ARCHIVES OF ACOUSTICS
19, 3, 395–404 (1994)

SIGNAL FILTRATION IN A PIEZOELECTRIC-SEMICONDUCTOR CONVOLVER WITH BROAD-BAND TRANSDUCERS

A. M. KAWALEC

Military University of Technology
(01-489 Warszawa ul. Kaliskiego 2)

The result of theoretical and experimental studies of a convolver in piezoelectric-semiconductor configuration (BGO-Si) are presented. Experimental results with using of the convolver for compression a signal with linear frequency modulation have been reported. Dispersive excitation transducers were used to improve the matching of the convolver inputs to the external sources of the signals in the pass band. A new measurement system for the amplitude characteristics of the convolver output has been proposed.

1. Introduction

Filtration of a signal in a filter with an acoustic surface wave SAW is performed by means of two co-operating interdigital transducers (Fig. 1a). The output signal is a convolution of an input signal $S_{\text{in}}(t)$ and a impulse response of the filter $h(t)$

$$S_{\text{out}}(t) = S_{\text{in}}(t) \otimes h(t). \tag{1.1}$$

The characteristic of such a filter is determined by the form of the transducers and the properties of the substrate, therefore it is invariable for a particular filter. Analogous filtration can be achieved by means of a convolver (Fig. 1b) except that, instead of the impulse response $h(t)$, the reference signal $S_{2\,\text{in}}(t)$ is used by applying it to the second input. The output signal $S_{\text{out}}(t)$ which is a result of nonlinear interaction of the acoustic signals moving in opposite directions is a convolution of the input signal $S_{1\,\text{in}}(t)$ and the reference signal $S_{2\,\text{in}}(t)$, that is

$$S_{\text{out}}(t) = S_{1\,\text{in}}(t) \otimes S_{2\,\text{in}}(t). \tag{1.2}$$

It follows that the reference signal replaces. In this case, the pulse response $h(t)$ of the filter with an acoustic surface wave cf. equation (1.1), therefore we can vary by simple change of the signal $S_{2\,\text{in}}(t)$, the characteristic of the convolver, which is decisive for its attraction for the signal processing and, in particular, the realization of matched filtering of signals.

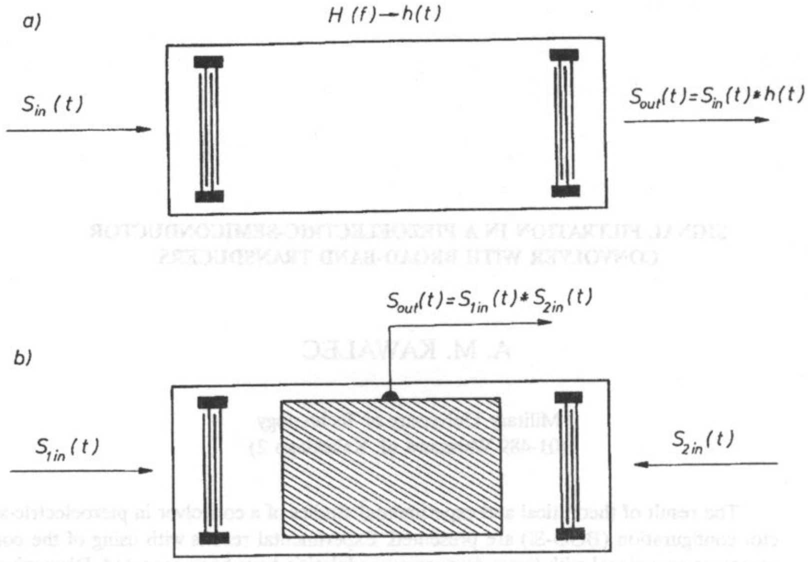

FIG. 1. a) A filter with an acoustic surface wave, b) A convolver with acoustic surface waves.

The nonlinear interaction of surface waves in a convolver can be made by making use of the mechanical nonlinearity of the material of the piezoelectric substrate [1] or electrical nonlinearity associated with the transport of electric charges in a piezoelectric semiconductor [2] or piezoelectric-semiconductor convolver system [3] as shown in Fig. 2. The transport of a charge is forced by an electric potential connected with a surface wave moving in the piezoelectric substrate and penetrating the semiconductor applied to the surface of the piezoelectric. For application, the convolver with charge nonlinearity appears to be better, owing to the effectiveness of the interaction of the surface waves being much higher.

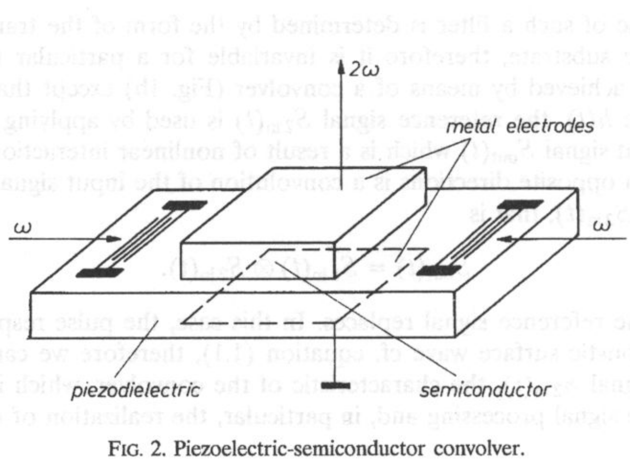

FIG. 2. Piezoelectric-semiconductor convolver.

2. The convolver with broad-band transducers

The source of a surfaces wave in a convolver are inter digital transducers. Common transducers contain a small number of electrodes in order to obtain a broad band operation. This is a consequence of the fact that the frequency band of a transducer structure is expressed by the formula

$$H_p(f) = \frac{\sin y}{y}, \tag{2.1}$$

where

$$y = \frac{N\pi(f - f_0)}{2f_0},$$

N is the number of electrodes of the transducer and f_0 — the middle frequency, the passband being, therefore, proportional to the number of electrodes. But transducers with a small number of electrodes are highly radiation resistivity, which makes impossible their being matched to the source of the electric signal. This in turn makes impossible generation of a surface wave with a sufficiently high amplitude such as is required for the nonlinear interaction of surface acoustic waves in a convolver.

The only effective method for generating broad-band signals is by using interdigital transducers with nonlinear phase characteristic [3], which makes possible considerable improvement of electric matching of convolver inputs.

In order to ensure that the convolver will be dispersionless two input transducers must be arranged as shown in Fig. 2. Then, their pulse responses will be $h_p(t)$ and $h_p(-t)$, which means that the spectra of their structures will be complex conjugate with each order.

$$H_p(\omega) = H_p^*(\omega) \tag{2.2}$$

In view of the form of the frequency characteristic and the dependence of the radiation

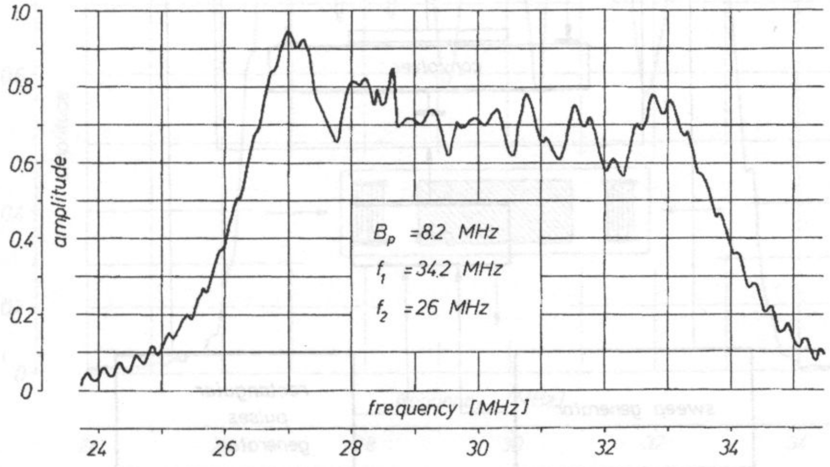

FIG. 3. The amplitude characteristic of a hyperbolic transducer

resistance of the frequency, it is advantagenous to apply hyperbolic dispersive transducers. The amplitude characteristic of such a transducer is shown in Fig. 3. The middle frequency of the transducer is $f_0 = 30$ MHz, the bandwidth — $B_p = 8.2$ MHz and the time duration of the impulse response — $T_p = 4$ μs.

3. The measurement of the frequency characteristic of the convolver

The insertion, loss which depend on the frequency transformed signal, are an important parameter of the convolver. The measurement of the frequency characteristic of the co-

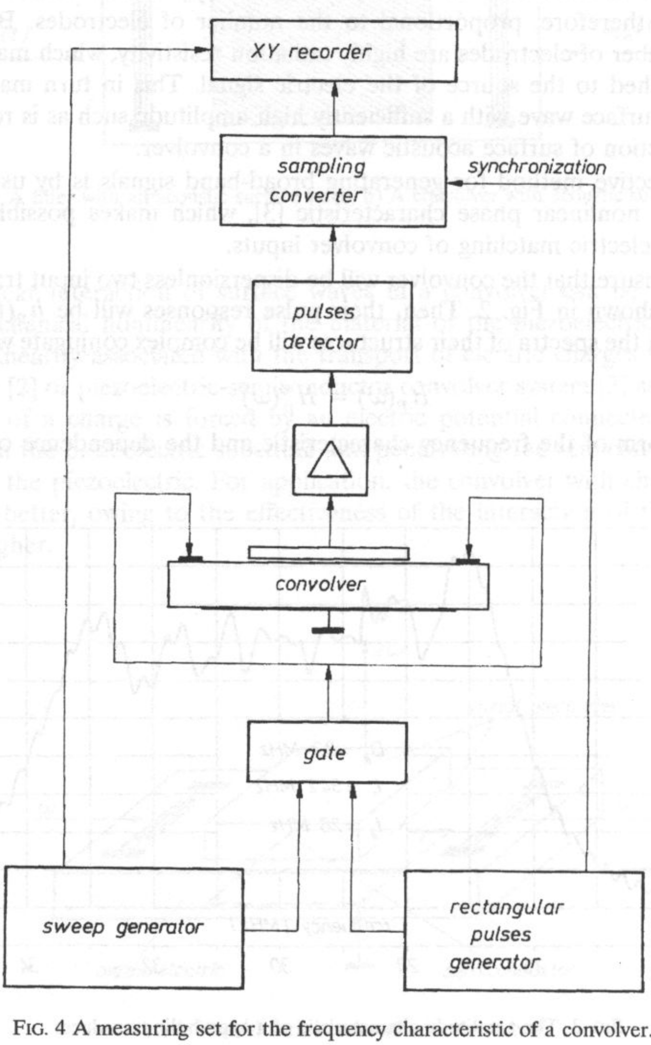

FIG. 4 A measuring set for the frequency characteristic of a convolver.

nvolver by means of continuous signals is difficult, the level of the electromagnetic signals between the interdigital transducers and the output electrode of the convolver being high. The measurement method which was used in the work reported here was of the pulse type, thus making possible separation of the useful output signal from false signals which usually are relatively strong. The proposed measurement system is illustrated in Fig. 4. The electrical signal produced by the generator, the frequency of which varies between the limits of 24 and 35 MHz is applied, in the form of rectangular pulses, to the input transducers of the convolver. After amplification and detection the output signal is transmitted to the input of the converter sampling. The investigated impulse is reproduced at the output of the converter in the form of samples. The sampling converter is able to move the sampling point of the signal, therefore other signal, delayed on each other, can also be analyzed, which is the greatest advantage of the system discussed. The amplitude characteristic of the convolver will depend on the frequency spectra $H_{p1}(\omega)$ and $H_{p2}(\omega)$ of the transducers generating surface waves, that is

$$|H(\omega)| = |H_{p1}(\omega)||H_{p2}(\omega)|. \tag{3.1}$$

Figure 5 shows the amplitude characteristic of the convolver output. Because the excitation transducers were identical (dispersive hyperbolic), the characteristic of the convolver output is the square of the spectrum of a single transducer. For the sake of comparison the amplitude characteristic was measured using the same measuring system, for two

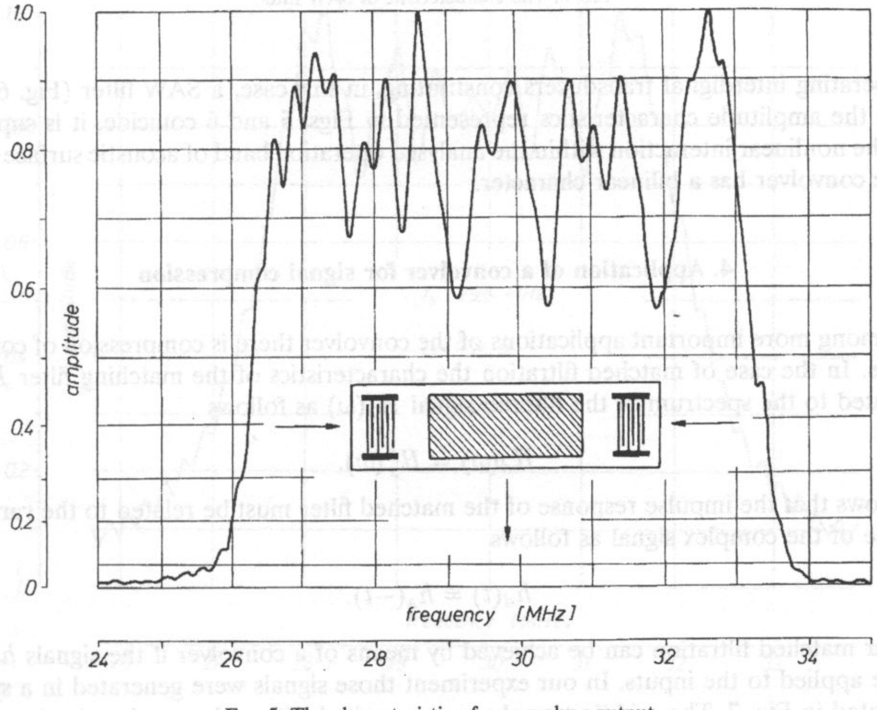

FIG. 5. The characteristic of a convolver output.

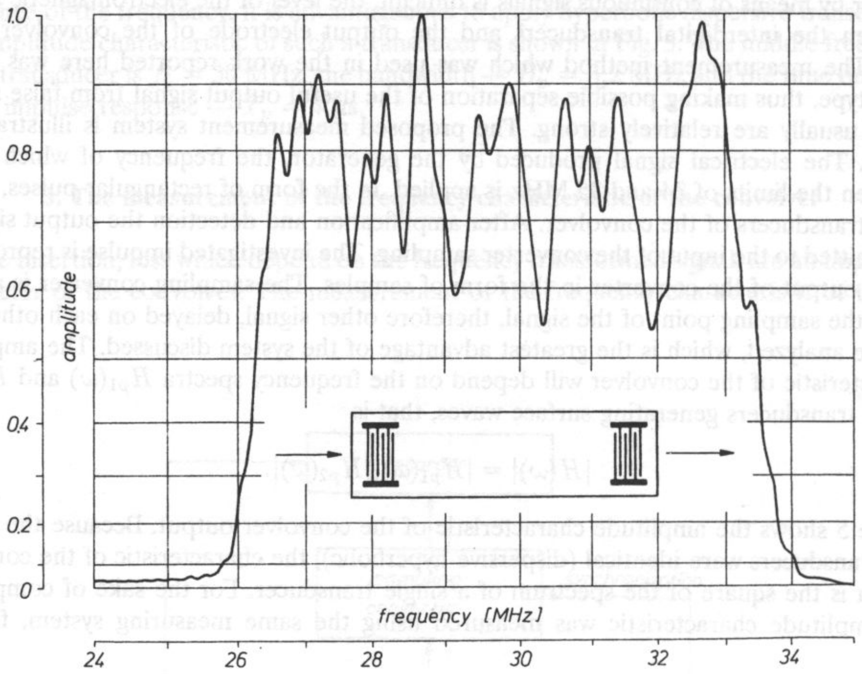

FIG. 6. The characteristic of SAW filter.

co-operating interdigital transducers constituting, in this case, a SAW filter (Fig. 6). Because the amplitude characteristics represented in Figs. 5 and 6 coincide, it is supposed that the nonlinear interaction within the analysed operation band of acoustic surface waves in the convolver has a bilinear character.

4. Application of a convolver for signal compression

Among more important applications of the convolver there is compression of complex signals. In the case of matched filtration the characteristics of the matching filter $H_d(\omega)$ is related to the spectrum of the filtered signal $H_s(\omega)$ as follows

$$H_d(\omega) = H_s^*(\omega). \tag{4.1}$$

It follows that the impulse response of the matched filter must be related to the variation in time of the complex signal as follows

$$h_d(t) = h_s(-t). \tag{4.2}$$

Similar matched filtration can be achieved by means of a convolver if the signals h_d and h_s are applied to the inputs. In our experiment those signals were generated in a system illustrated in Fig. 7. The middle transducer was excited with a short pulse. At the output of the identical transduces located on both sides of the dispersive transducer the signals were obtained as described by the relation (4.2)

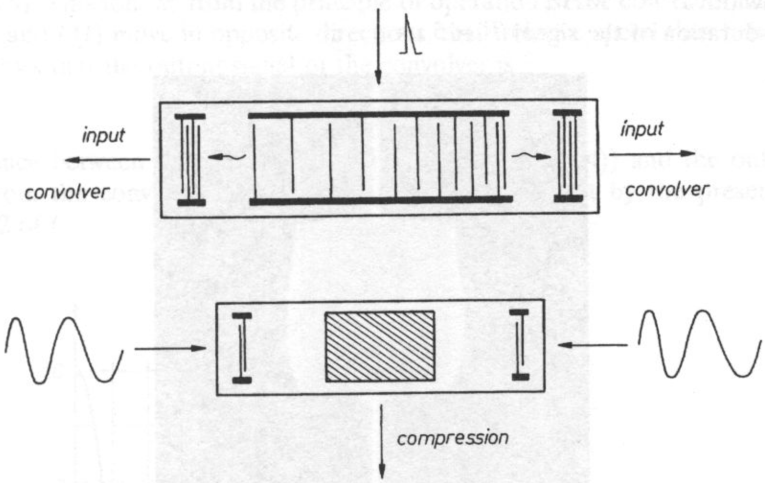

FIG. 7. A compressing set for a complex signal in convolver.

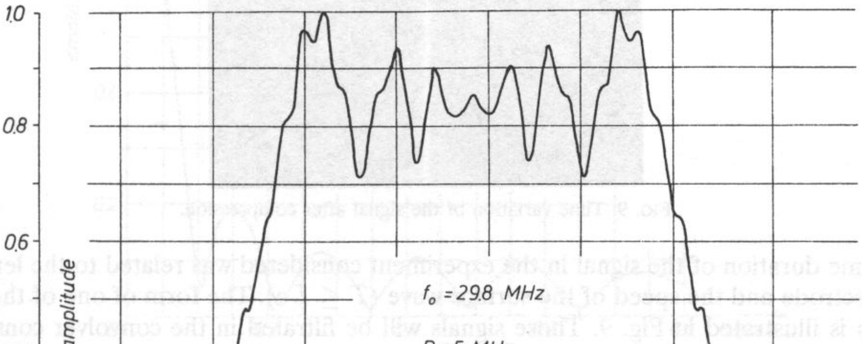

FIG. 8. The amplitude characteristic of a signal with L.f.m.

A signal with linear frequency modulation has been realized in practice, its amplitude spectrum being illustrated in Fig. 8. The parameters of the complex signal were as follows.

- middle frequency $f_0 = 29.8$ MHz,
- bandwidth $B = 5$ MHz,
- time-duration of the signal $T = 5$ μs

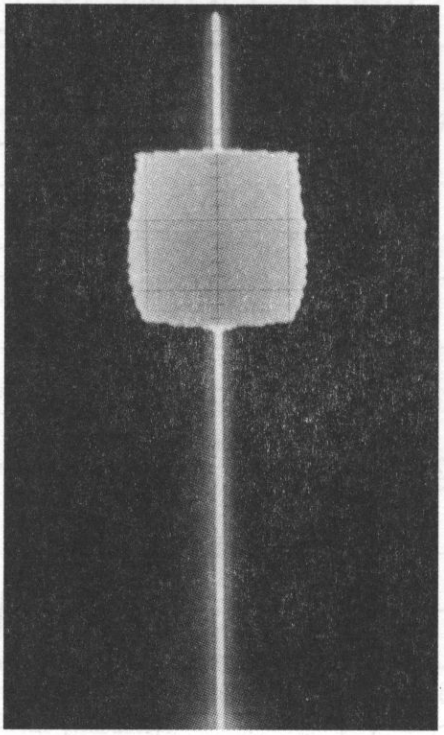

FIG. 9. Time variation of the signal after compression.

The time duration of the signal in the experiment considered was related to the length of the electrode and the speed of the surface wave ($T \leq Lv$). The form of one of the input signals is illustrated in Fig. 9. Those signals will be filtrated in the convolver considered (Fig. 7). The spectrum of the acoustic signal generated by the hyperbolic transduces used is a product of the spectrum of the signal $H_s(\omega)$ and that of the transducer structure $H_p(\omega)$, that is

$$H_a(\omega) = H_s(\omega)H_p(\omega) \tag{4.3}$$

The time variation of the acoustic surface wave thus generated in the convolver is an inverse Fourier transform

$$s(t) = \mathcal{F}^{-1}\{H_a(\omega)\} \tag{4.4}$$

The simple convolution of the two signals $s(t)$ and $h(t) = s(-t)$ is as follows

$$g(t) = s(t) * h(t) = \mathcal{F}^{-1}\{H_s(\omega)H_s^*(\omega)H_p(\omega)H_p^*(\omega)\} \tag{4.5}$$

In our experiment the signal was compressed by means of a $Bi_{12}GeO_{20}$—S_i convolver incorporating two identical hyperbolic transducers. The specific conductivity of Silicon was $1.4.10^{-1}$ [$1/\Omega$m]. From the computation which was carried out according to the relation (4.5) it follows that the compressed out signal has 0.2 μs width.

The output signal of the convolver is 1/2 the length of the signal described by the equation (4.5). This follows from the principle of operation of the convolver, in which the signals $s(t)$ and $h(t)$ move in opposite directions, their relative speed thus being twice as high. It follows that the output signal of the convolver is

$$g_k(t) = \int s(\tau)h(2t-\tau)\,d\tau \tag{4.6}$$

The difference between the simple convolution signal (cf. (4.4)) and the output signal obtained from the convolver (cf. (4.6)) is taken into account by the presence of the coefficient 2 of t.

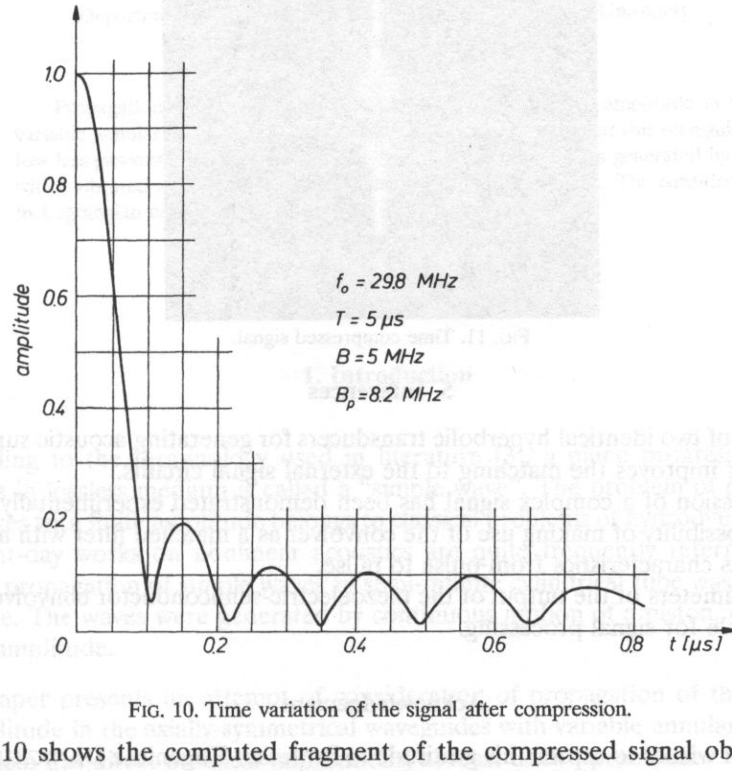

FIG. 10. Time variation of the signal after compression.

Figure 10 shows the computed fragment of the compressed signal obtained at the output of the considered convolver. The sidelobe level of the compressed signal is −14 dB. The photograph in Fig. 11 illustrates the experimental compression of the signal with linear frequency modulation in the BGO–Si convolver. The parameters of the signal represented are as follows:

- the width of the signal at a level of −4 dB: 0.1 μs,
- the sidelobe level: −14 dB.

The photograph shows also a false input signal passing through the air to the output electrode of the convolver. This signal presents a fundamental difficulty in measuring the frequency characteristic of the convolver output.

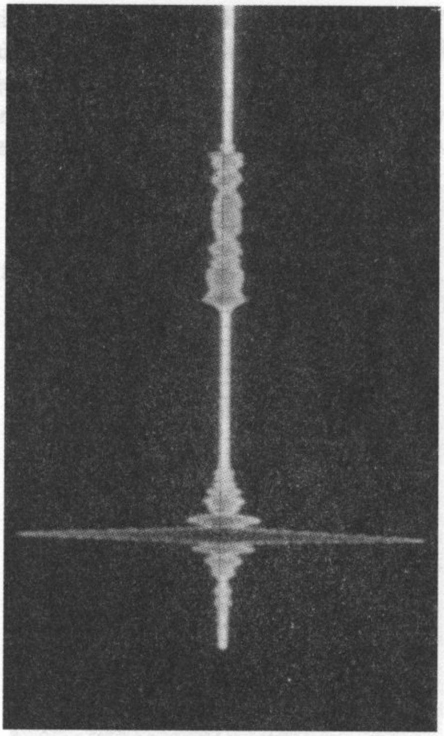

FIG. 11. Time compressed signal.

5. Inferences

• The use of two identical hyperbolic transducers for generating acoustic surface waves in a convolver improves the matching to the external signal circuits.

• Compression of a complex signal has been demonstrated experimentally, thus confirming the possibility of making use of the convolver as a matched filter with a possibility of changing its characteristics from pulse to pulse.

• The parameters of the output of the piezoelectric-semiconductor convolver BGO–Si make it suitable for signal processing.

Acknowledgement

The author wishes to express his gratitude to Professor Eugeniusz DANICKI for fruitful discussion and help in the realization of the experiment and the editorial work of the present paper.

References

[1] G. S. KINO, S. LUDVIK, H. J. SHAW, W. R. SHREVE, J. W. WHITE and D. K. WINSLOW, IEEE Trans. Sonics and Ultras., **SU-20**, 162 (1973).

[2] S. KALISKI, A. KAWALEC, Tringh DONGÁ and B. WĘCKI, Journal of Tech. Physics, **16**, 97 (1975).

[3] A. KAWALEC, Doctor's thesis (1980).