Contributed paper

OPTO-ELECTRONICS REVIEW **11**(1), 45–50 (2003)

Method of popcorn-noise reduction

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A new type of passive infrared human body detecting photoreceiver with popcorn noise reduction systems is presented. When the range of operating temperatures and temperature gradients of a pyroelectric detector are spread, the popcorn noise occurs. To avoid error signal at the system output we designed two-signal processing circuits. We observed a difference of frequency components at the photoreceiver output. The output current resulting from popcorn noise holds high frequency components compared with frequency components of a moving person. So, we can distinguish popcorn noise by analysing frequency components of the output current from the pyroelectric detector.

Keywords: pyroelectric detectors, low-noise preamplifier, thermal imaging systems.

1. Introduction

Pyroelectric sensors can detect IR source and temperature, as well as using them we can determine direction of an moving object and its speed, emissivity, and radiation wavelength [1–3]. They are applied as single elements or multielement arrays. As single elements they are applicable for intruder alarms, spectroscopy, fire alarms, chemical analysis, energy metering, thermal recording, laser detection, and so on.

When a pyroelectric detector is exposed to radiation of the power $P(t) = P_0 e^{i\omega t}$, which is modulated at the frequency ω, the voltage responsivity is defined as [4,5]

$$R_v = \frac{V}{P_0} = \frac{I}{G_E + i\omega C_E}\frac{1}{P_0} = \frac{\eta p A\omega}{G_T G_E (1+\omega^2\tau_T^2)(1+\omega^2\tau_E^2)}, \tag{1}$$

and

$$\tau_T = \frac{H_T}{G_T}, \qquad \tau_E = \frac{C_E}{G_E}, \tag{2}$$

where V, I, C_E, G_E, p, η, A, G_T, H_T, τ_T, and τ_E represent the output voltage, output current, electrical capacitance, electrical conductance, pyroelectric coefficient, light absorbing coefficient, detector area, thermal conductivity, heat capacity, thermal time constant, and electrical time constant, respectively. Following Eq. (1), large values η, p, A, small G_T, and small G_E are required for high detector responsivity.

The performance of a detector can be expressed in many different ways. Most useful is the noise-equivalent power (NEP). The NEP is given by

$$NEP = \frac{V_n}{R_v}. \tag{3}$$

The detectivity (D^*) is reciprocal of the NEP

$$D^* = \frac{A^{1/2}}{NEP}. \tag{4}$$

Five sources of the noise in a pyroelectric detector for a source follower impedance converter are known [6]:
thermal noise

$$V_T = \frac{R_v}{\eta}(4kT^2 G_T)^{1/2}, \tag{5}$$

Johnson noise (V_J)

$$V_j = \frac{4kT\omega R^2 C_E tg\delta}{1+\omega^2\tau_E^2}, \tag{6}$$

preamplifier voltage noise

$$V_{Vn} = V_n\left(\frac{1+\omega^2 R^2 C_E^2}{1+\omega^2\tau_E^2}\right)^{1/2}, \tag{7}$$

preamplifier current noise

$$V_{In} = \frac{I_a R}{(1+\omega^2\tau_E^2)^{1/2}}, \tag{8}$$

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and shunt resistor noise

$$V_R = \left(\frac{4kTR}{1+\omega^2 \tau_E^2} \right)^{1/2}, \qquad (9)$$

where k is the Boltzmann constant, $tg\delta$ is the dielectric loss factor, V_{Vn} and V_{In} are the voltage and current noise of the FET transistor respectively, R is the equivalent resistance of the resistance pyroelectric sensing element, the gate resistance, and FET input resistance.

Pyroelectric detectors generate noises due to environmental effects such as temperature fluctuation, electromagnetic interference, mechanical vibration, and so on. Several methods have been proposed to reduce the unwanted output signals such as the use of less right mounting, single point supports, polycrystalline materials, electrically conducting windows, good package design and by using compensated detectors [7–10].

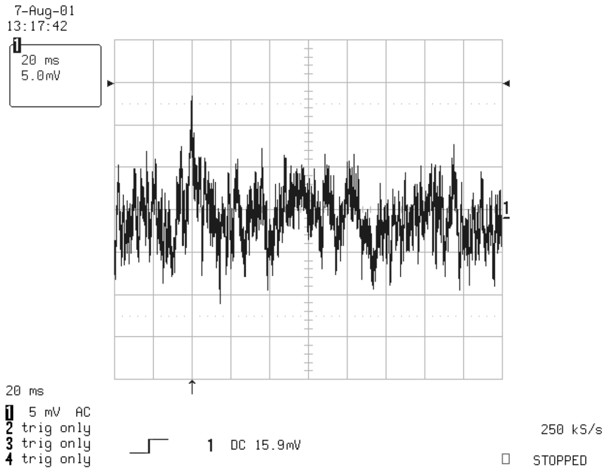

Fig.1. Popcorn noise at the output of conventional circuit.

When the range of operating temperatures and temperature gradients of a pyroelectric detector are spread, the popcorn noise occurs (piezoelectric noise) (Fig. 1). This noise is in form of output spikes that are particularly significant for critical low frequency applications in which output spikes cannot be tolerated, e.g., for infrared barriers [11]. The total mean square voltage for these noises can be written as [12,13]

$$V_n^2 = V_T^2 + V_J^2 + V_{Vn}^2 + V_{In}^2 + V_R^2 + V_P^2, \qquad (10)$$

where V_P is the popcorn noise.

2. Popcorn-noise model

Popcorn noise generated in a pyroelectric detector, due to the changes in its working temperature, causes rapid change in instantaneous mean value of a signal [14]. After random time from the change of a mean signal value, the previous state occurs. Duration of a state of the changed mean signal value can be of several microseconds to several milliseconds. The change in a mean value can be positive – increase in a mean signal value and negative – decrease in a mean signal value.

A voltage signal from the detector, originating from a thermal object (e.g., from a moving person), is characterised by rise and decay times that are long in comparison with popcorn noise time [15]. A spectrum of an effective signal is in the range of the lowest frequencies, i.e., below 20 Hz (Fig. 2). Additionally to the effective signal and popcorn noise, significant are also other noises generated in a detector (first of all thermal noise and *1/f* type noise). It results from the measurements that the spectrum of these noises is almost uniform for the frequencies of above 10 kHz. Below this frequency, the noises of *1/f* type are dominant.

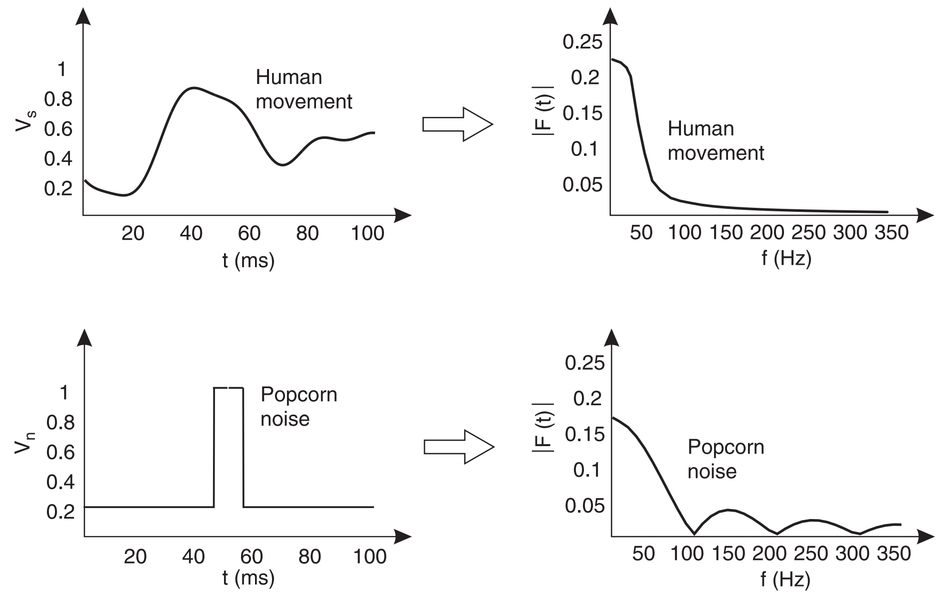

Fig. 2. Frequency spectrum.

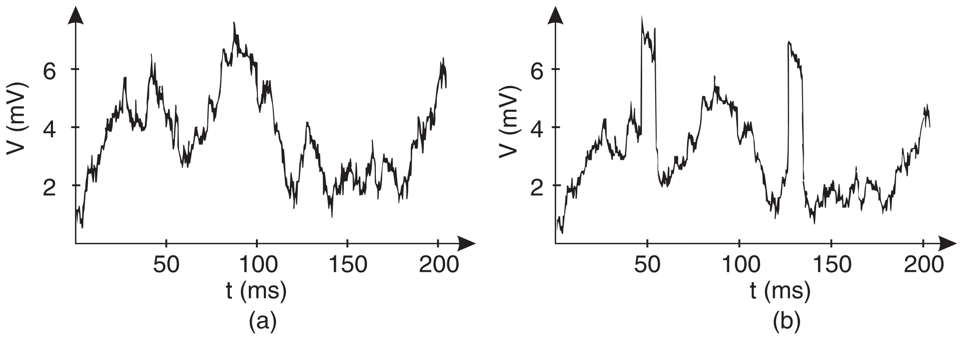

Fig. 3. Diagram of a signal spectrum from a pyroelectric detector with no popcorn-noise (a), and with popcorn-noise (b).

It is difficult to reduce thermal noise and *1/f* noises occurring in a useful band. However, in some conditions, popcorn noise can be identified and reduced. Popcorn noise in analogue signal can be identified both in time and frequency domains.

Exemplary signal courses obtained from a pyroelectric detector with no popcorn noise and with popcorn noise are presented in Figs. 3, 4, and 5. Figure 3(a) shows a diagram of signal spectrum from a pyroelectric detector with no popcorn noises. The spectrum was obtained using fast Fourier transform (FFT) for consecutive 256 samples of a signal and sampling frequency equal to 1.2 kHz. Additionally, Fig. 4 presents a graph (dashed line) of the function $a(f) = r/f + b$ that limits a signal spectrum from the upper part. For the considered case $r = 23$ [mV/Hz] and $b = 0.1$ [mV] was assumed.

The values of the limiting function parameters *r* and *f* were chosen on the basis of spectrum analysis of a signal from pyroelectric detector obtained for a lot of input data (tens of consecutive groups of 256 samples of a signal). It can be seen that any graphs of particular group of samples intersects the limiting function graph *a(f)*.

Similar diagram for the signal with popcorn noise is shown in Fig. 5. It can be clearly seen that spectrum components exceed the limiting curve. Detection of popcorn noise consists in determination of the spectrum components fulfilling the condition

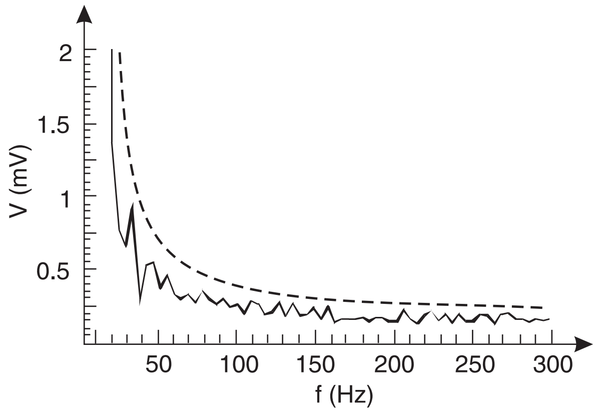

Fig. 4. Graph (dashed line) of a function *a*(*f*) that limits a signal spectrum.

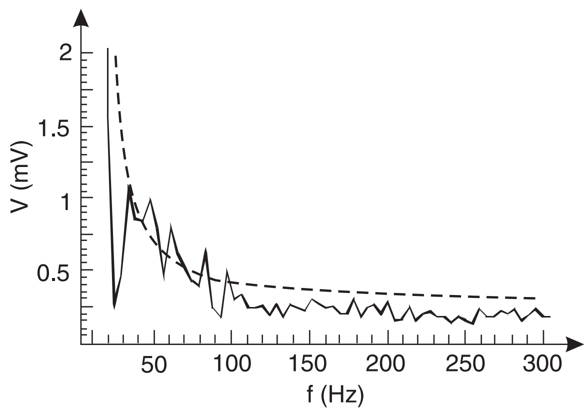

Fig. 5. Graph of a function *a*(*f*) when popcorn noise occur.

$$V(f) > a(f) \tag{11}$$

where *a(f)* is the function limiting spectrum from the upper part.

Values of the parameters *r* and *b* should be chosen experimentally. The function *a(f)* is the upper limit of a spectrum of the input signal when only white noise and *1/f* noise occur. The parameter *r* determines accessible level of *1/f* noises and the parameter *b* maximum accessible level of white noise. It results from the presence of components from the popcorn noise in the input signal that the components exceeding values of the limiting function *a(f)* appear.

Reduction of the popcorn noise, on the basis of spectral analysis, is as follows:

- input signal is analysed in the groups of *n* samples (*n* have to be natural power of the number 2), e.g., $n = 256$),
- group of *n* samples is converted, using discrete Fourier transform, resulting in the sequence of complex numbers of the transform of V_i form,
- n/2 – 1 comparisons is performed, $V_i > \alpha i f_{samp} / n$ $i = 1, 2, \ldots, n/2-1$, number of positive comparison results is denoted as *c,*
- checking of the condition $c \geq k$: when the condition is fulfilled – popcorn noise is present, instead of the analysed group of samples, the samples of the value equal to mean value of the samples of the previous group are taken, when condition is not fulfilled – the content of the analysed group is not changed.

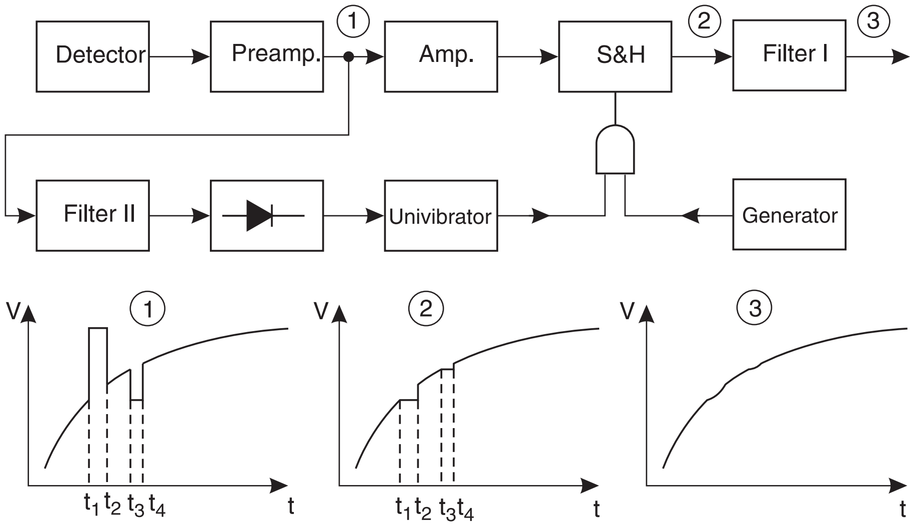

Fig. 6. Block diagram of detection system I.

Efficiency of the described method depends on the number of samples in the analysed group of signal samples and, first of all, adequate selection of the parameters *k, r,* and *b*. The parameters *r* and *b* can be determined directly on the basis of a measurement of envelope of the input signal spectrum before the signal analysis. Optimum value of the parameter *k* depends on particular application, detector type, and the nature of disturbances (noise). To eliminate the popcorn noise we designed two signal-processing circuits. First, a signal processing circuit of the photoreciver contains: low noise preamplifier, voltage amplifier, comparator, output circuit, and a circuit detecting popcorn noise. Second, we used digital signal processor (DSP) in a signal processing circuit. It blocks frequency components of the popcorn noise. So, an error signal is reduced from the photoreciver output even if popcorn noise occurs.

3. Signal processing circuits

Figure 6 shows the block diagram of the receiver with a circuit of popcorn noise reduction of the detector (version I). This circuit of signal processing of the photoreciver contains: low noise preamplifier, voltage amplifier, sample and hold circuit, low pass filter, and a circuit detecting the popcorn noise [16].

Low pass filter I "smooths" the output signal peaks generated in the process of signal switching. The detecting popcorn-noise circuit contains high pass filter extracting popcorn pulses – filter II, rectifier, univibrator, generator, and a gate.

Time courses for particular points of a receiver are denoted 1, 2, and 3. In the main path of the receiver, sample & hold (S&H) system has been used which samples the signal with a frequency of about 200 kHz. The sampled signal is filtrated before its reaches the receiver output. Blocking the sampling pulses for the period a little longer than the disturbance duration reduces the disturbing pulses. The S&H system records the latter value of the useful signal (before a popcorn noise occurs). The disturbing pulses are separated by high-pass filter and directed to two-half rectifier. Positive pulses trigger the univibrator. The pulses from univibrator and generator simultaneously reach the gate's output causing the break in a signal sampling.

Figure 7 shows the block diagram of the microprocessor circuit for the detector. There are nine main blocks: preamplifier, filter, A/D converter, digital signal processor,

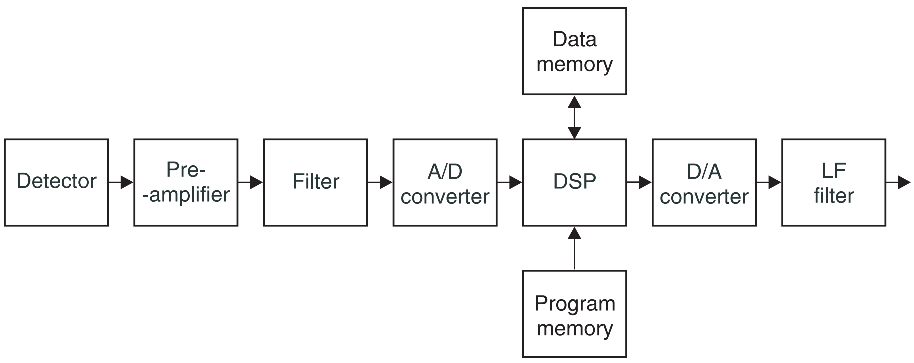

Fig. 7. Block diagram of digital signal processor circuit.

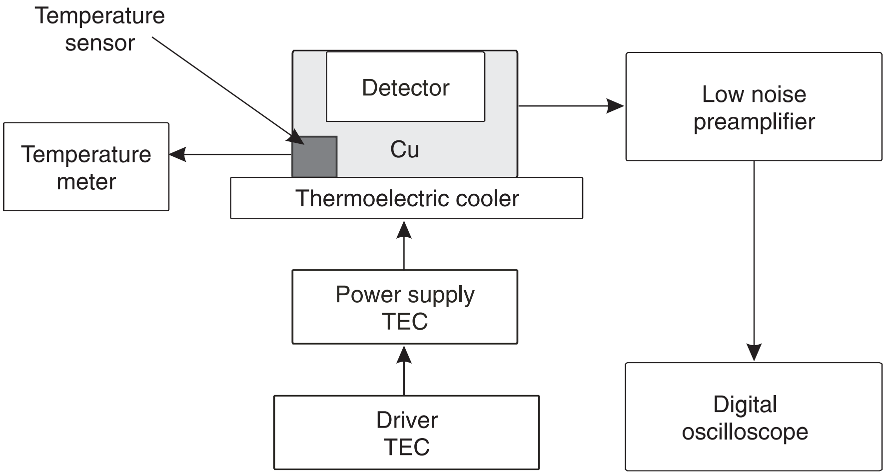

Fig. 8. Block diagram of a stand for popcorn-noise measurement.

D/A converter, low frequency filter, data memory, and programme memory. Signal form the preamplifier and low pass filter is converted in A/D converter. In the digital signal processor circuit (DSP), spectrum of the signal is compared with mathematical model of the popcorn noise. If the popcorn noise appears its spectrum is removed by the digital filter in the DSP. Then, inverse fast Fourier transform (IFFT) was applied to the signal. In this way we removed a spectrum of the popcorn noise. Thus, at the output, we can receive only the signal from a thermal object.

4. Experimental results

Special stand has been built for popcorn noises investigations (Fig. 8). Detector with a temperature sensor was located in a copper block fixed to thermoelectric cooler (TEC). Programmable controller and TEC supplier ensure the required velocity and mode of changes in a detector temperature vs. time. Both heating and cooling of a detector were possible. Data recorded with digital oscilloscope were used to formulate mathematical model of the considered popcorn noise. Figure 9 shows the results of investigations of receiver I and in Fig. 10 of receiver II [16].

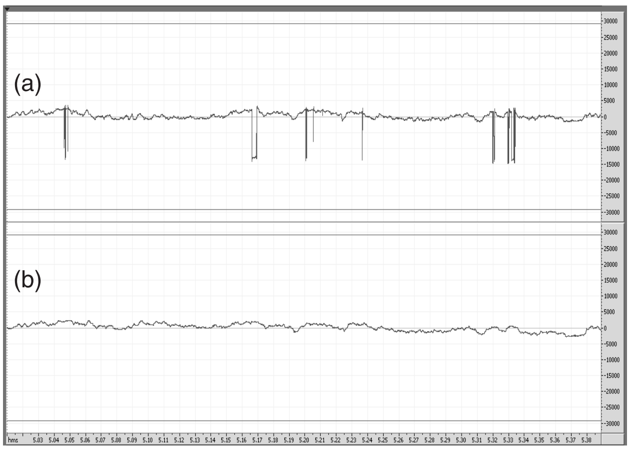

Fig. 9. Results of investigation of receiver I.

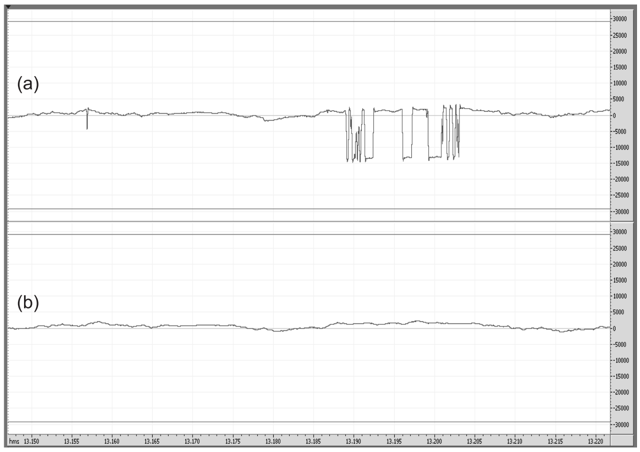

Fig. 10. Results of investigation of receiver II.

The course presented in the upper part of the screen illustrates the voltage signal at the detector output and the bottom course shows the voltage signal at the output of a receiving path equipped with the system of popcorn noise elimination.

5. Conclusions

The described methods of noise reduction (in time and frequency domains) were used to develop algorithms useful for design of IR receivers. Unique receivers with pyroelectric detectors have been made, i.e., one analogous receiver and another one operating on the basis of digital processing of the signals. Investigations of these receivers have been carried out using specially built measuring stand.

The obtained results confirmed correctness of the used mathematical models and algorithms ensuring minimisation of popcorn noise influence.

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