Nuclear Instruments and Methods in Physics Research A 351 (1994) 592–594

ELSEVIER

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

Letter to the Editor

Deconvolution of pulses from a detector-amplifier configuration

Valentin T. Jordanov *

Amptek Inc., 6 De Angelo Dr., Bedford, MA 01730, USA

Received 18 April 1994

Abstract

A technique for deconvolution of pulses from a detector–amplifier configuration is presented. The method also allows deconvolution of the pulses obtained using CR–RC shaping networks. Analog and digital realizations of the technique are described.

Interest in using deconvolution technique in radiation measurements has recently increased, especially in the area of digital pulse processing. Deconvolution algorithms have been employed in high energy physics experiments [1] and nuclear spectroscopy [2]. Restoration of the original pulse shape (or its approximation) can be used for pileup detection and can provide a basis for new pulse-shaping techniques.

In common spectroscopy systems, the detector-preamplifier configuration is followed by a high-pass filter (pole-zero cancellation, CR differentiation) that produces a pulse with a short rise time followed by an exponential tail. The shortened pulses are then amplified. An idealized block diagram of a charge-integration configuration is depicted in Fig. 1a. The detector signal is assumed to be a delta function and the impulse response of the system is shown. The amplifiers A1 and A2 are considered ideal elements which do not affect the pulse shapes. The configuration in Fig. 1a can also be represented as an ideal current-to-voltage converter followed by an RC low-pass network. This idealized configuration is shown in Fig. 1b. In both cases in Fig. 1 the time constant of the high-pass and the low-pass filter is $\tau = RC$.

It is obvious that the voltage signal at the output of the current-to-voltage converter has the same shape as the input current signal. Therefore, the problem of deconvolution of the signal from the detector–amplifier–differentiator configuration can be solved by finding the inverse transfer function of the low-pass RC network. Fig. 2 shows a block diagram of the low-pass filter followed by the desired deconvolver. The purpose of the deconvolver is to cancel the effect of convolution of the input signal with the impulse response of the RC network. The deconvolver can be considered as a time-invariant linear system having an impulse response which when convolved with the impulse response of the low-pass filter will give a delta function. Instead of finding the desired impulse response of the deconvolver, we can easily find a deconvolver transfer function which will convert the impulse response of the low-pass filter into a delta function.

It is well known [3] that the impulse response $h(t)$ of a low-pass filter can be found by solving the differential equation

$$h(t) + \tau\frac{\mathrm{d}h(t)}{\mathrm{d}t} = \delta(t), \quad t > 0, \tag{1}$$

with initial condition $h(0) = 0$.

The impulse response of the low-pass filter $h(t)$ must satisfy Eq. (1). Thus, intuitively, the relationship between the input signal and the output signal of the desired deconvolver can be written as

$$v_{\mathrm{out}}(t) = v_{\mathrm{in}}(t) + \tau\frac{\mathrm{d}v_{\mathrm{in}}(t)}{\mathrm{d}t}. \tag{2}$$

The impulse response $h'(t)$ of the deconvolver can be expressed in terms of unit impulse and unit doublet functions

$$h'(t) = \delta(t) + \tau\dot{\delta}(t). \tag{3}$$

Note that the convolution of $h(t)$ and $h'(t)$ gives a delta function $-h(t) * h'(t) = \delta(t)$. If the signal from the output of the configuration in Fig. 1a is followed by one or more RC shaping networks it is possible to fully deconvolve the shaped signal by using deconvolvers connected in series. Each of these deconvolvers should cancel the convolution effect of one of the low-pass shaping networks.

Eq. (2) has a more practical meaning, because it defines a direct algorithm to deconvolve pulses from the detector-

* Tel. +1 (617) 275 2242, fax +1 (617) 275 3470.

SSDI 0168-9002(94)01054-4

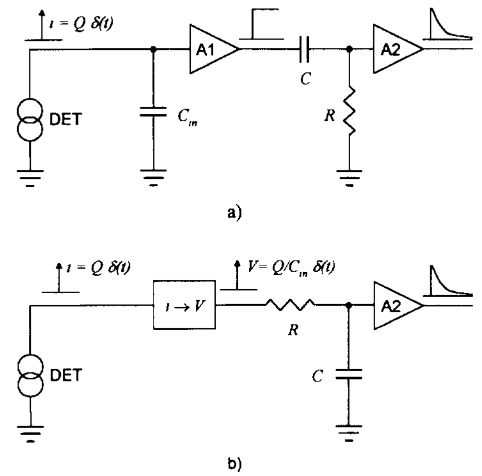


Fig. 1. Idealized detector–amplifier configuration.

amplifier configuration. In the discrete time domain Eq. (2) can be expressed in terms of the sampled signal as

$$v_{out}(n) = v_{in}(n) + [v_{in}(n) - v_{in}(n-1)]M, \tag{4}$$

where M is a measure of the time constant τ in units of the sampling period t_c given as $M = [\exp(t_c/\tau) - 1]^{-1}$. For $\tau/t_c > 5$, M can be approximated as $M \approx \tau/t_c - 0.5$.

The deconvolution method can be implemented in analog or digital circuits. The analog approach is shown in Fig. 3. The circuit in Fig. 3a is an ideal analog deconvolver in which the time constant RC is equal to the time constant of the low-pass network which is subject to deconvolution. The resistor R_g determines the gain of the circuit and does not affect the shape of the output pulse. The analog solution of Fig. 3a, however, is impractical and in reality the circuit in Fig. 3b can be used instead. Due to the resistor R_1 the circuit in Fig. 3b is equivalent to the ideal deconvolver of Fig. 3a followed by a low-pass filter with time constant R_1C. Shown in Fig. 4 is an example of an analog deconvolution circuit (a) and an oscillogram (b) representing the response of the circuit to an exponential pulse.

Fig. 5 shows the digital realization of the deconvolver. The sampled signal is delayed one clock cycle in the register (REG) and then is subtracted from the prompt signal. The difference is multiplied by the digital equiva-

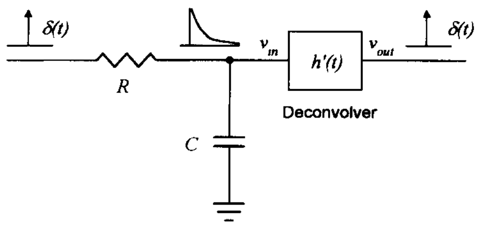


Fig. 2. Deconvolution of the signal from a low-pass network.

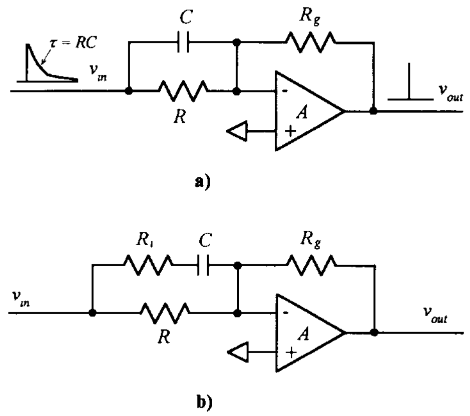
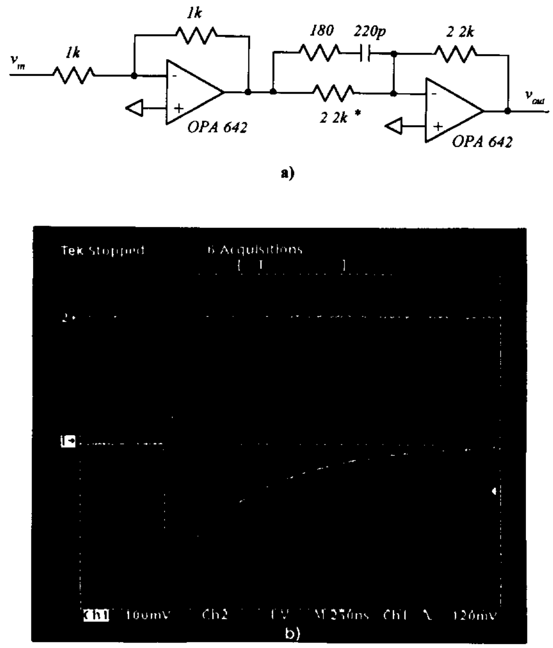


Fig. 3. Analog deconvolving circuits: (a) ideal and (b) practical ($R_1C \ll RC$).



b)

Fig. 4. Analog deconvolver (a) and oscillogram of the input and output signals (b). Trace 1 shows the input exponential pulse with decay time constant of 500 ns and trace 2 represents the deconvolver response.

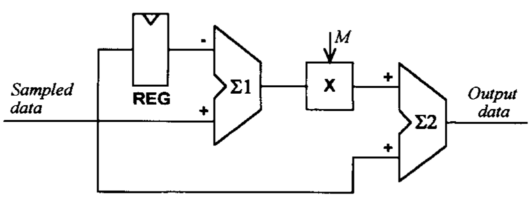


Fig. 5. Block diagram of the digital deconvolver. REG – one clock delay register, Σ1, Σ2 – arithmetic units, X – multiplier.

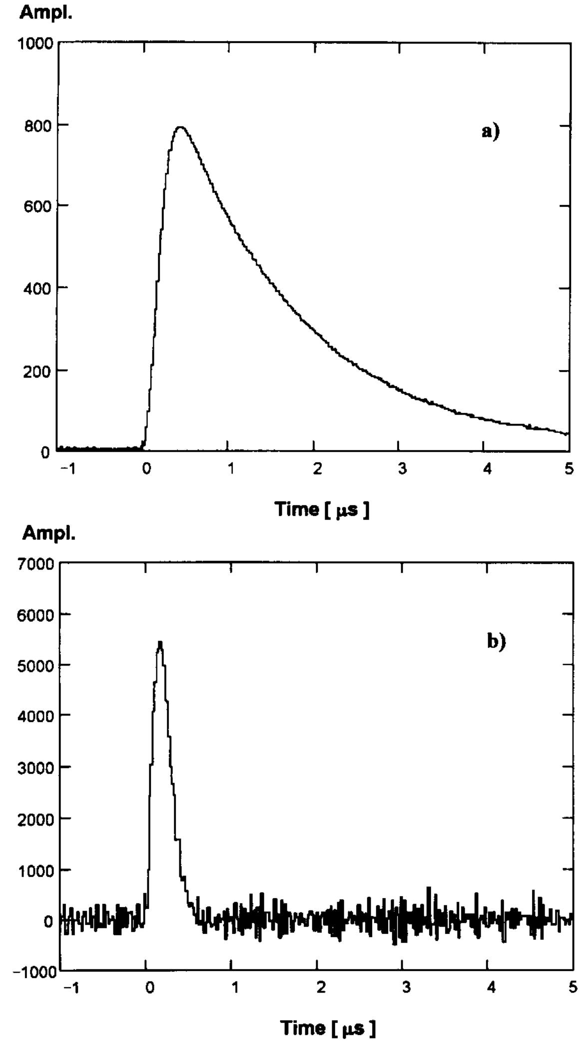


Fig. 6. Sampled exponential pulse (a) and digitally deconvolved signal (b).

lent of the decay-time constant M of the low-pass network (see Fig. 2). Finally, the result of multiplication is added to the prompt digital sample. The result is a digital representation of the signal at the input of the low-pass network (Fig. 2) undergoing deconvolution.

The digital technique was applied to sampled data obtained by digitizing the exponential pulse from the fast amplifier of an Ortec 673 spectroscopy pulse shaper [4]. The sampled data are shown in Fig. 6a. This pulse originated from an HPGe detector. The decay-time constant of the sampled pulse is 1.5 μs. Fig. 6b shows the deconvolved pulse. Two important observations can be made. First, restoration of the original signal will inevitably cause restoration of the noise related to the input of the preamplifier. Second, due to imperfections in the real amplifiers and the connecting networks, the deconvolved signal does not exactly represent the original shape of the detector pulse. The pulse obtained in this case is a result of convolution of the original detector pulse with the impulse response of a system which accounts for all effects due to imperfections of the real amplifiers and the connecting networks.

The tests performed using prototypes of the convolvers indicate the potential of using these circuits for shortening the pulses from the detectors. The deconvolved pulses can be used for pile-up detection and for pulse shaping in nuclear spectroscopy.

References

[1] S. Gadomski et al., Nucl. Instr. and Meth. A 320 (1992) 217.
[2] A. Georgiev and W. Gast, IEEE Trans. Nucl. Sci. NS-40 (1993) 770.
[3] R.J. Schwarz and B. Friedland, Linear Systems (McGraw-Hill, New York, 1965) p. 83.
[4] Ortec 673 Manual, Ortec, Oak Ridge, 1984.