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A thermopyroelectric infra-red detector

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Abstract—A new type of thermal infra-red detector is described which combines a thermoelectric and a pyroelectric detector in a single element and which has a uniform frequency response in the range from zero to high frequencies determined by the detector electric time constant. An equivalent circuit of the detector is proposed, the frequency and transient responses are analysed and the results of the analysis are checked experimentally. Calculation of the frequency and practically attainable noise characteristics of the detector with most effective thermoelectric and pyroelectric materials is carried out. The detector noise equivalent power and detectivity constitute 10^{-9} W Hz$^{-0.5}$ and 10^{8} cm Hz$^{0.5}$ W^{-1}, respectively, at the time constant of 36 ms. A decrease in the time constant by a factor of 100 causes deterioration of the noise equivalent power and of the detectivity to 2×10^{-8} W Hz$^{-0.5}$ and 15×10^{6} cm Hz$^{0.5}$ W^{-1}, respectively.

INTRODUCTION

ONE OF the main tasks facing heat sensing is the design of dynamically perfect heat flow detectors characterized by broad band and high signal-to-noise ratios. The use of such instruments is the essential prerequisite to obtain reliable information about the thermal state of the object under study. Most of industrial technological processes are characterized by variable heat generations with frequencies from hundredths of one hertz to hundreds of kilohertz and over. For example, in radiative heat transfer in the furnaces of steam generators, high-rate slowly varying radiation fluxes are accompanied by weak rather quickly changing (with frequencies above 1 Hz) thermal fluctuations—the so-called 'fire twinkling'. The frequency of twinkling depends on the quality and stability of burners and therefore is an important characteristic of the process.

Investigations of radiative heat transfer make imperative a search for infra-red detectors, thermal ones in particular, which have uniform frequencies and spectral responsivities within wide ranges [1–6]. Among thermal infra-red devices the greatest interest is being shown in thermoelectric (TD) and pyroelectric (PD) detectors which are generator-type instruments needing no additional power sources [7, 8].

Usually, the sensing element of a PD is a spontaneously polarizable crystal with metal electrodes attached to its opposite faces. If the temperature of the sensing element is constant, the internal charge of the crystal–electrodes system is balanced out by the surface charges. On variation of temperature, when, for example, the detector is exposed to a modulated radiation flux, unbalanced charges appear on the sensing element electrodes and a pyroelectric current passes across the load resistor. The current strength is proportional to the derivative of the temperature increment in time. Therefore, a PD is insensitive to constant or slowly varying radiation fluxes and its responsivity in the infralow frequency range is proportional to the modulation frequency. The response time of a PD is determined by the speed of the attainment of spontaneous polarization the theoretical limit of which is about 10^{-12} s [8].

Generally a TD is an inertial detector with the response time determined by the thermal time constant. Special constructions of a TD with a low heat capacity and forced heat removal permit one to attain a time constant of 10^{-6} s [9], but at the cost of a sharp decrease in the detectivity. Therefore, when used separately, PD and TD cannot measure radiation fluxes over wide ranges—from zero to high frequencies—with a fairly good detectivity. Electric correction of the TD and PD frequency responses, for example, by means of operational amplifiers, is of little value at a correction factor of more than 100 [10].

The possibility of creating a thermopyroelectric infra-red detector (TPD) which combines, in a single element, the advantages of the TD and PD was first demonstrated in ref. [1], and its realization, calibration and application for studying continuous radiation power fluctuations were described in refs. [4, 5].

The aim of this paper is to give a theoretical analysis of the frequency response of a TPD, to verify theoretical results experimentally and to calculate the practically attainable noise characteristics of this device.

DETECTOR DESIGN

A TPD (Fig. 1) consists of a pyroactive lithium niobate plate (1) (c-cut crystal of 16 mm in diameter and 0.2 mm thick) with an NiCr electrode (2) deposited on the irradiated face and a constantan electrode on the non-radiated face of the crystal placed on a massive copper ring (3). The central part of the constantan electrode is connected to a 0.1 mm

NOMENCLATURE

A_0 receiving area [cm^2]
C_0, C_p, C_c total, pyroelectric crystal and input circuit capacitance, respectively [F]
c heat capacity of sensor element [$J\,K^{-1}$]
c_1 heat capacity of sensor unit volume [$J\,K^{-1}\,m^{-3}$]
D^* normalized detectivity [$cm\,Hz^{0.5}\,W^{-1}$]
d sensor thickness [m]
$\sqrt{(\bar{e}^2)}$ equivalent generator of scheme noise voltages reduced to the inlet
f frequency [Hz]
Δf equivalent noise bandwidth [Hz]
G total coefficient of heat losses [$W\,K^{-1}$]
$\sqrt{(\bar{I}^2_D)}, \sqrt{(\bar{I}^2_{DC})}, \sqrt{(\bar{I}^2_C)}$ equivalent generators of noise currents caused by detector Johnson noise, input circuit Johnson noise and scheme current reduced to the inlet
i_n equivalent noise current reduced to the inlet
N gain coefficient of d.c. amplifier
R_C, R_L, R_T, R_0 input resistance, load resistance, resistance of thermoelectric detector, and total resistance, respectively [Ω]
R_p equivalent resistance of detector losses for pyroelectric detector [Ω]
S_r voltage responsivity [$V\,W^{-1}$]
T sensor temperature [K]
t time [s]
V_p, V_{DP}, V_T, V_{DT} signal and Johnson noise voltage of pyroelectric and thermoelectric detectors [V]
V_n equivalent noise voltage reduced to the inlet [$V\,Hz^{-0.5}$].

Greek symbols
α thermoelectric power [$V\,K^{-1}$]
γ pyroelectric coefficient [$C\,m^{-2}\,K^{-1}$]
δ dielectric loss angle [dimensionless]
ε electrical permittivity [dimensionless]
ε_0 permittivity of free space, $8.854 \times 10^{-2}\,F\,m^{-1}$
$\varepsilon_1, \varepsilon_2$ emissivity of the sensor front and rear faces [dimensionless]
θ average temperature increment in the sensor [K]
σ Stefan–Boltzmann constant, $5.6697 \times 10^{-8}\,J\,m^{-2}\,s^{-1}\,K^{-4}$
τ_e, τ_T electrical and thermal time constant of the detectors [s]
τ time [s]
Φ radiant flux [W]
ω angular frequency [$rad\,s^{-1}$].

Subscripts
0 thermopyroelectric detector
1 pyroelectric detector
2 thermoelectric detector
Σ sum.

diameter copper wire (5). The constantan electrode (4), together with the copper ring (3) and the copper wire (5) form a Gardon type thermoelectric detector [11] which is also the ground electrode of a PD. On irradiation of the detector, a pyroelectric output signal from electrode 2 bears information about a rapidly varying radiation flux, while a thermoelectric output from electrode 5 bears information about a constant, or a slowly varying, radiation flux.

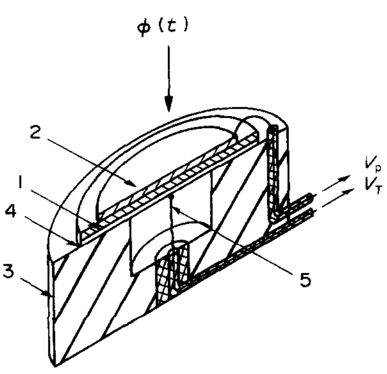


FIG. 1. Arrangement of the thermopyroelectric detector design.

HEAT-ELECTRIC EQUIVALENT CIRCUIT

The heat balance equation for a TPD as a system with lumped parameters can be written as

$$c\frac{d\theta}{dt} + G\theta = \varepsilon_1 \Phi(t). \qquad (1)$$

If an average temperature increment of the detector is far smaller than the ambient temperature, then, under zero initial conditions ($\theta = 0$; $t = 0$), the solution of equation (1) can be presented as [12]

$$\theta = \frac{\varepsilon_1}{c} e^{-t/\tau_T} \int_0^t e^{\tau/\tau_T} \Phi(\tau)\, d\tau \qquad (2)$$

where

$$t = \frac{c}{G}.$$

The thermoelectric equivalent circuit is presented in

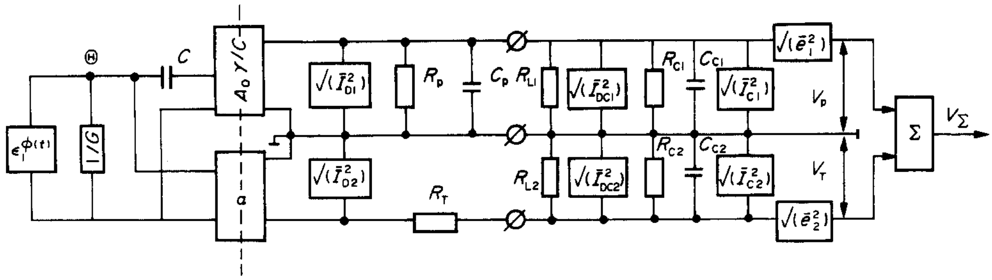


FIG. 2. Heat-electric equivalent circuit of the TPD.

Fig. 2 [6]. To the left of the dashed line, the equivalents of the thermal quantities of equation (1) are plotted, to the right the equivalents of the electric quantities (indices 1 and 2 correspond to PD and TD, respectively). Blocks 1 and 2 'simulate' the processes of radiation flux transformation into pyroelectric and thermoelectric signals. The transition coefficient for block 1 is $A_0\gamma/c$, for block 2 it is α.

From the equivalent circuit for PD and TD one can write the following equations:

$$\frac{\mathrm{d}(V_p C_0)}{\mathrm{d}t} - \frac{V_p}{R_0} = I_p \tag{3}$$

$$V_T = \alpha\theta \tag{4}$$

where V_p is the voltage signal measured across the load resistor

$$I_p = A_0\gamma\frac{\mathrm{d}\theta}{\mathrm{d}t}$$

is the pyroelectric current [11]

$$C_0 = C_p + C_c, \quad R_0 = R_p + R_L + R_c.$$

Taking into account equation (2), equations (3) and (4) will take on the forms

$$\frac{\mathrm{d}(V_p C_0)}{\mathrm{d}t} + \frac{V_p}{R_0} = \frac{\varepsilon_1}{c}A_0\gamma\frac{\mathrm{d}}{\mathrm{d}t}\left(\mathrm{e}^{-t/\tau_T}\int_0^t \mathrm{e}^{\tau/\tau_T}\Phi(\tau)\,\mathrm{d}\tau\right) \tag{5}$$

$$V_T = \frac{\varepsilon_1\alpha}{c}\left(\mathrm{e}^{-t/\tau_T}\int_0^t \mathrm{e}^{\tau/\tau_T}\Phi(\tau)\,\mathrm{d}\tau\right). \tag{6}$$

ANALYSIS OF FREQUENCY AND TRANSIENT CHARACTERISTICS OF A TPD

Frequency and transient characteristics of a TPD can be analysed by solving equations (5) and (6) for two cases:

(a) for a sinusoidally modulated radiation flux $\Phi(\tau) = \Phi_0(1+\mathrm{e}^{\mathrm{i}\omega t})$ where Φ_0 is the amplitude of the radiation flux;

(b) for step irradiation of a TPD at $\Phi(\tau) = 0 (\tau < 0)$ and $\Phi(\tau) = \Phi_0 (\tau \geqslant 0)$.

For the steady-state conditions in case (a), the solutions of equations (5) and (6) can be written as

$$V_p = \frac{\varepsilon_1 A_0\gamma R_0 \mathrm{i}\omega\Phi_0\,\mathrm{e}^{\mathrm{i}\omega t}}{G(1+\mathrm{i}\omega\tau_T)(1+\mathrm{i}\omega\tau_e)} \tag{7}$$

$$V_T = \frac{\varepsilon_1\alpha\Phi_0\,\mathrm{e}^{\mathrm{i}\omega t}}{G(1+\mathrm{i}\omega\tau)} + \frac{\varepsilon_1\alpha\Phi_0}{G} \tag{8}$$

where

$$\tau_e = R_0 C_0.$$

In case (b) the solutions of equations (5) and (6) will be

$$V_p(t) = \frac{\varepsilon_1 A_0\gamma R_0}{c}\frac{\tau_T}{\tau_T-\tau_e}\Phi_0(\mathrm{e}^{-t/\tau_T}-\mathrm{e}^{-t/\tau_e}) \tag{9}$$

$$V_T(t) = \frac{\varepsilon_1\alpha}{G}\Phi_0(1-\mathrm{e}^{-t/\tau_T}). \tag{10}$$

In accordance with the scheme of Fig. 2, the output signal of the ideal summing element without any noise and distortions for case (a) is

$$V_\Sigma(\omega) = V_p(\omega) + V_T(\omega)$$

$$= \frac{\varepsilon_1\alpha}{G}\frac{\left[1+\mathrm{i}\omega\left(\tau_e + \dfrac{A_0\gamma R_0}{\alpha}\right)\right]}{(1+\mathrm{i}\omega\tau_T)(1+\mathrm{i}\omega\tau_e)}\Phi_0(1+\mathrm{e}^{\mathrm{i}\omega t}) \tag{11}$$

and for case (b) is

$$V_\Sigma(t) = V_p(t) + V_T(t)$$

$$= \frac{\varepsilon_1\alpha}{G}\Phi_0\frac{A_0\gamma R_0}{\alpha}\frac{\tau_T}{\tau_T-\tau_e}(1-\mathrm{e}^{-t/\tau_e}). \tag{12}$$

In equations (11) and (21)

$$S_0 = \frac{\varepsilon_1\alpha}{G}$$

and

$$\tau_0 = \frac{A_0\gamma R_0}{\alpha}.$$

Physically S_0 is the volt–watt responsivity of a TPD to a non-modulated radiation flux. Taking equations (5) and (6) into account τ_0 is the ratio of temperature increase of the TPD element to the derivative of this value in the case of small τ_e and equal voltage signals of a PD and a TD.

The volt–watt responsivity of a TPD in the cases of sinusoidally modulated and step-wise irradiation are determined, respectively, as

$$S_v(\omega) = \left|\frac{V_\Sigma(\omega)}{\Phi_0(1+e^{i\omega t})}\right|$$

$$= S_0\left[\frac{1+\omega^2(\tau_e+\tau_0)^2}{(1+\omega^2\tau_T^2)(1+\omega^2\tau_e^2)}\right]^{0.5} \quad (13)$$

$$S_v(t) = \frac{V_\Sigma(t)}{\Phi_0} = S_0\frac{\tau_0}{\tau_T-\tau_0}(1-e^{-t/\tau_e}). \quad (14)$$

Letting $\tau_0/\tau_T = m$ and $\tau_e/\tau_T = n$ equations (13) and (14) can be written, respectively, as

$$S_v(\omega)/S_0 = \left[\frac{1+\omega^2\tau_T^2(m+n)^2}{(1+\omega^2\tau_T^2)(1+\omega^2\tau_e^2)}\right]^{0.5} \quad (15)$$

$$S_v(t)/S_0 = \frac{m}{1-n}(1-e^{-t/n\tau_T}). \quad (16)$$

It follows from equations (15) and (16) that when $n \ll 1$ and $m \gg 1$ a TPD operates as a pyroelectric detector and when $n \ll 1$ and $m \ll 1$ it operates as a thermoelectric detector with the time constant τ_T. When $n \ll 1$, $m = 1$, a TPD has a uniform frequency response in the range from ultralow to high frequencies bounded by the speed of spontaneous polarization establishment and, virtually, by the electric time constant τ_e of the detector. Figures 3 and 4 show $S_v(\omega)/S_0$ and $S_v(t)/S_0$ for different values of m and n.

EXPERIMENTAL DATA

The transient characteristics of the TPD specimen under study were taken on application of step-wise illumination. The light from a reflector lamp was formed by an optical system with a mechanical shutter placed in the first focus to produce a 2 ms radiation leading edge and with the TPD placed at the second focus. The other input was connected with the reference Si photodiode irradiated simultaneously with the TPD.

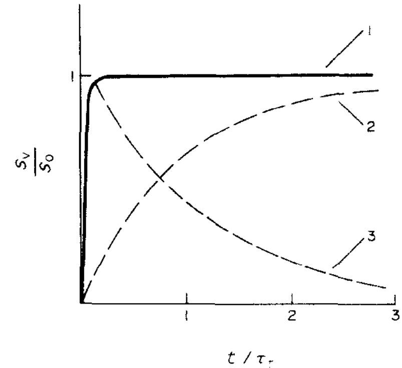


FIG. 4. Transient characteristics of the TPD: curve 1 ($n \ll 1$, $m = 1$); curve 2 ($n \ll 1$, $m = 0.1$); curve 3 ($n \ll 1$, $m = 100$).

In Figs. 5(a)–(c) the oscillograms of the transient characteristics of the TPD, PD, TD and of the Si photodiode (upper curve on each oscillogram) are presented. For the TPD specimen studies (Fig. 1) $\tau_0 = 0.13$ ms, $\tau_T = 2.5$ s. It is seen from Figs. 5(a) and (b) that the transient characteristics of the TD and PD rise and fall together with the thermal time constant τ_T. The transient characteristics of the TPD at $m = 1$ (Fig. 5(c)) and of a quantum detector are similar, thus confirming the uniformity of the TPD frequency response.

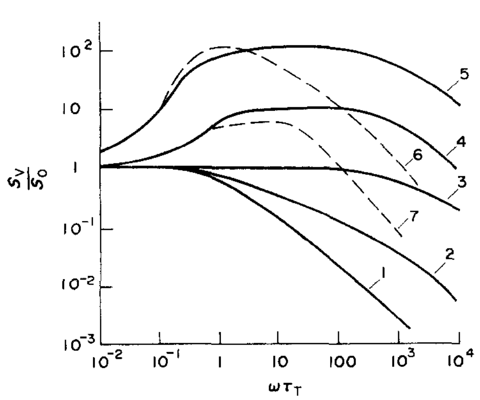


FIG. 3. TPD frequency response: curve 1 ($n = 10^{-3}$, $m = 0.1$); curve 2 ($n = 10^{-3}$, $m = 0.5$); curve 3 ($n = 10^{-3}$, $m = 1$); curve 4 ($n = 10^{-3}$, $m = 10$); curve 5 ($n = 10^{-3}$, $m = 10$); curve 6 ($n = 10^{-1}$, $m = 1$); curve 7 ($n = 10^{-1}$, $m = 100$).

NOISE CHARACTERISTICS

The consideration in the paper is confined to the case $m = 1$. The limiting noise characteristics of a TPD are determined for the best thermoelectric and pyroelectric materials. Since the Johnson noise in all of the known thermal detectors exceeds the temperature fluctuation noise by about two orders of magnitude, it is assumed that only the Johnson noise limits the noise equivalent power of the TPD.

The r.m.s. of the Johnson noise voltage for the TPD is

$$\bar{V}_{TPD}^2 = \bar{V}_{PD}^2 + \bar{V}_{TD}^2. \quad (17)$$

Taking into account the Nyquist generalized equation for a PD, equation (17) can be written as

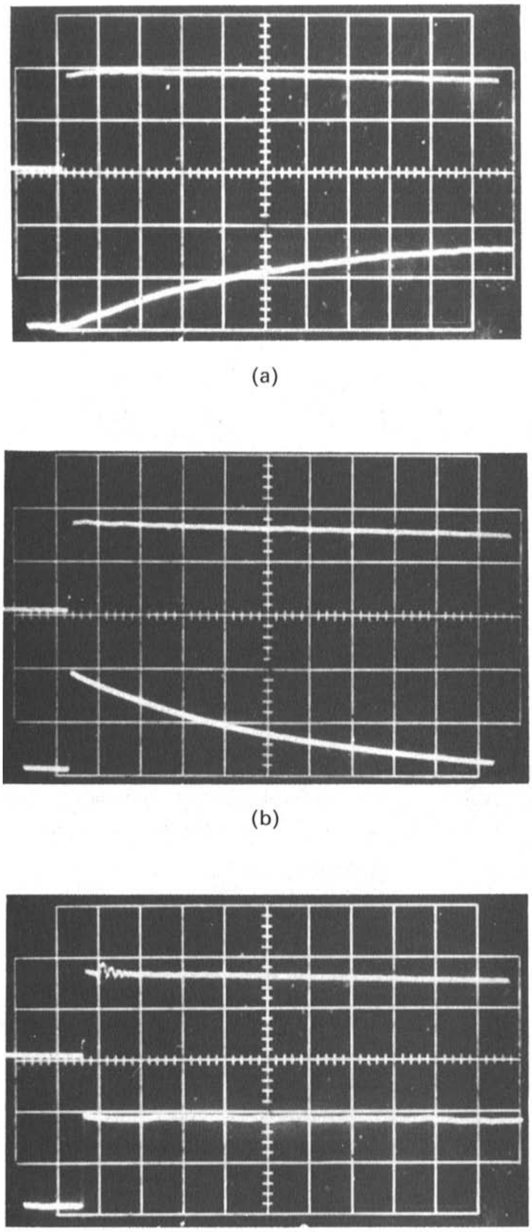
$$\bar{V}_{TPD} = [4kT\Delta f(R_0/(1+\omega^2\tau_e^2)+R_T)]^{0.5}.$$

Then the noise equivalent power normalized to a 1 Hz bandwidth is

$$\Phi_n = \frac{\bar{V}_{TPD}}{S_v}$$

$$= \frac{1}{S_0}\left[\frac{4kT[R_T(1+\omega^2\tau_e^2)+R_0](1+\omega^2\tau_T^2)}{1+\omega^2(\tau_e+\tau_0)^2}\right]^{0.5}. \quad (18)$$

The detectivity is $D^* = A_0^{0.5}/\Phi_n$.



(a) (b) (c)

FIG. 5. Oscillograms of the transient characteristics: (a) of the TD; (b) of the PD; (c) of the PTD and of the Si photodiode (upper ray on each photograph).

The analysis of equation (18) for the frequency range $0 \leqslant \omega \leqslant \tau_e^{-1}$ and for $R_{L1} \ll R_p$, $R_T \ll R_{L1}$, $\tau_0 = \tau_T = A_0\gamma R_0/\alpha$ yields

$$\Phi_n = (4kTR_{L1})^{0.5}\frac{G}{\varepsilon_1\alpha} = \frac{c(4kTR_{L1})^{0.5}}{\varepsilon_1 A_0\gamma R_{L1}}$$

$$= \frac{c_1 d}{\varepsilon_1\gamma}\left(\frac{4kT}{R_{L1}}\right)^{0.5}. \quad (19)$$

With a very high R_{L1}, $R_0 = R_p = (\omega C_0 \tan\delta)^{-1}$ and $C_0 = \varepsilon\varepsilon_0 A_0/d$. Then, when $\tau_T \gg \tau_e$, the relationship of the noise equivalent power is

$$\Phi_n = \frac{c_1}{\varepsilon_1\gamma}(4kTA_0\omega\varepsilon\varepsilon_0 d\tan\delta)^{0.5} \quad (20)$$

and the detectivity is

$$D^* = \frac{\varepsilon_1\gamma}{c_1}(4kT\omega\varepsilon\varepsilon_0 d\tan\delta)^{-0.5}.$$

Using equation (18) it is possible to obtain relationships for the noise equivalent power of a PD at low frequencies and for a TD at high frequencies

$$\Phi_{np} = \frac{(4kTR_0)^{0.5}G(1+\omega^2\tau_T^2)^{0.5}}{\omega\varepsilon_1 A_0\gamma R_0} \quad (21)$$

$$\Phi_{nT} = \frac{(4kTR_T)^{0.5}\omega c}{\varepsilon_1\alpha}. \quad (22)$$

Comparison of equations (19)–(22) shows that at ultralow frequencies the TPD has an advantage in Φ_n over the PD, since the responsivity of the latter over this range is proportional to ω. On the other hand, at high frequencies the Φ_n of the PD is better than that of the TD, because at high frequencies the Φ_n of the PD falls proportionally to $\omega^{0.5}$, while the Φ_n of the TD falls proportionally to ω. The physical explanation of this fact is as follows. The PD is a capacitive element and therefore when $\omega > (R_0C_0)^{-1}$ a decrease in the responsivity is accompanied by noise reduction according to the Nyquist generalized equation. The volt–watt responsivity of the TD at high frequencies also falls proportionally to ω, but the Johnson noise is 'white', i.e. it is independent of frequency within a wide band.

Determine D^* for the hybrid TPD having a uniform frequency response within the range $0 \leqslant \omega \leqslant \tau_e^{-1}$. Among thermoelectric and pyroelectric detectors the most sensitive are the Schwarz thermopiles, used in spectral devices, and pyroactive elements based on triglycine sulphate or lithium tantalate crystals. Consider a hypothetical model based on the Schwarz thermopile with the receiver made from a lithium tantalate plate with electrodes applied to both its sides. One of the electrodes is blackened and the detector is placed in vacuum. The values of Φ_n and D^* of the TPD will be determined at the following parameters of thermo- and pyroelectric materials: $\alpha = 0.5$ mV K^{-1}, $d = 10$ μm, $A_0 = 0.01$ cm^2, $\gamma = 2.5\times10^{-4}$ C m^{-2} K^{-1}, $c_1 = 4.43\times10^6$ J m^{-3} K^{-1}, $\varepsilon = 46$, $\tan\delta = 0.01$.

From the condition $m = 1$ determine the load resistance of the TPD

$$R_{L1} = \frac{\alpha\tau_T}{A_0\gamma} = \frac{\alpha c_1 d}{\gamma G}.$$

As the volume is evacuated it is assumed that the coefficient of heat loss G is mainly controlled by radiation from the receiver surface. With this assumption and taking into account that the receiver temperature increase is much smaller than its absolute value, it is possible to write

$$G \cong 4(\varepsilon_1+\varepsilon_2)A_0\sigma T^3.$$

The electric constant time of the TPD is given by the formula $\tau_e = \varepsilon\varepsilon_0 A_0 R_{L1}/d$. At $R_{L1} = 15$ MΩ, $\tau_e = 3.6 \times 10^{-4}$ s and, consequently, the upper boundary frequency is $f_{0.5} = 770$ Hz. Assuming, that $\varepsilon_1 + \varepsilon_2 \approx 1$, one obtains $S_0 = 77.5$ V W^{-1}. For $T = 295$ K the noise equivalent power and the detectivity of the TPD under study are, respectively

$$\Phi_n = 2 \times 10^{-8}\,\mathrm{V\,Hz^{-0.5}}$$

and

$$D^* = 5 \times 10^6\,\mathrm{cm\,Hz^{0.5}\,W^{-1}}.$$

The above relations are valid for a TPD operating under the conditions of ideal summing.

The TPD noise characteristics can be considerably improved by increasing the signal of the TD by a factor of N and at the same time by increasing the load resistance of the PD (R_{L1}) but this, however, will cause a decrease of $f_{0.5}$. In this case it is necessary to allow for the noise of the d.c. amplifier and of the PD matching circuit, for instance, of the source follower. Then, taking into account the additional noise, the expression for the Φ_n of TPD for frequencies $\omega < \tau_e^{-1}$ can be written as

$$\Phi_n = \frac{1}{S_0}[N^2 4kT(R_T + R_{L1}) + N^2 \overline{V_{n2}^2} + \overline{V_{n1}^2} + 4kTR_{L1} + \overline{i_{n1}^2} R_{L1} + N^2 \overline{i_{n1}^2}(R_T + R_{L1})]^{0.5}.$$

Due to the fact that ultralow frequency noise has been virtually little studied, the calculation was carried out for the frequencies higher than 1 Hz. At these frequencies, the equivalent noise voltages and currents of operational amplifiers do not exceed the values $\sqrt{(\overline{V_{n2}^2})} = 10^{-8}$ V Hz$^{-0.5}$, $\sqrt{(\overline{i_{n2}^2})} = 5 \times 10^{-10}$ A Hz$^{-0.5}$ [14] and for low noise FET transistors, $\sqrt{(\overline{V_{n1}^2})} = 10^{-8}$ V Hz$^{-0.5}$ and $\sqrt{(\overline{i_{n1}^2})} = 10^{-15}$ A Hz$^{-0.5}$.

Therefore, at $N = 100$, $R_{L1} = 1.5$ GΩ, one obtains $\tau_e = 36$ ms, $f_{0.5} = 7.7$ Hz and $\Phi_n = 10^{-9}$ W Hz$^{-0.5}$, $D^* = 10^8$ cm Hz$^{0.5}$ W^{-1}. The calculation shows that a further increase in the magnifying power ($N > 100$) and a simultaneous growth in R_{L1} do not lead to the gain in D^* because of the growing effect of the amplifier and FET transistor noises. Figure 6 shows the frequency characteristics of the responsivity and the detectivity of the TPD for different values of N and R_{L1}.

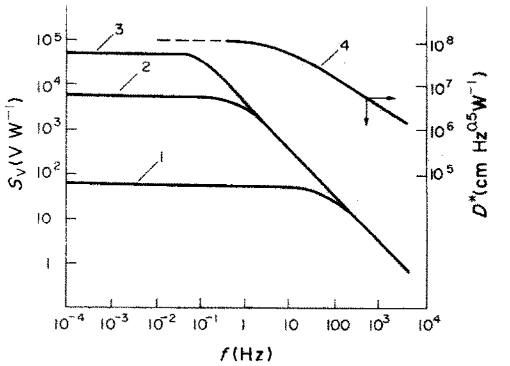


FIG. 6. Frequency response and detectivity of the TPD model: curve 1 ($R_{L1} = 15$ MΩ, $N = 1$); curve 2 ($R_{L1} = 1.5$ GΩ, $N = 100$); curve 3 ($R_{L1} = 15$ GΩ, $N = 10^3$); curve 4 ($R_{L1} = 1.5$ GΩ, $N = 100$).

CONCLUSIONS

The analytical and experimental studies of the proposed detector show that the TPD has a frequency response similar to that of a quantum infra-red detector, but at the same time it preserves the main advantage of a thermal detector—its flat spectral response. As a generator-type device the TPD does not need any additional power sources which is of great importance in practice. The design relationships obtained make it possible to determine the TPD volt–watt responsivity under sinusoidally modulated and stepwise radiation of the detector as well as its detectivity.

Though the existing methods of the PD low-frequency and the TD high-frequency corrections can be used for obtaining the uniform frequency response of each of these detectors, sharp deterioration of noise characteristics at the boundaries of the frequency bands decreases their detectivity. At the same time, the detectivity of the TPD with the uniform frequency response within the range $0 \leqslant \omega < \tau_e^{-1}$ varies comparatively little at the boundaries of this band.

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UN DETECTEUR THERMOPYROELECTRIQUE D'INFRAROUGE

Résumé—On décrit un nouveau type de détecteur d'infrarouge qui combine deux détecteurs, l'un thermoélectrique et l'autre pyroélectrique, dans un seul élément et qui a une réponse en fréquence uniforme depuis zéro jusqu'aux hautes fréquences, avec une constante de temps. Un circuit équivalent du détecteur est proposé, les réponses en fréquence et transitoires sont analysées et les résultats de l'analyse sont vérifiés expérimentalement. On calcule la fréquence et le bruit de fond caractéristique du détecteur pour différents matériaux thermoélectriques et pyroélectriques. La puissance équivalente du bruit du détecteur et la détectivité sont respectivement de 10^{-9} W $Hz^{-0,5}$ et 10^{8} cm $Hz^{0,5}$ W^{-1}, avec une constante de temps de 36 ms. Une diminution de la constante de temps par un facteur 100 provoque une détérioration de la puissance équivalente du bruit et de la détectivité, respectivement 2×10^{-8} W $Hz^{-0,5}$ et 15×10^{6} cm $Hz^{0,5}$ W^{-1}.

EIN THERMO- UND PYROELEKTRISCHER INFRAROTDETEKTOR

Zusammenfassung—Es wird ein neuer Typ eines thermischen Infrarotdetektors beschrieben, welcher einen thermoelektrischen und einen pyroelektrischen Detektor in einem einzigen Element kombiniert. Der Detektor hat ein einheitliches Frequenzverhalten im Bereich von Null bis zu hohen Frequenzen. Dies wurde aus der elektrischen Zeitkonstante des Detektors ermittelt. Es wird ein Ersatzschaltbild für den Detektor vorgeschlagen und das Frequenz- und Zeitverhalten analysiert. Die Ergebnisse werden durch Experimente überprüft. Berechnungen zur Frequenzcharakteristik und praktisch erreichbarem Rauschverhalten werden für die effektivsten thermo- und pyroelektrischen Materialien durchgeführt. Die äquivalente Rauschleistung beträgt 10^{-9} W $Hz^{-0,5}$ und die Detektierbarkeit 10^{8} cm $Hz^{0,5}$ W^{-1} bei einer Zeitkonstanten von 36 ms. Eine Verkleinerung der Zeitkonstante um den Faktor 100 bewirkt eine Verschlechterung der äquivalenten Rauschleistung auf 2×10^{-8} W $Hz^{-0,5}$ und der Detektierbarkeit auf 15×10^{6} cm $Hz^{0,5}$ W^{-1}.

ТЕРМОПИРОЭЛЕКТРИЧЕСКИЙ ПРИЕМНИК ИЗЛУЧЕНИЯ

Аннотация—Представлено устройство теплового приемника излучения нового типа, сочетающего в едином элементе термоэлектрический и пироэлектрический приемники и имеющий равномерную частотную характеристику чувствительности в диапазоне от нуля до высоких частот модуляции, определяемых электрической постоянной времени приемника. Предложена эквивалентная схема замещения приемника, проведен анализ частотных и переходных характеристик приемника, а также экспериментальная проверка результатов анализа. Проведен расчет частотных и практически достижимых предельных пороговых характеристик приемника при условии использования наиболее эффективных термоэлектрических и пироэлектрических материалов. Пороговый поток и обнаружительная способность приемника составили соответственно 10^{-9} Вт $Гц^{-0,5}$ и 10^{8} см $Гц^{0,5}$ $Вт^{-1}$ при постоянной времени 36 мс. Уменьшение постоянной времени в 100 раз влечет за собой ухудшение порогового потока до 2×10^{-8} Вт $Гц^{-0,5}$ и обнаружительной способности до 15×10^{6} см $Гц^{0,5}$ $Вт^{-1}$.