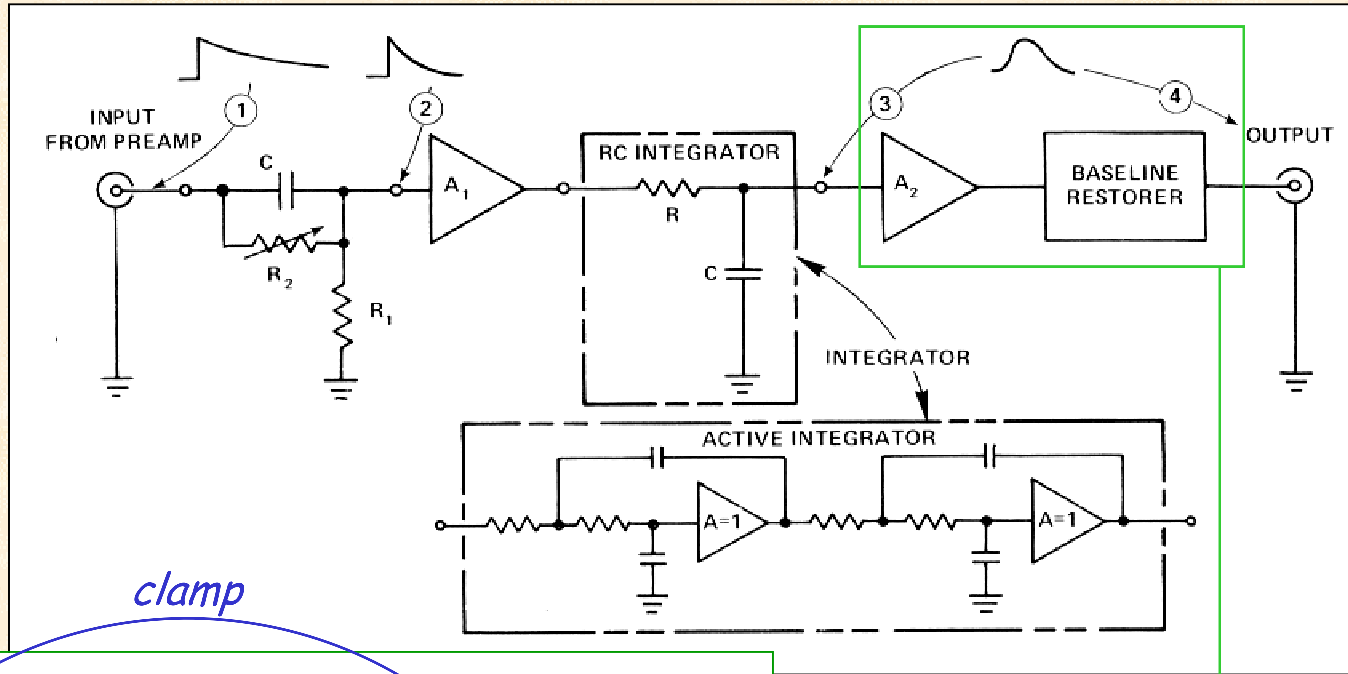
Rif. Ohk1

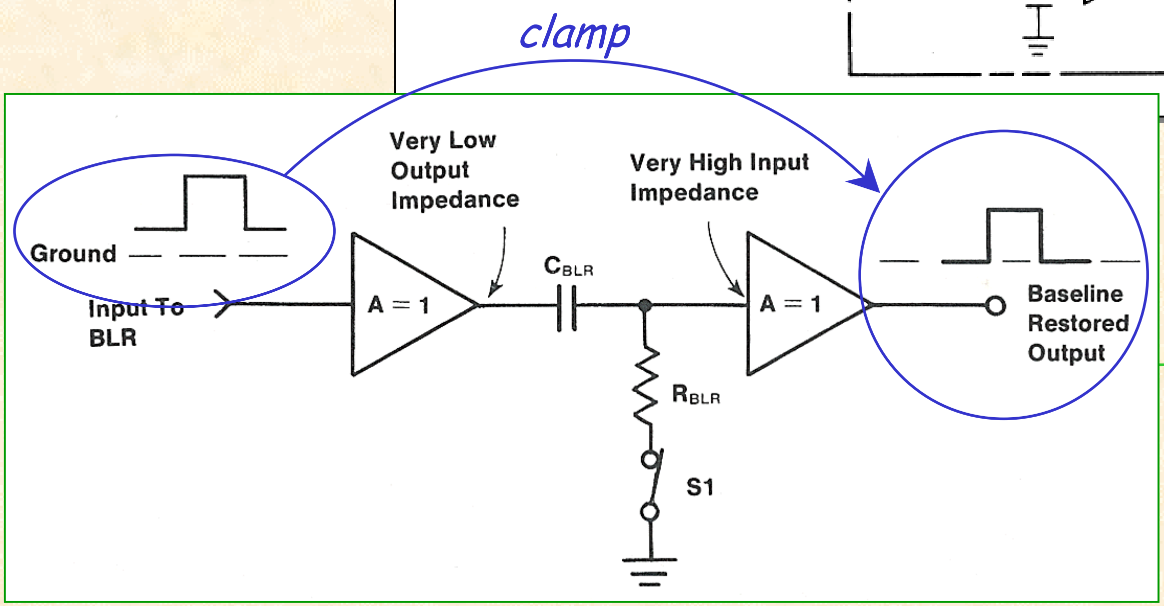


Sia il rumore che il deficit balistico migliorano all'aumentare del numero dei poli.

Formatori quasi-Gaussiani

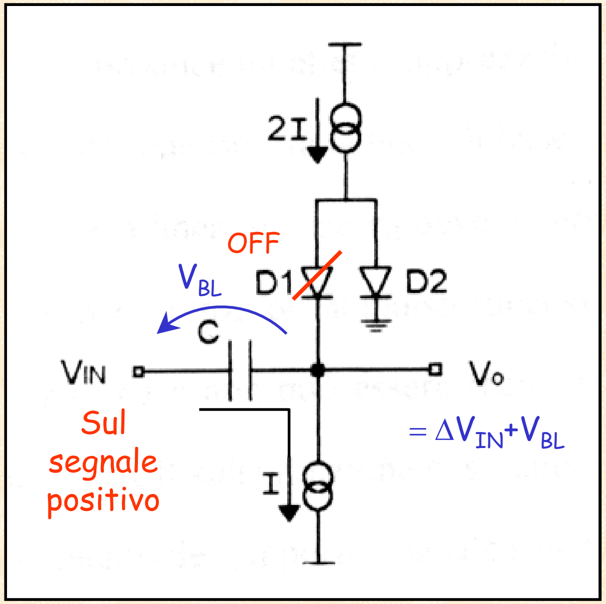
Rif. Ort1





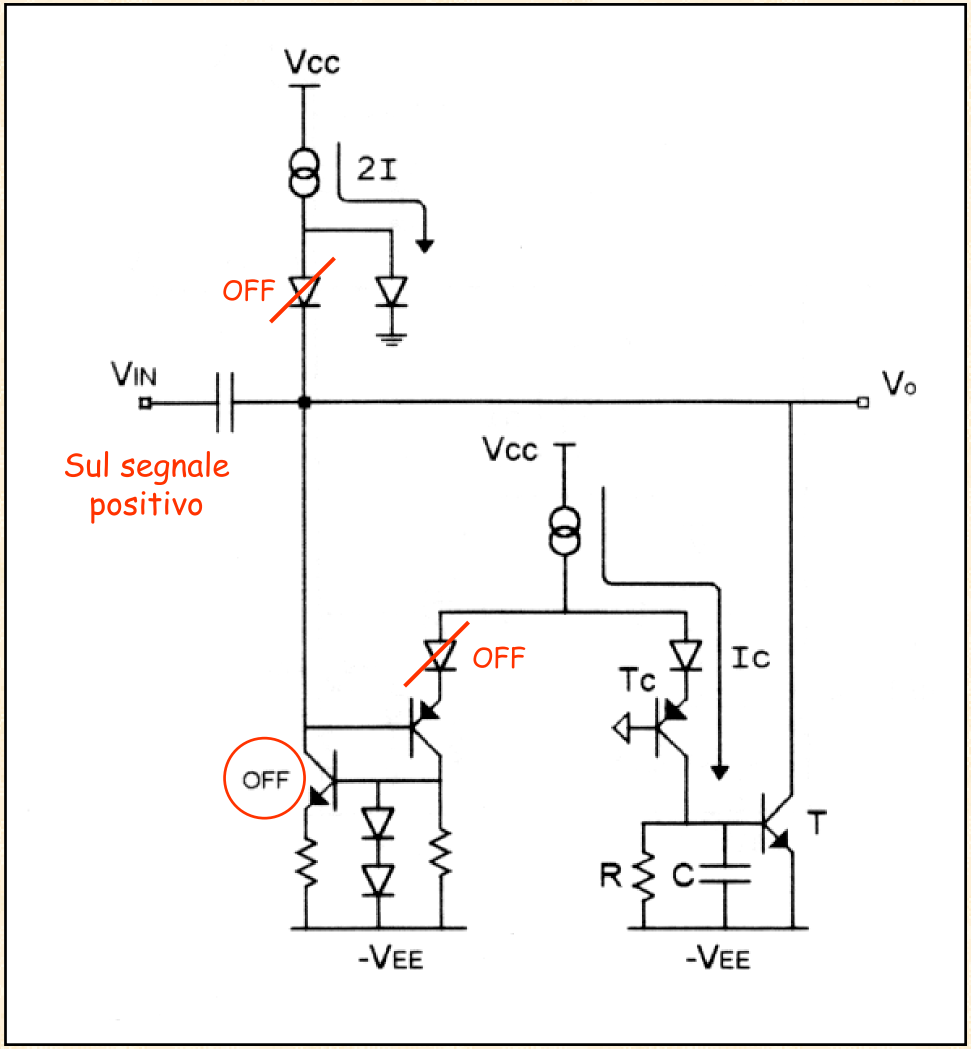
STADIO BLR

Baseline restorer, esempi



Baseline restorer di Robinson

Rif. Rob1

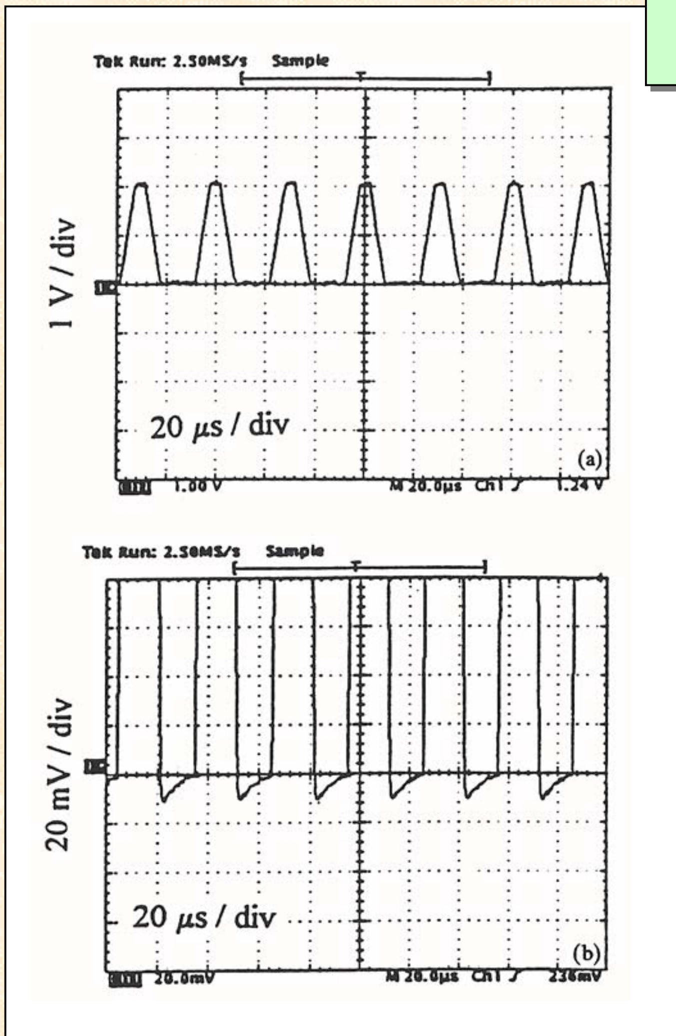


Switch-off baseline restorer

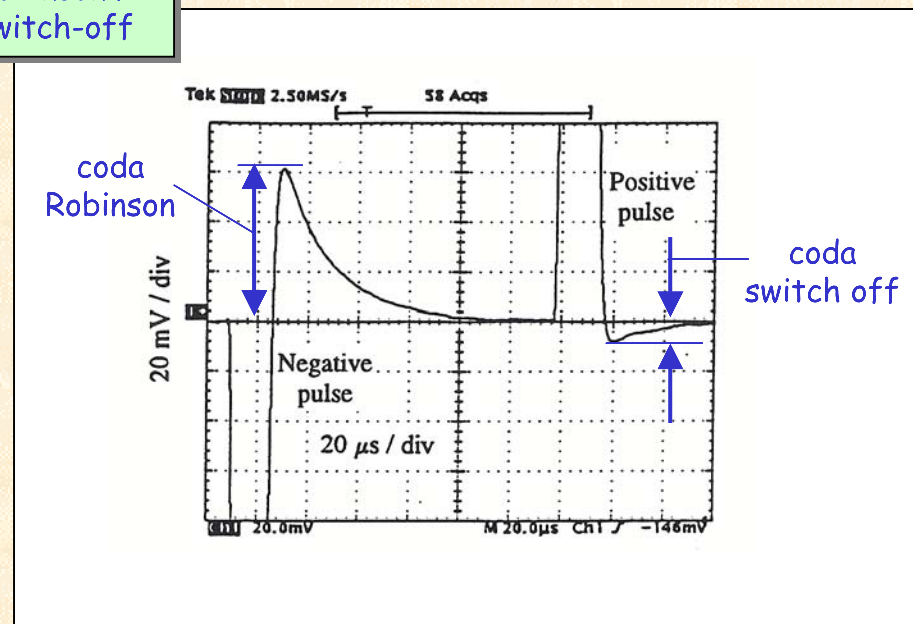
Rif. Pul4

Switch-off restorer, performance

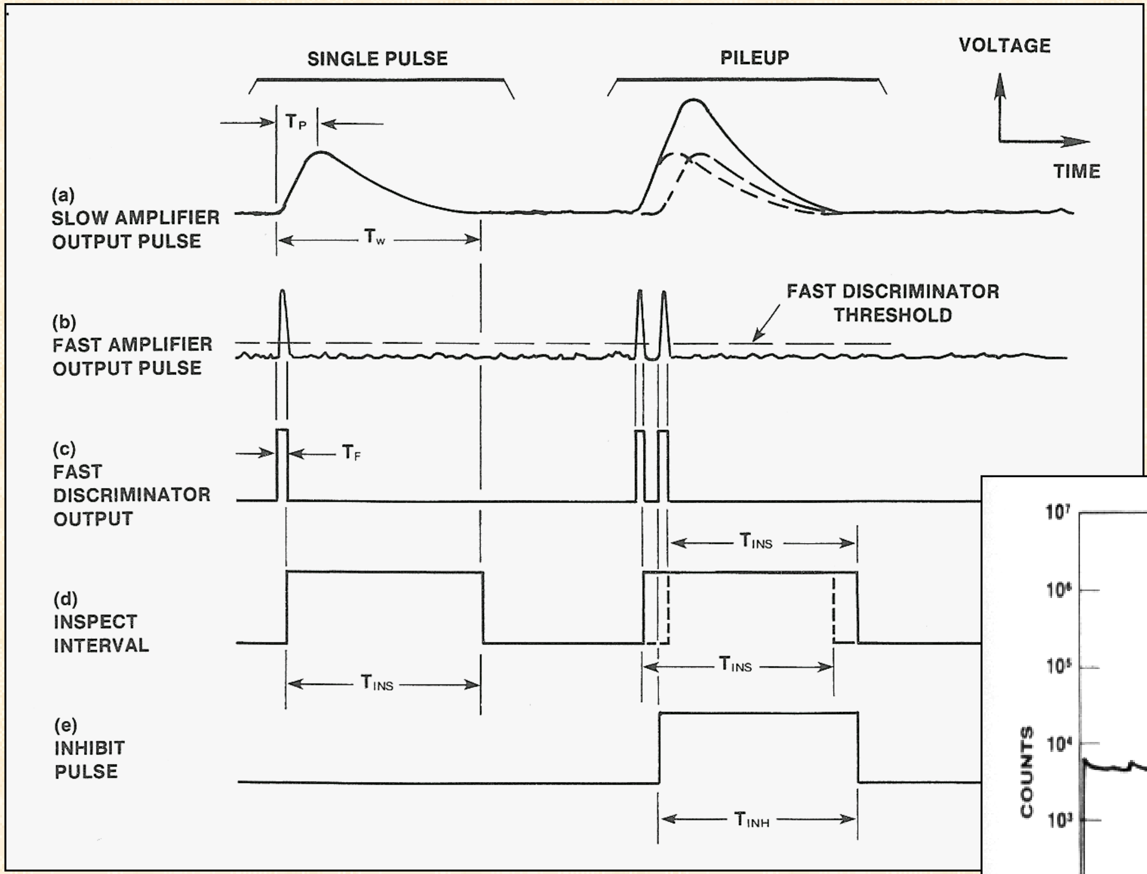
coda *switch off restorer* con densità = 60%

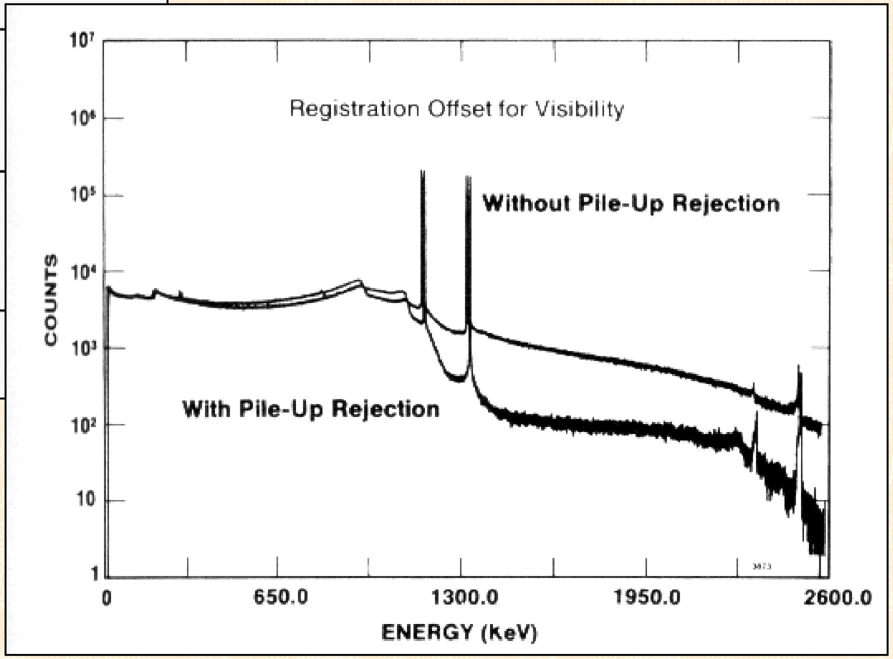


Confronto Robinson / switch-off



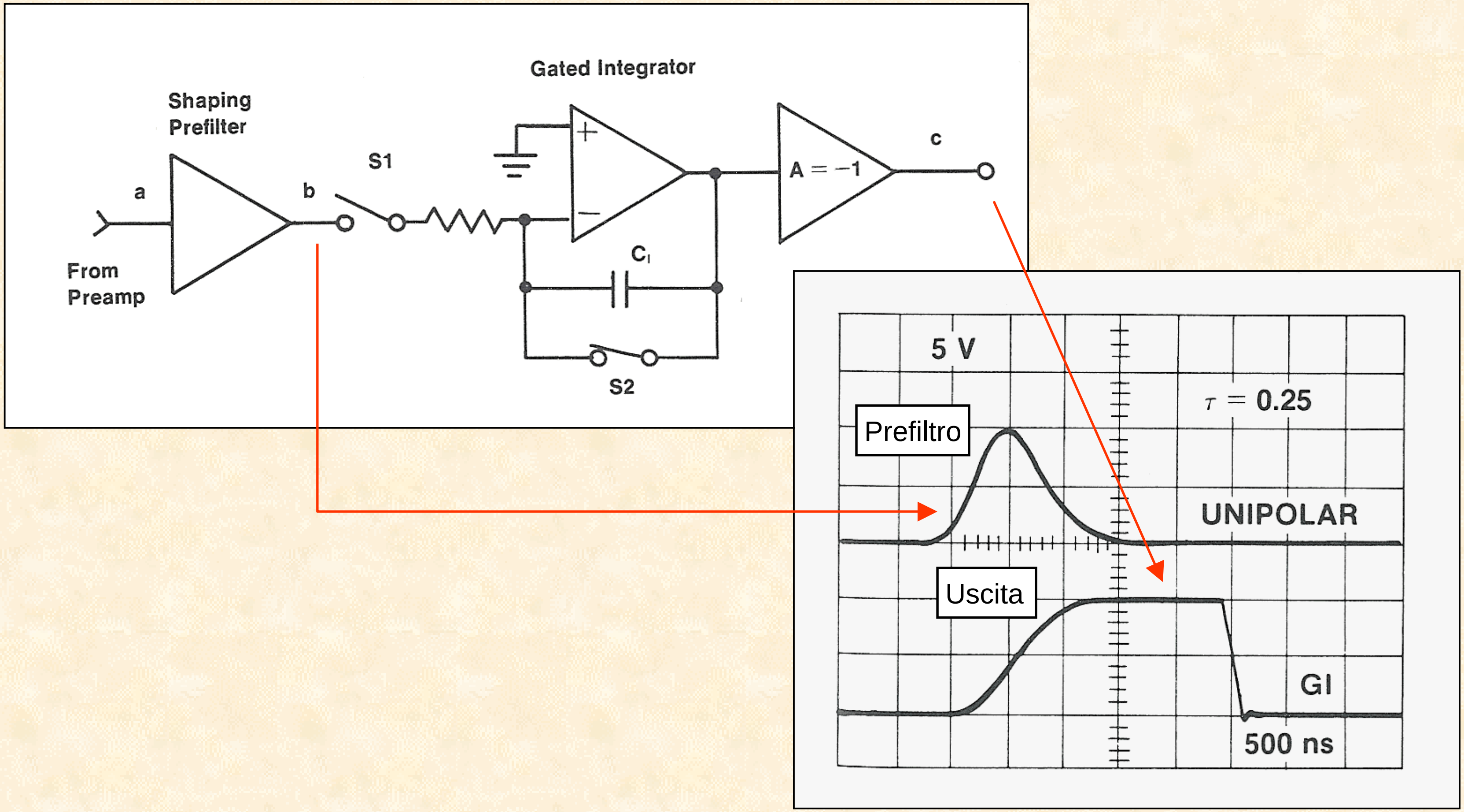
Pileup rejector





Formatori tempo-varianti

Filtro a *gated integrator*

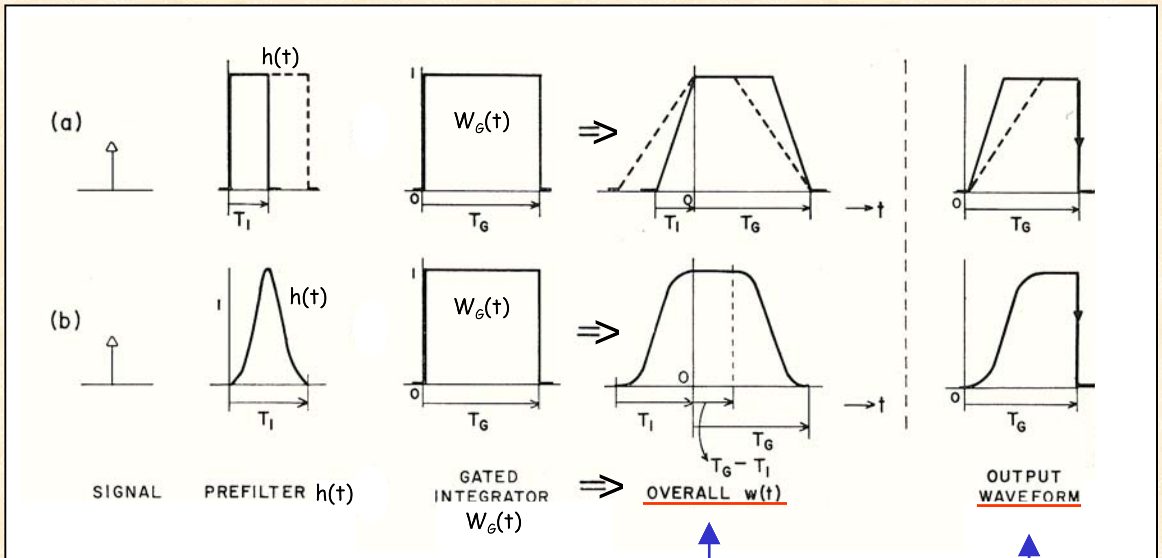


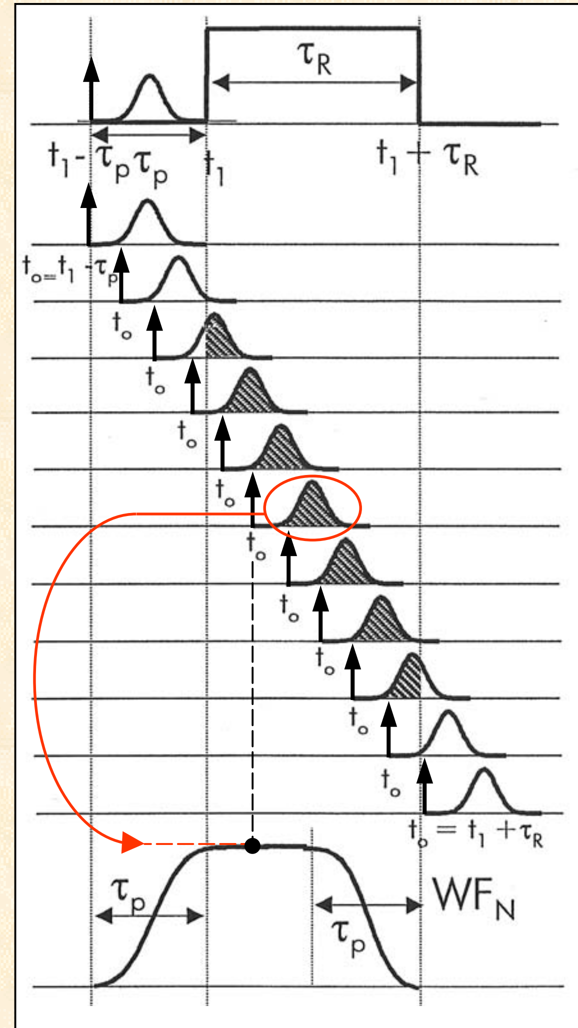
Qual è la funzione peso di questo filtro ?

Filtro a *gated integrator, fz peso*

a) Prefiltro a delay-line

b) Prefiltro quasi-gaussiano





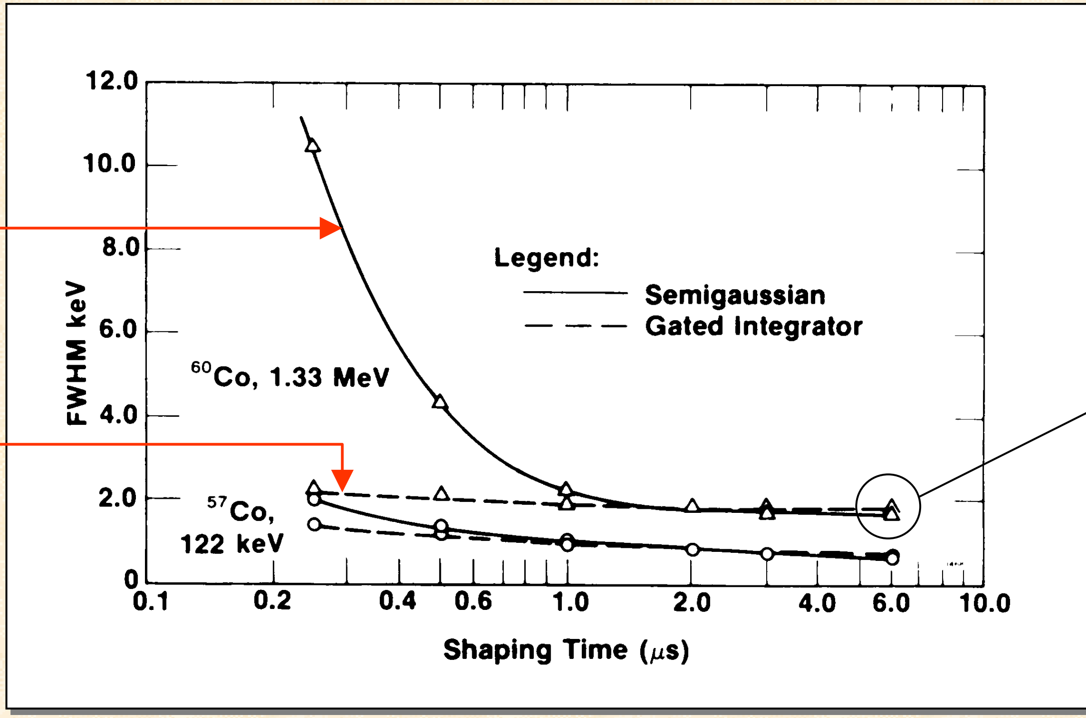
Si noti che **fz peso** e **segnale d'uscita** sono diversi, come spesso accade per i sistemi tempo-varianti

$$WF_N = \int_{-\infty}^{\infty} W_G(\xi)\, h(\xi - t)\, d\xi = \mathrm{corr}(W_G, h)$$

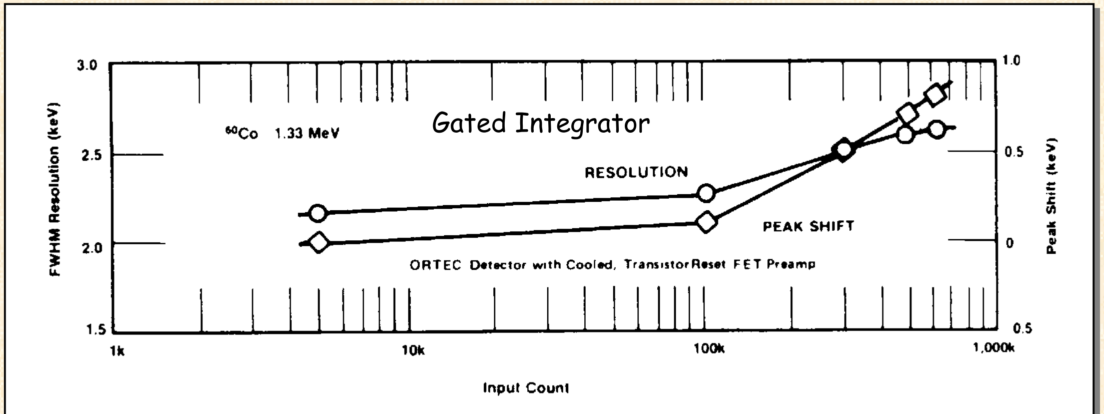
Filtro a *gated integrator, fz performance*

Senza integrazione: il deficit balistico degrada la risoluzione

Con integrazione: il deficit balistico è eliminato dal flat top

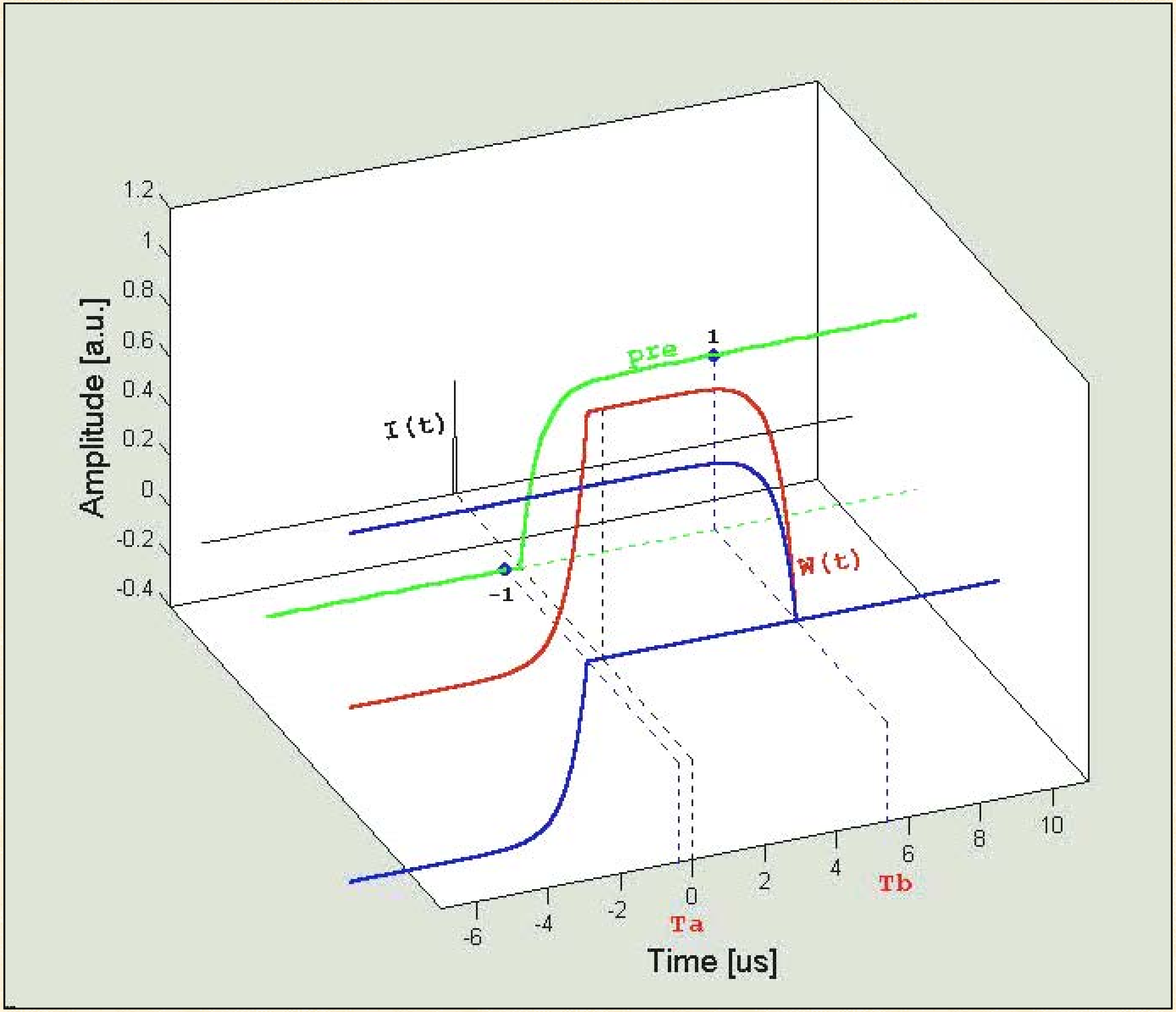


A tempi di formatura lunghi il filtro gaussiano è migliore

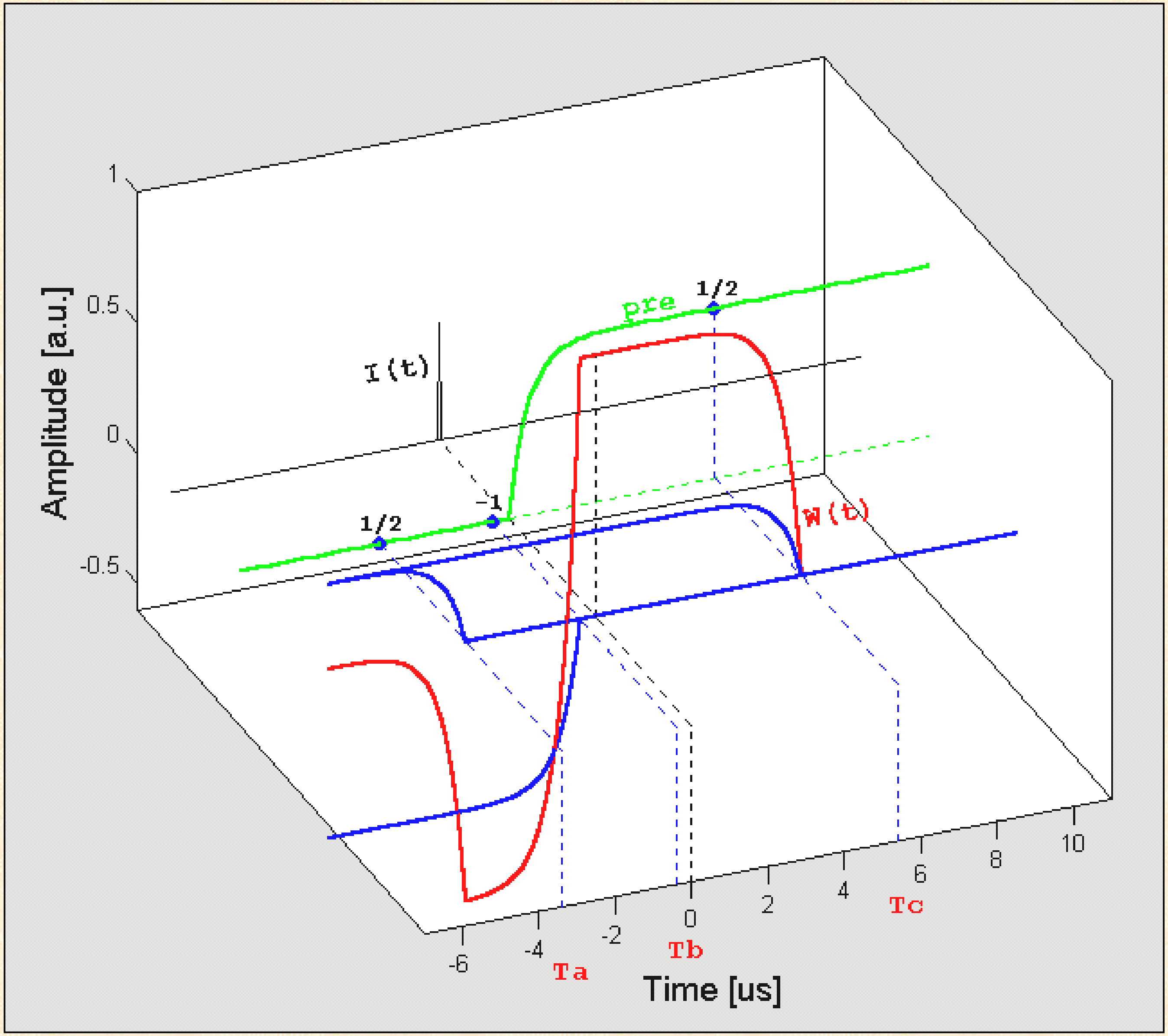


La risoluzione resta buona anche ad altissimi count rates

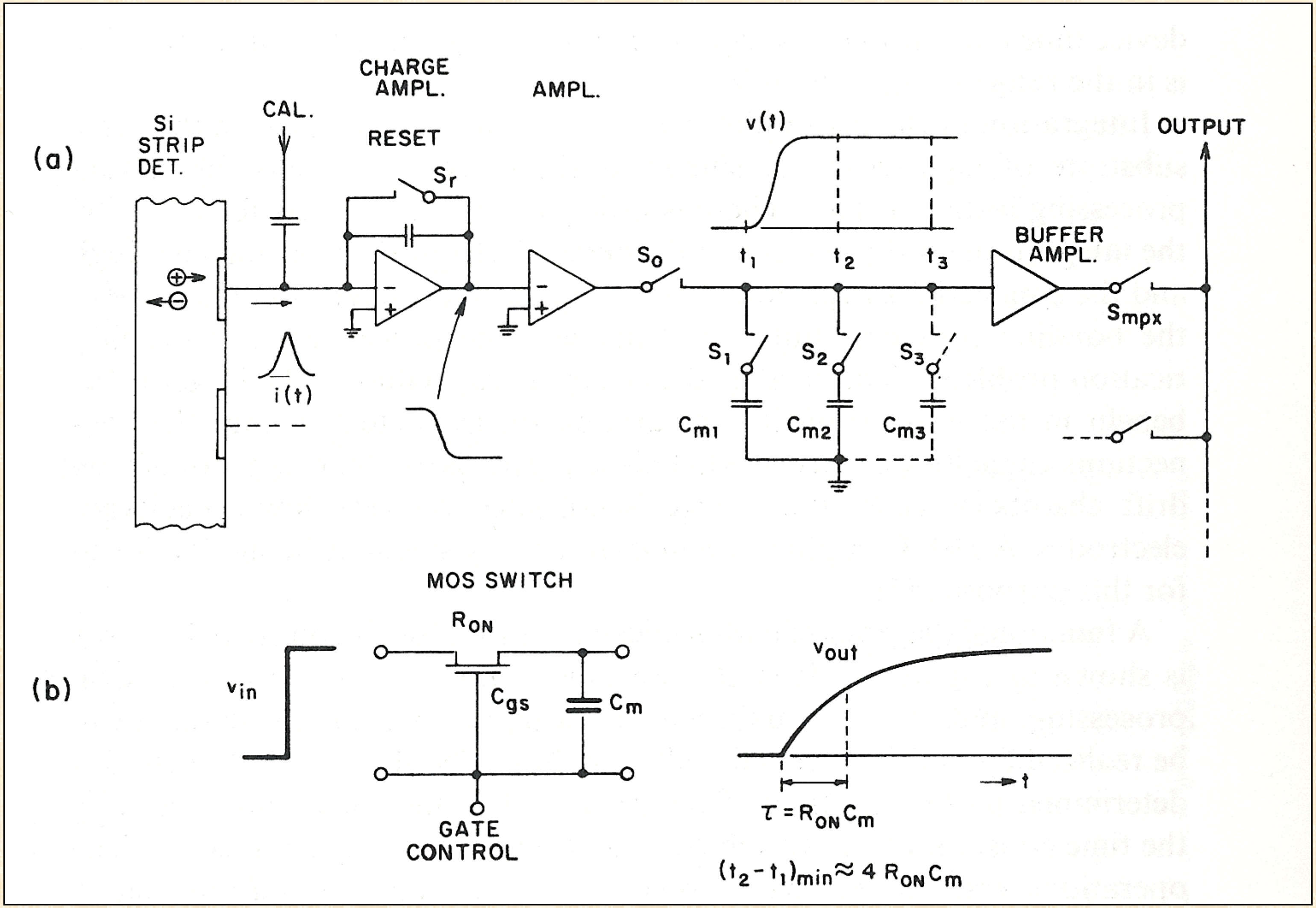
Campionamento doppio correlato



Campionamento triplo

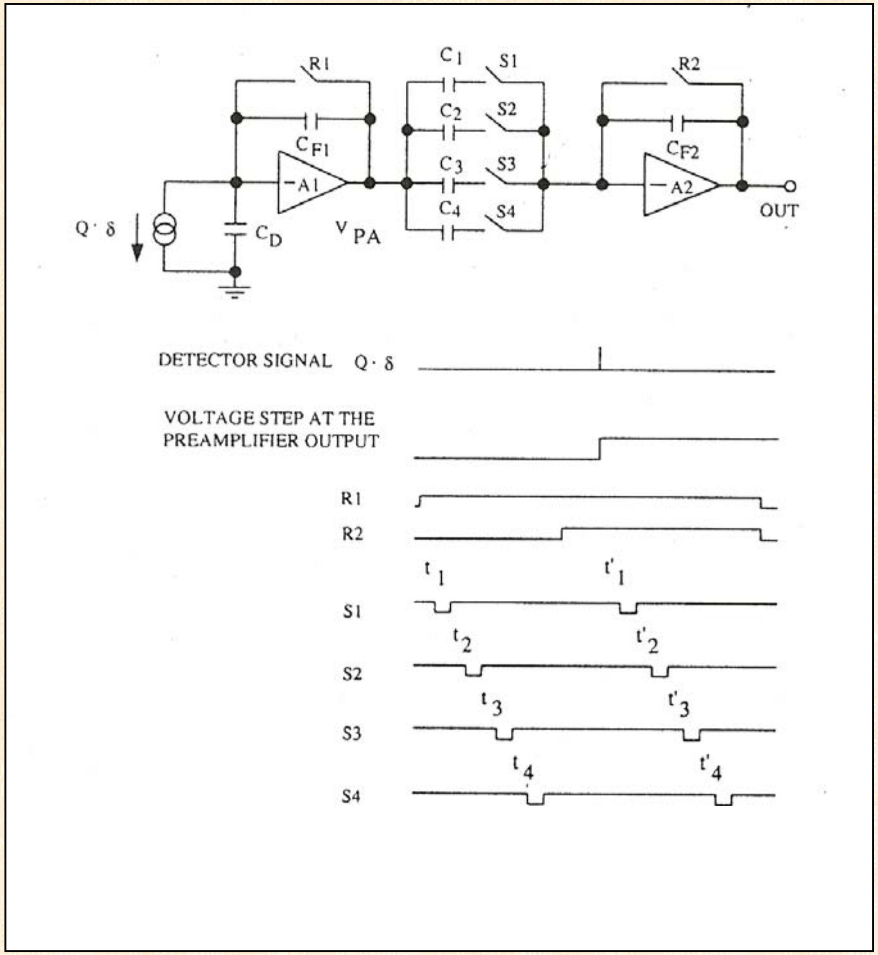


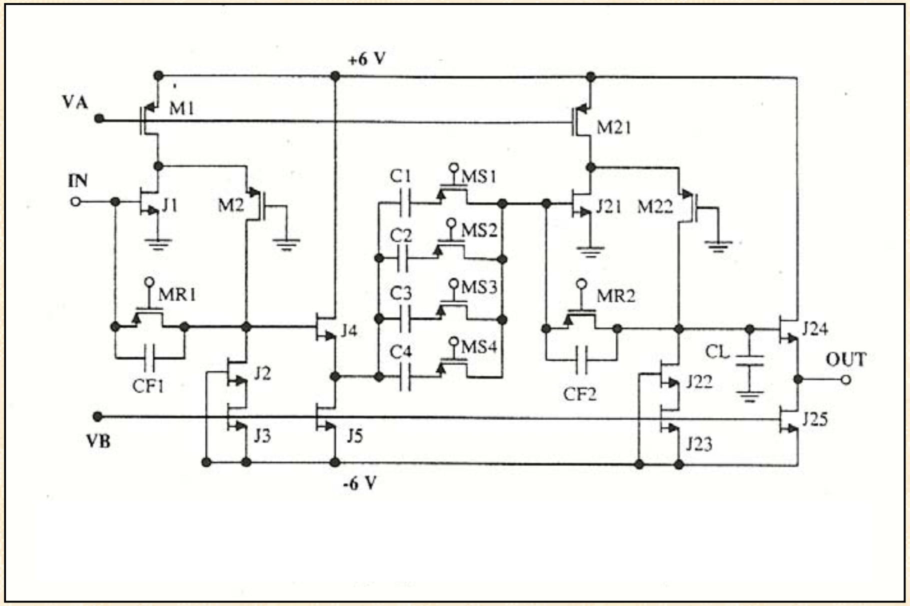
Campionamento multiplo, esempio



Rif. Rad4

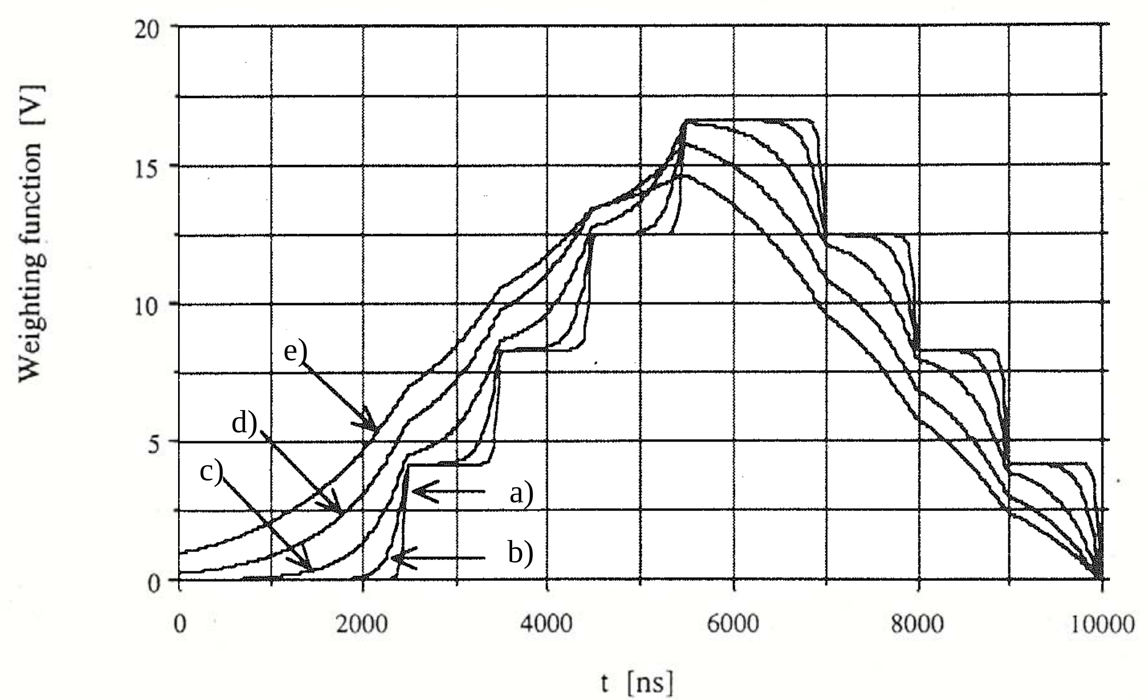
Campionamento multiplo: CAMEX / JAMEX





Rif. Man2

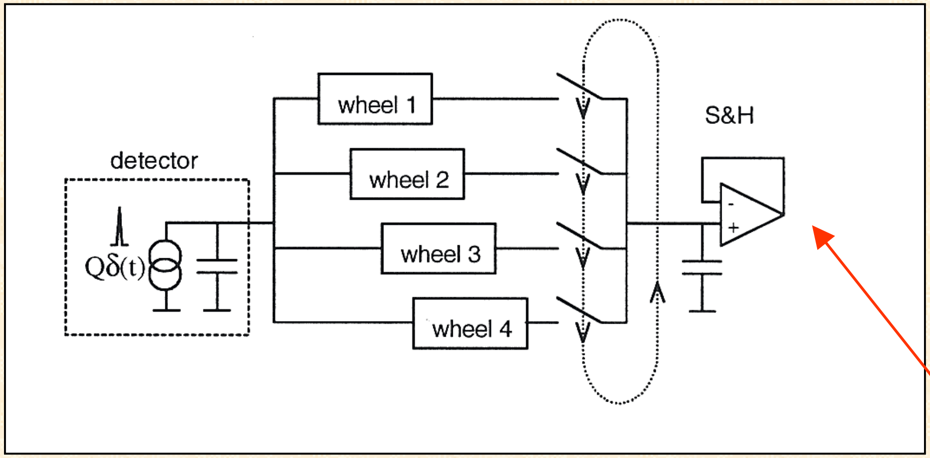
Funzione peso CAMEX



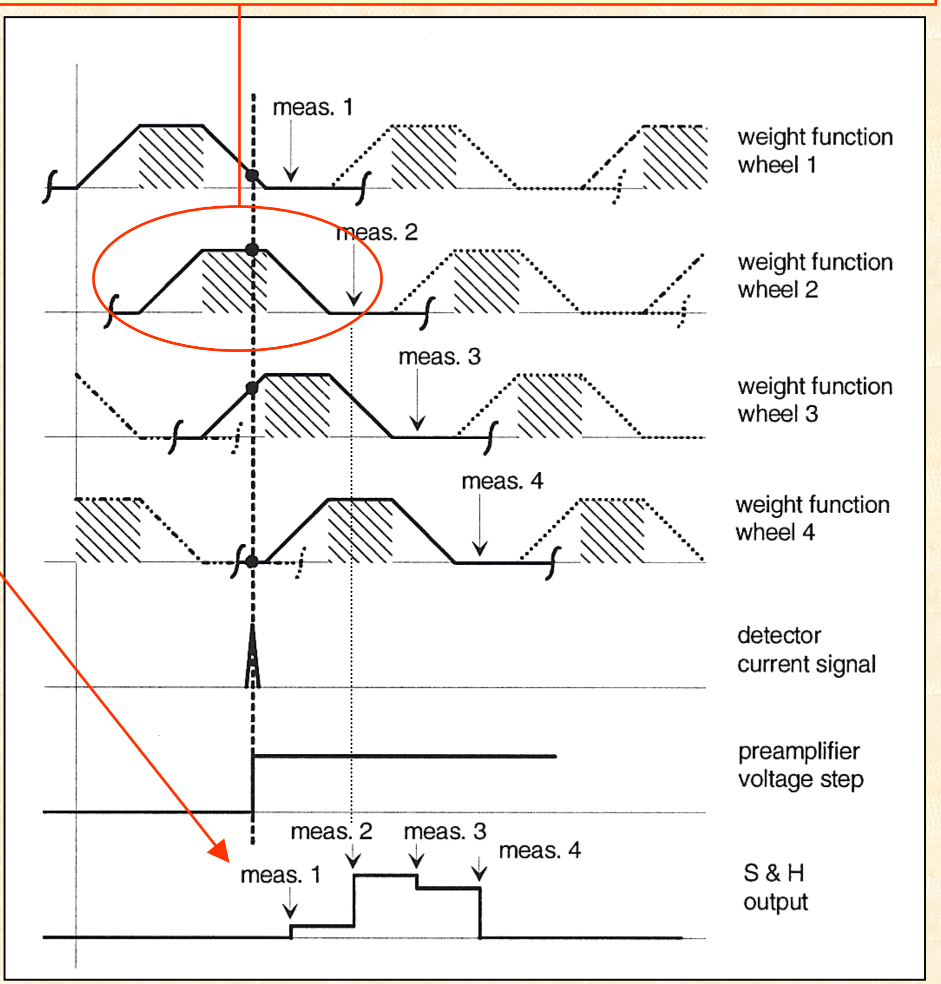
a) τ_p = 25 ns, b) τ_p = 150 ns, c) τ_p = 400 ns, d) τ_p = 800 ns, e) τ_p = 1200 ns

ROTOR

La ruota 2 cattura il pieno segnale e lo trasmette con massimo guadagno



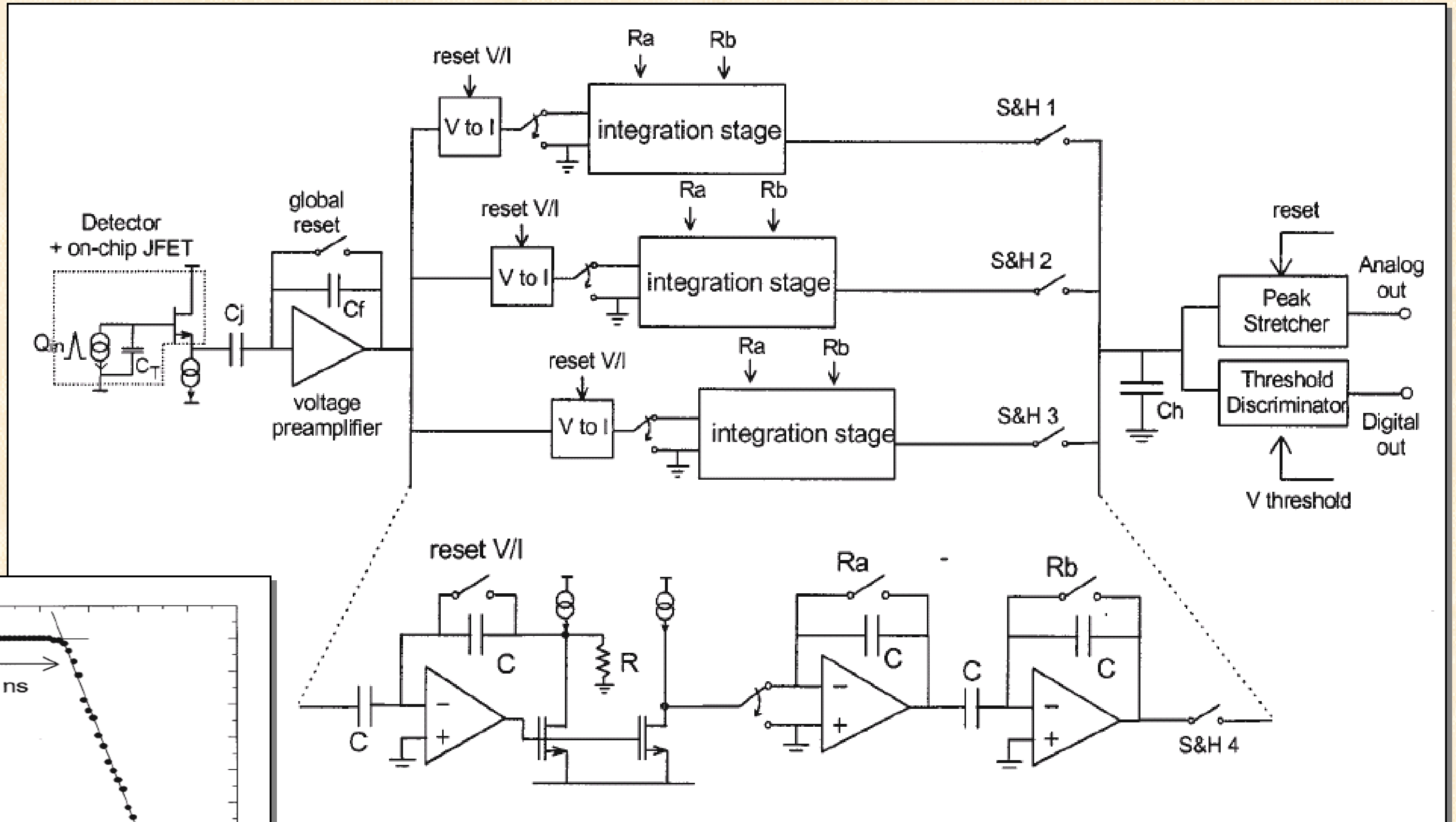
Struttura a " ruote" sfalsate di ROTOR



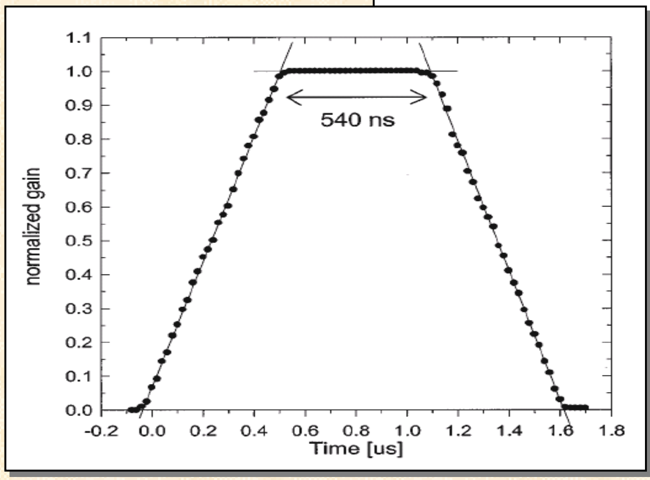
Principio di funzionamento ROTOR

Rif. Pul5

ROTOR



Schema ROTOR



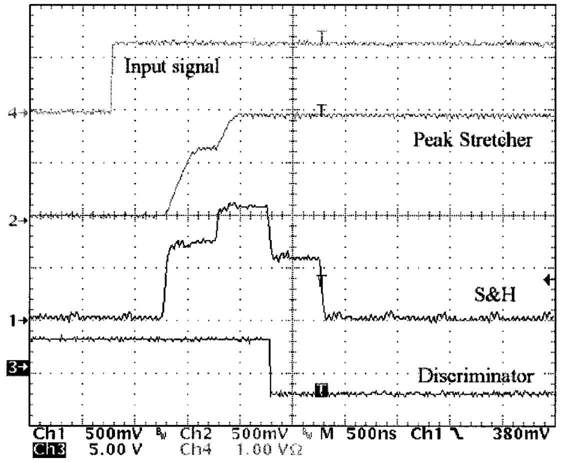
Funzione peso ROTOR

Rif. Fior1

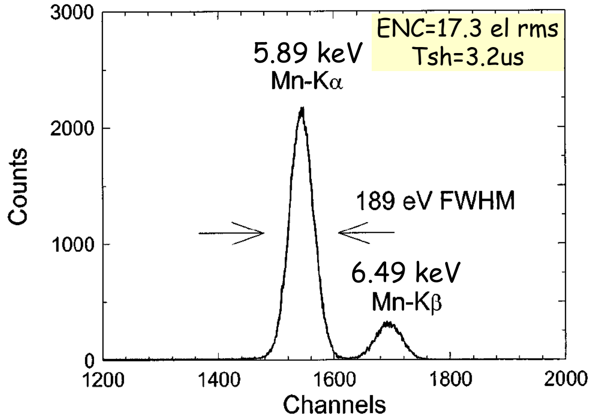
ROTOR, performance

SDD 5 mm² + ROTOR (L=1.6 μs, FT=0.54 μs)

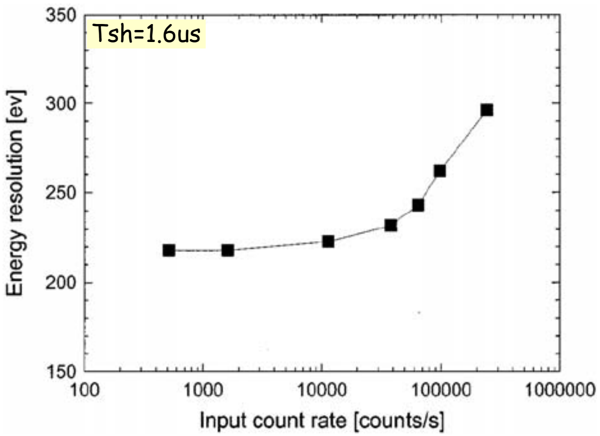
Segnali osservati



Spettro ^{55}Fe



Risoluzione ad alti tassi di conteggio



Rif. Fior1

Riferimenti

Rad1) V. Radeka, IEEE Trans. Nucl. Sci. NS-15, No. 3, 455 (1968)

Pul1) A. Pullia, S. Riboldi, IEEE Trans. Nucl. Sci. 51, 1817 (2004)

Rad2) V. Radeka, N. Karlovac, Nucl. Instrum. Methods 52, 86 (1967)

Rad3) V. Radeka, Nucl. Instrum. Methods 99, 525 (1972)

Pul2) A. Pullia, Nucl. Instrum. Methods A397, 414 (1997)

Pul3) A. Pullia, Nucl. Instrum. Methods A405, 121 (1998)

Man1) E. Gatti, P.F. Manfredi, M. Sampietro, V. Speziali, Nucl. Instrum. Methods A297, 467 (1990)

Ohk1) S. Ohkawa, M. Yoshizawa, K. Husimi, Nucl . Instrum. Methods 138, 85 (1976)

Ort1) www.ortec-online.com

Rob1) L.B. Robinson, Rev. Sci. Instr. 32, 1057 (1961)

Pul4) A. Pullia, Nucl. Instrum. Methods A370, 490 (1996)

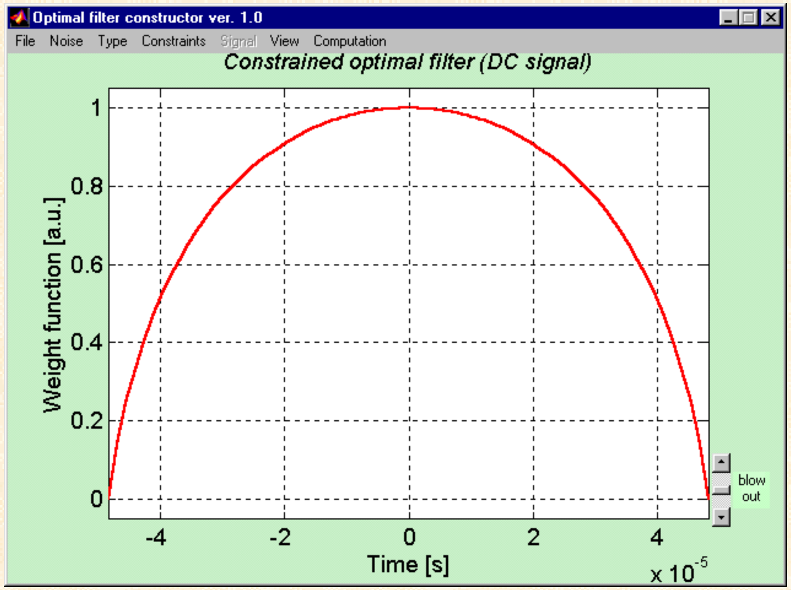
Rad4) V. Radeka, Ann. Rev. Part. Sci. 38, 217 (1988)

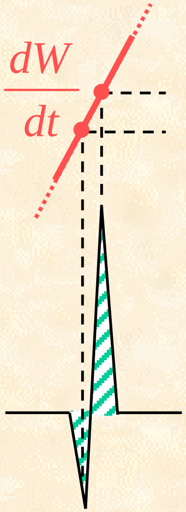
Man2) Buttler W., G. Lutz, P.F. Manfredi, V. Re, V. Speziali, A. Tomasini, Nucl. Instrum. Methods, vol. A315, p. 420 (1992)

Pul5) A. Pullia, C. Fiorini, E. Gatti, A. Longoni, W. Buttler, Nucl. Instrum. Methods A439, 385 (2000)

Fior1) C. Fiorini, A. Longoni, W. Buttler, IEEE Trans. Nucl. Sci. 49, 1763 (2002)

Disegni vari





Fac simile