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Solar wind sensors: a method of increase in sensitivity

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Introduction

The measurements of the interplanetary plasma parameters allow to forecast a great number of phenomena in the Earth ionosphere and magnetosphere [1-6]. Finding out the fine structure of the Solar wind increases forecast accuracy.

The trapping multielectrode-modulation sensors have a wide spread due to the possibility of measuring the Solar-wind differential-energetic spectrum.

The measurements at a. c., having great advantages in the case, have some disadvantages as well. This is the shunting of the input signal by sensor-collector capacitance. The existence of this capacitance limits the value of the input preamplifier resistance and as a result — the sensor sensitivity. The decrease of the modulation frequency is undesirable due to sharp increasing of the flicker noise. Sensitivity increasing by means of the collector area enhancing is impossible on account of the proportional increasing of the shunting capacitance value. The authors of the work [6] have proposed to introduce a positive feed-back of capacitive character to the input preamplifier. But this method hardly decreases the sensor stability. The total input capacitance of the system becomes frequency dependent. In the same time it is well known that the maximum level of the sensor sensitivity can be realized when using wide-band pulse-amplitude modulation with pulse duration of 1/2 of the period.

A method of increase in sensitivity of Solar-wind sensor has been developed on the basis of the general principle of the modulation-parametric interactions reversibility, formulated [7, 11, 12]. The principle is in force for all kinds of signal manipulations. The essence of the principle consists in the equal possibility for "direct" and "reverse" conversions when interacting. Usually, as a result of direct conversion combined products (e. g. lower and higher combined-frequencies components) arise, which if exposed to reverse conversions cause a reaction of the system to external influences. The inversibility of interactions in electronic modulation-parametric systems allows to obtain effective low-noise negative C_-, G_- and L_-, R_- [10]. Using electromechanical modulation-parametric systems one can implement negative flexibility and friction [9].

The method proposed consists in the utilization of the developed four-frequency parametric systems (FFPS), exhibiting wide-band low-noise negative capacitance (C_-) and negative conductance (G_-). The sensitivity of the Solar-wind multielectrode-modulation sensor is increased essentially as a result of the compensation of its own capacitance and conductance by implemented effective low-noise negative C_- and G_-, having constant absolute values in a wide videofrequency bandwidth.

A general theory of the proposed FFPS, exhibiting wide-band (videofrequency bandwidth) low-noise negative C_- and G_- is developed. Expressions for absolute values of the negative parameters are derived and the dynamic characteristics are studied.

The noise properties of the system determining the sensor sensitivity are investigated theoretically. The system of parallely connected one-port of the Solar-wind trap, one-port with negative parameters C_- and G_- (FFPS) and two-port of the preamplifying stage is considered. General criteria for advisable use of negative parameters one-ports in the system are derived on the basis of comparison of the system-fluctuation sensitivities under the circumstances of present and absent parametric one-port (FFPS).

The system stability has been considered theoretically on the basis of a diagram of the interrelations of all influencing factors.

Analysis of noise properties

The interplanetary-plasma-trapping multielectrode-modulation sensor with a FFPS is schematically presented in Fig. 1. FFPS implements negative C_- and G_- in parallel with trap collector — sensor body.

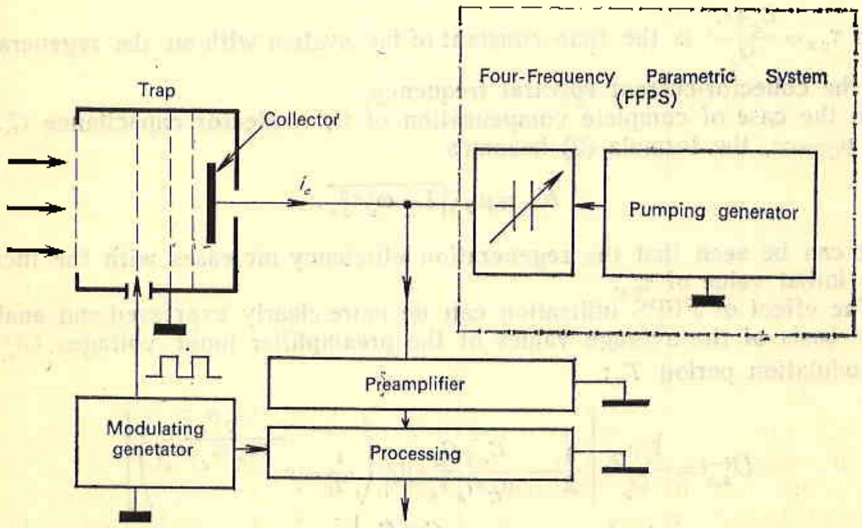

Fig. 1

The sensor electrical equivalent scheme is presented in Fig. 2, where i_c and C_c are respectively trap collector current and capacitance; C_- and G_- are wide-band low-noise negative capacitance and conductance, implemented by FFPS; G_a and C_a are preamplifier input conductance and capacitance and $U^{(\mp)}$

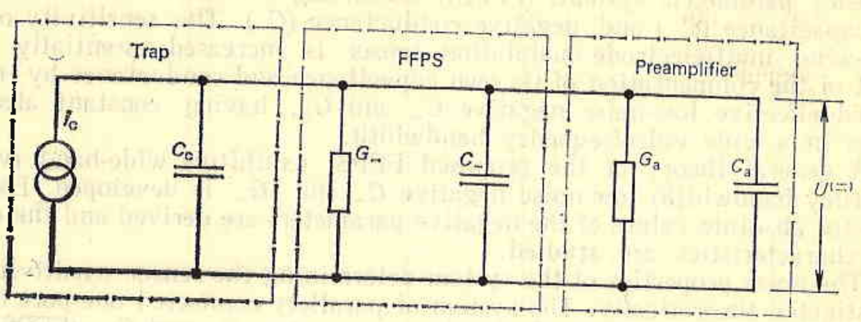

Fig. 2

is input preamplifier voltage with and without regenerative action of FFPS. Here and further on we use the index (−) for the regenerative case when using FFPS and the index (+) — for the common case without FFPS.

Introducing the regenerative gains

(1) $$\mu_C=\frac{C_c+C_a}{C_c+C_a-C_-}, \quad \mu_G=\frac{G_a}{G_a-G_-},$$

one could receive the gain of the resultant input-voltage increasing as

(2) $$K=\frac{U^{(-)}}{U^{(+)}}=\frac{\mu_C}{\left(\frac{\mu_C}{\mu_G}\right)^2+\omega_s^2\tau_{c\,a}^2}\sqrt{\left(\omega_s^2\tau_{c\,a}^2+\frac{\mu_C}{\mu_G}\right)^2+\omega_s^2\tau_{c\,a}^2\left(\frac{\mu_C}{\mu_G}-1\right)^2},$$

where $\tau_{c\,a}=\frac{C_c+C_a}{G_a}$ is the time constant of the system without the regeneration. ω_s is the collector-current spectral frequency.

In the case of complete compensation of the collector capacitance C_c, i. e. when $\mu_C\to\infty$, the formula (2) becomes

(3) $$K_\infty=\mu_G\sqrt{1+\omega_s^2\tau_{c\,a}^2}.$$

It can be seen that the regeneration efficiency increases with the increase of the initial value of $\tau_{c\,a}$.

The effect of FFPS utilization can be more clearly expressed and analysed on the basis of the average values of the preamplifier input voltages $U^{(\mp)}_{a,a}$ for the modulation period T_0:

(4) $$U^{(-)}_{a,a}=\frac{i_c\mu_G}{G_a}\left[\frac{1}{2}-\frac{C_c+C_a}{\mu_C G_a T_0}\mu_G\left(\frac{1}{2}-e^{-\frac{\mu_C G_a T_0}{2\mu_G(C_c+C_a)}}\right)\right]$$

$$\simeq\frac{1}{2}\frac{i_c}{G_a}\mu_G, \text{ since } \frac{C_c+C_a}{\mu_C G_a T_0}\mu_G\ll 1,$$

(5) $$U^{(+)}_{a,a} = \frac{i_c}{G_a}\left[\frac{1}{2} - \frac{C_c+C_a}{G_a T_0}\left(\frac{1}{2} - e^{-\frac{G_a T_0}{2(C_c+C_a)}}\right)\right] \simeq \frac{i_c T_0}{4(C_c+C_a)}, \text{ when } \frac{C_c+C_a}{G_a} \gg T_0.$$

The ratio of expressions (4) and (5) gives the gain, showing the efficiency of the FFPS utilization:

(6) $$K_a = \frac{U^{(-)}_{a,a}}{U^{(+)}_{a,a}} \simeq \frac{2(C_c+C_a)}{G_a T_0}\mu_G.$$

In all practical cases $K_a \gg 1$.

The effect of the sensitivity increase due to the FFPS utilization is to be considered more thoroughly. It is necesssry to prove that the ratio signal/noise $N^{(\mp)}$ is not getting worse when FFPS is added. The quantity $N^{(\mp)}$ can be expressed as follows:

— case with regeneration

(7) $$N^{(-)} = \frac{U^{(-)}_{a,a}}{\sqrt{\overline{U^2_{N\Sigma}}}} \simeq \frac{1}{2}\,\frac{i_c \mu_G}{G_a\sqrt{\overline{U^2_{N\Sigma}}}} = \frac{n S_c \Phi(W_\beta)\mu_G}{2G_a\sqrt{\overline{U^2_{N\Sigma}}}};$$

— case without regeneration

(8) $$N^{(+)} = \frac{U^{(+)}_{a,a}}{\sqrt{\overline{U^2_{Na}}}} \simeq \frac{1}{4}\,\frac{i_c T_0}{(C_c+C_a)\sqrt{\overline{U^2_{Na}}}} = \frac{n S_c \Phi(W_\beta) T_0}{4(C_c+C_a)\sqrt{\overline{U^2_{Na}}}}$$

where $i_c = n S_c \Phi(W_\beta)$, n — is the plasma density, S_c — is the trap collector area, $\Phi(W_\beta)$ — is a function, characterizing the charged-particles distribution in energy, $\overline{U^2_{N\Sigma}}$ — is the total average-quadratic noise voltage in the regenerative case (when FFPS is presented), $\overline{U^2_{Na}}$ — is the average-quadratic noise voltage of the preamplifier.

From Eqns. (7) and (8) one could derive expressions for minimum plasma density and minimum trap-collector current, which can be registered in two cases:

(9) $$n^{(-)}_{\min} = \frac{2N^{(-)}G_a\sqrt{\overline{U^2_{N\Sigma}}}}{\mu_G S_c \Phi(W_\beta)},$$

(10) $$n^{(+)}_{\min} = \frac{4N^{(+)}\sqrt{\overline{U^2_{Na}}}}{S_c \Phi(W_\beta)},$$

(11) $$i^{(-)}_{c\,\min} = \frac{2N^{(-)}G_a}{\mu_G}\sqrt{\overline{U^2_{N\Sigma}}},$$

(12) $$i^{(+)}_{c\,\min} = \frac{2N^{(+)}(C_c+C_a)}{T_0}\sqrt{\overline{U^2_{Na}}}.$$

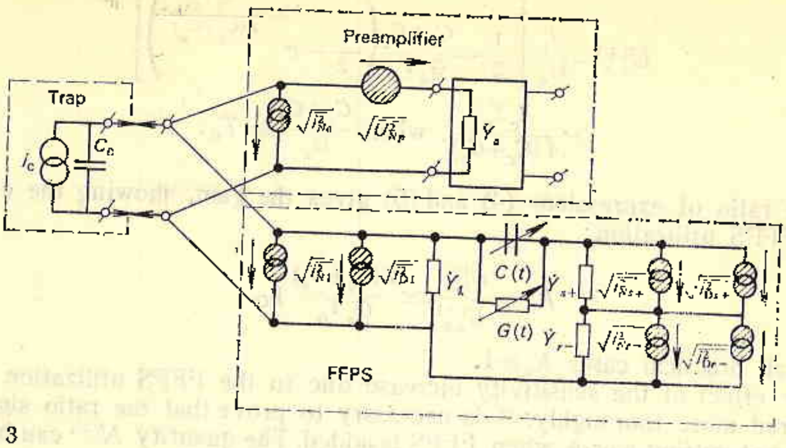

Fig. 3

Obviously, the conditions for efficient FFPS utilization can be written as

(13) $$N^{(-)} > N^{(+)},$$

(14) $$n^{(-)}_{\min} < n^{(+)}_{\min},$$

(15) $$i^{(-)}_{c\,\min} < i^{(+)}_{c\,\min}.$$

In order to form correct estimations of conditions (13), (14) and (15) it is necessary to determine the noise voltages $\overline{U^2_{N\Sigma}}$ and $\overline{U^2_{Na}}$.

The equivalent noise scheme of the Solar-wind sensor with FFPS is given in Fig. 3. The preamplifier is presented by its admittance $\dot{Y}_a = G_a + jB_a$ and noise sources $\overline{i^2_{Na}} = G_{Na} A$ and $\overline{U^2_{Np}} = R_{Na} A$, where $A = 4kT\,\Delta f$, G_{Na} and R_{Na} are equivalent preamplifier noise conductance and resistance respectively, k is Boltzman constant, T is absolute temperature and Δf is frequency band. A correlation admittance $\dot{Y}_{cor} = \frac{\sqrt{\overline{i^2_{Na}}}\ \sqrt{\overline{U^2_{Np}}}^{\,*}}{\left|\overline{U^2_{Np}}\right|}$ will be taken into account as well; here and further on the sign (*) marks the complex conjugate quantities.

FFPS is presented by parametric elements — capacitance $C(t)$ and conductance $G(t)$, input admittance $\dot{Y}_1 = G_1^0 + jB_1$ and admittances $\dot{Y}_{s+}$, $\dot{Y}_{r-}$ at combined frequencies $f_+ = f_p + f_s$ and $f_- = f_p - f_s$, $\dot{Y}_{s+} = G[1 + 2Qj(\eta - \xi)]$, $\dot{Y}^*_{r-} = G \times [1 - 2Qj(\eta - \xi)]$, f_p — pumping frequency, f_s — FFPS input signal or input noise-spectrum frequency, G — conductance of the FFPS oscillatory circuit, Q — Q-factor, $\eta = \frac{f_p^2 - f_r^2}{f_p^2}$ — relative detuning, f_r — oscillatory circuit resonance frequency, $\xi = \frac{f_s}{f_p}$, $f_s \ll f_p$.

Thermal noise and schrot noise are taken into consideration connecting to the circuit (Fig. 3) the corresponding noise sources $\overline{i^2_{Nm}} = ARe\,(\dot{Y}_m)$ and $\overline{i^2_{Dm}} = 2\,e\,I_0\,\Delta f_m$, where e — is the electron charge, I_0 — is d. c. through the parametric element; $m \to 1$, s+, r— indicate correspondingly the FFPS input circuit (1) and FFPS circuits of sum (s+) and difference (r—) combined frequencies.

A general noise equivalent scheme (Fig. 4) is formed on the basis of Fig. 3. FFPS is presented by the input admittance $\dot{Y}_1$ and the negative ad-

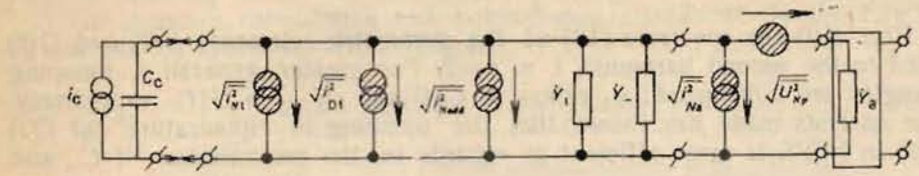

Fig. 4

mittance $\dot{Y}_- = -G_- - jB_-$, $B_- = \omega_s C_-$, input-circuit noise sources $\overline{i^2_{N1}}$ and $\overline{i^2_{D1}}$ and some additional noise source $\overline{i^2_{N\,add}}$, caused by noise conversion from the other FFPS circuits.

Using Fig. 4, desired noise voltages $\overline{U^2_{N\Sigma}}$ and $\overline{U^2_{Na}}$ may be expressed:

(16)
$$\overline{U^2_{N\Sigma}} = \frac{\overline{i^2_{N1}} + \overline{i^2_{D1}} + \overline{i^2_{N\,add}} + \overline{i_{Na}}}{|\dot{Y}_1 + \dot{Y}_- + \dot{Y}_a|^2} + \frac{\overline{U^2_{Np}}}{\left|\frac{\dot{Y}_a}{\dot{Y}_1 + \dot{Y}_-} + 1\right|} - 2\dot{Y}_{cor}\,\overline{U^2_{Np}}\;\overline{\frac{\dot{Y}^*_1 + \dot{Y}^*_-}{|\dot{Y}_1 + \dot{Y}_- + \dot{Y}_a|^2}},$$

(17)
$$\overline{U^2_{Na}} = \frac{\overline{i^2_{Na}}}{|\dot{Y}_a|^2}.$$

In (16), the quantities $\overline{i^2_{N\,add}}$ and $\dot{Y}_-$ remain unspecified.

The FFPS time-varying parametric elements $C(t)$ and $G(t)$ can be presented by the Fourier series

(18)
$$C(t) = C_0 + 2\sum_{n=1}^{\infty} C_n \cos n\omega_p t$$
$$G(t) = G_0 + 2\sum_{n=1}^{\infty} G_n \cos n\omega_p t,$$

where $\begin{Bmatrix} C_n \\ G_n \end{Bmatrix} = \frac{1}{2\pi}\int_{-\pi}^{\pi} \begin{Bmatrix} C(t) \\ G(t) \end{Bmatrix} \cos n\omega_p t \, d(\omega_p t)$.

The processes in FFPS may be generally described by the following matrix equation [7, 12]:

$$(19)\quad \begin{Vmatrix} \dot{I}_1 \\ \dot{I}_{s+} \\ \dot{I}^*_{r-} \end{Vmatrix} = \begin{Vmatrix} \dot{Y}_1 & G_1 e^{-j\psi_2} + j\omega_s C_1 e^{-j\psi_1} & G_1 e^{j\psi_2} + j\omega_s C_1 e^{j\psi_1} \\ G_1 e^{j\psi_2} + j\omega_+ C_1 e^{j\psi_1} & \dot{Y}_{s+} & G_2 e^{2j\psi_2} + j\omega_+ C_2 e^{j\psi_1} \\ G_1 e^{-j\psi_2} - j\omega_- C_1 e^{-j\psi_1} & G_2 e^{-2j\psi_2} - j\omega_- C_2 e^{-2j\psi_1} & \dot{Y}^*_{r-} \end{Vmatrix} \begin{Vmatrix} \dot{U}_1 \\ \dot{U}_{s+} \\ \dot{U}^*_{r-} \end{Vmatrix}$$

In Eqn. (19) the spectrum (18) of the parametric elements $C(t)$ and $G(t)$ is limited to the second harmonic, i. e. $n=2$. For greater generality, pumping phase angles are introduced: ψ_1 refers to $C(t)$ and ψ_2 — to $G(t)$, respectively.

The analysis made has shown, that the pumping in "quadrature" of $C(t)$ and $G(t)$ in FFPS is most efficient as regards to the maximization of C_- and G_- absolute values, i. e. $\psi_1 = -\frac{\pi}{2}$, $\psi_2 = 0$.

When the equation (19) is used for studying the noise properties, the currents and voltages have to be replaced as follows

$$I_1 \to \sqrt{\overline{i^2_{N1\Sigma}}} = \sqrt{\overline{i^2_{N1}} + \overline{i^2_{D1}}}\,,\quad I_{s+} \to \sqrt{\overline{i^2_{Ns+\Sigma}}} = \sqrt{\overline{i^2_{Ns+}} + \overline{i^2_{Ds+}}}\,,$$

$$I_{r-} \to \sqrt{\overline{i^2_{N\,r-\Sigma}}} = \sqrt{\overline{i^2_{Nr-}} + \overline{i^2_{Dr-}}}\,,\quad U_1 \to \sqrt{\overline{U^2_{N1}}}\,.$$

The noise voltage $\overline{U^2_{N1}}$ in the FFPS input circuit can be determined from (19):

$$(20)\qquad \overline{U^2_{N1}} = \overline{i^2_{N1\Sigma}} \left|\frac{D_1}{D}\right|^2 + \overline{i^2_{N\,s+\Sigma}} \left|\frac{D_{s+}}{D}\right|^2 + \overline{i^2_{N\,r-\Sigma}} \left|\frac{D_{r-}}{D}\right|^2,$$

where D is determinant of the matrix in Eqn. (19), D_1, D_{s+} and D_{r-} are corresponding algebraic adjuncts.

The total noise current in the FFPS input circuit can be obtained in the form

$$(21)\qquad \overline{i^2_{NFFPS}} = \overline{U^2_{N1}} \left|\dot{Y}_1 + \dot{Y}_-\right|^2 = \overline{i^2_{N1\Sigma}} + \overline{i^2_{Ns+\Sigma}} \left|\frac{D_{s+}}{D_1}\right|^2 + \overline{i^2_{N\,r-\Sigma}} \left|\frac{D_{r-}}{D_1}\right|^2$$

since $\dot{Y}_1 + \dot{Y}_- = \frac{\dot{I}_1}{\dot{U}_1} = \frac{D}{D_1}$.

Hence, the desired additional noise current $\overline{i^2_{N\,\mathrm{add}}}$ (Fig. 4) is obtained

$$(22)\qquad \overline{i^2_{N\mathrm{add}}} = \overline{i^2_{N\,s+\Sigma}} \left|\frac{D_{s+}}{D_1}\right|^2 + \overline{i^2_{N\,r-\Sigma}} \left|\frac{D_{r-}}{D_1}\right|^2.$$

Using (19) the reverse conversion gains in (22) can be determined in the form:

$$(23)\qquad K_+ = \frac{D_{s+}}{D_1} = \frac{M_1 - m_1 \xi Q (1+2M_2) + j2Q\,[m_1 \xi (\xi_0 - \xi) - M_1 (\xi_0 + m_2 - \xi)]}{1 + 2M_2 + 4Q^2 (\xi_0^2 + \xi_0 m_2 - \xi^2)},$$

$$(24)\qquad K_- = \frac{D_{r-}}{D_1} = \frac{M_1 + m_1 \xi Q (1+2M_2) + j2Q\,[m_1 \xi (\xi_0 + \xi) + M_1 (\xi_0 + m_2 - \xi)]}{1 + 2M_2 + 4Q^2 (\xi_0^2 + \xi_0 m_2 - \xi^2)},$$

where $m_1=\frac{C_1}{C_{eff}}$, $m_2=\frac{C_2}{C_{eff}}$, $M_0=\frac{G_0}{G_{eff}}$, $M_1=\frac{G_1}{G_{eff}}$ and $M_2=\frac{G_2}{G_{eff}}$ are modulation coefficients of the FFPS parametric elements, $C_{eff}=C_0-C_2$ and $G_{eff}=G_0-G_2$ are the mean effective parameters of the system, $\xi_0=\eta-\frac{m_2}{2}$ is the effective relative detuning of the FFPS oscillatory circuit.

The negative capacitance and conductance introduced to the FFPS input circuit can be expressed from (19) as

$$C_-=\frac{1}{j\omega_s}\, Im\left(\dot{Y}_1-\frac{\dot{I}_1}{\dot{U}_1}\right)=\frac{1}{j\omega_s}\, Im\left(\dot{Y}_1-\frac{D}{D_1}\right) \tag{25}$$

$$=4C_{eff}\,(M_1+m_1 Q)\,\frac{(M_1+Q\,\xi_0\, m_1)\,[1+Q^2\,(\varkappa-4\xi^2)]-2M_0\, M_1}{[1+Q^2\,(\varkappa-4\xi^2)]^2+(4Q\,\xi\, M_0)^2},$$

$$G_-=Re\left(\dot{Y}_1-\frac{\dot{I}_1}{\dot{U}_1}\right)=Re\left(\dot{Y}_1-\frac{D}{D_1}\right) \tag{26}$$

$$=2G_{eff}\,(M_1+m_1 Q)\,\frac{M_1\,[1+Q^2\,(\varkappa-4\xi^2)]+8Q^2\,\xi^2\, M_0\,(M_1+Q\,\xi_0\, m_1)}{[1+Q^2\,(\varkappa-4\xi^2)]^2+(4Q\,\xi\, M_0)^2},$$

where $\varkappa=4\,(\xi_0^2+\xi_0\, m_2)+\frac{2M_2}{Q}$ is the general detuning.

For the considered case we introduce a noise figure of FFPS in the form

$$F_{FFPS}=\frac{G_{FFPS}}{G_-'}=\frac{\overline{i^2_{N\,FFPS}}}{4k\,T\,\Delta f\, G_-'}, \tag{27}$$

where G_{FFPS} — is the equivalent FFPS noise conductance, $G_-'=G_--G_1^0$.

Using Eqn. (21) we receive the expression

$$F_{FFPS}\, G_-'=G_1^0+G\left(\left|\frac{D_{s+}}{D_1}\right|^2+\left|\frac{D_{r-}}{D_1}\right|^2\right)+\frac{e\, I_0}{2kT}\left(1+\left|\frac{D_{s+}}{D_1}\right|^2+\left|\frac{D_{r-}}{D_1}\right|^2\right). \tag{28}$$

The FFPS stability is defined generally by fluctuations of the pumping amplitude δ_{A_p}, pumping frequency δ_{ω_p} and parametric element bias δ_E.

The sensitivity of the implemented negative capacitance C_- to the fluctua tions δ_{A_p}, δ_{ω_p} and δ_E can be expressed as

$$S_A=\left(\frac{\Delta C_-}{C_-}\,\delta_{A_p}^{-1}\right)=K(\xi)\,\frac{m_2}{m_1}\,\psi(2Q\,\xi)\,\frac{2}{1+Qm_2\,\mu(\xi_0)}, \tag{29}$$

$$S_\omega=\left(\frac{\Delta C_-}{C_-}\,\delta_{\omega_p}^{-1}\right)=S_A\, Q\,\xi, \tag{30}$$

$$S_E=\left(\frac{\Delta C_-}{C_-}\,\delta_E^{-1}\right)=K(\xi)\,\frac{m_2}{m_1}\,\psi(2Q\xi)\left[1+\frac{Q\, m_1\,\xi}{1+Qm_2\,\mu(\xi_0)}\right], \tag{31}$$

where $K(\xi)=2\sqrt{\frac{(M_1+2Q^2\, m_1\,\xi_0)^2+(2Q\,\xi\, M_1)^2}{[1+2M_2+4Q^2\,(\xi_0^2+\xi_0\, m_2-\xi^2)]^2+(4Q\,\xi\, M_0)^2}}$,

$$\psi(2Q\,\xi)=\frac{1+4Q^2\,(\xi_0^2+\xi_0\, m_2-\xi^2)}{\sqrt{[1+4Q^2\,(\xi_0^2+\xi_0\, m_2-\xi^2)]^2+(4Q\,\xi)^2}},$$

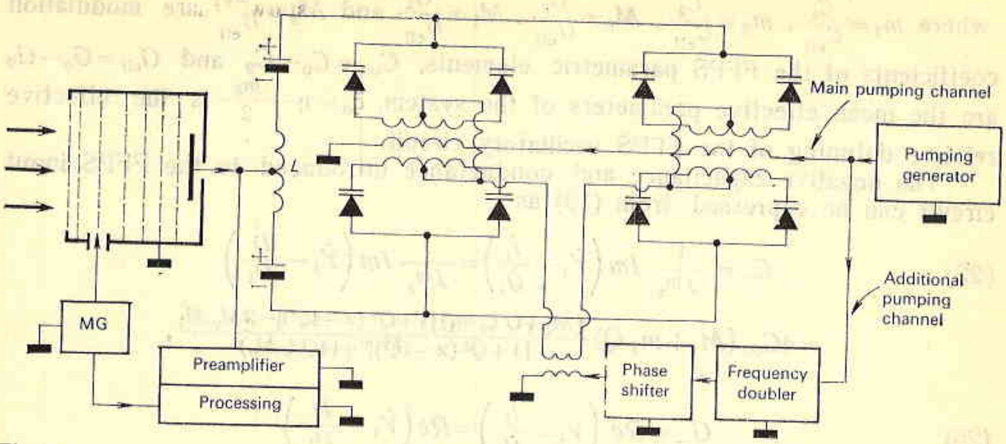

Fig. 5

$$\mu(\xi_0) = -\frac{4Q\xi_0}{1+4Q^2\xi_0^2}.$$

The total unstability of C_- (assuming a statistically independence of the external influencing factors) is equal to:

$$\frac{\Delta C_-}{C_-} = \sqrt{S_A \delta^2_{A_p} + S_\omega \delta^2_{\omega_p} + S_E \delta^2_E}. \tag{32}$$

The sensitivity of the implemented negative conductance G_- to the fluctuations of δ_{A_p}, δ_{ω_p} and δ_E has been derived in a similar manner.

FFPS, described in [8] can be used in designing trapping multielectrode-modulation sensors of Solar wind.

The electrical scheme of a multielectrode-modulation sensor of solar wind with FFPS is presented in Fig. 5. The FFPS oscillatory circuit is formed by linear inductance L and a nonlinear capacitance constructed as a balanced-bridge scheme with negative-biased parametric diodes. The main pumping channel secures a great variation of the diodes capacitances. The additional pumping channel is used to put down the effect of the second harmonic in the spectrum of the parametric element. As it can be seen from the expressions (25) and (26), the second harmonic of varying diodes capacitance reduces the absolute values of implemented negative C_- and G_-. That leads to the necessity its influence to be eliminated. FFPS implements negative C_- and G_- with necessary absolute values in parallel with trap collector — sensor body. The resonant frequency of FFPS oscillatory circuit and correspondingly — the pumping frequency can be of the order of 100 MHz. In such case the effective C_- and G_- with constant absolute values exist in a frequency band from 0 Hz up to a limited frequency equal to $\sim$15 MHz.

Estimations and conclusion

The general analysis made allows the following general estimations be made.

The study of Eqn. (28) using Eqns. (23) and (24) shows that for all real parameters

(33) $$F_{FFPS}\, G'_{-} \sim (1 \div 1{,}5)\, G_1^0.$$

As FFPS is actually an one-port with negative admittance, i. e. FFPS provides $\frac{G_1^0}{G_-} \ll 1$, then

(34) $$F_{FFPS} \sim (0{,}1 \div 0{,}2)\ \mathrm{dB}.$$

Taking into account that the modern FET preamplifiers have noise figure $F_a \sim (2 \div 3)$ dB, it is not difficult to estimate that the total average-quadratic system noise $\overline{U^2_{N\Sigma}}$ distinguishes from the average-quadratic preamplifier noise from 3—10 %.

The ratio of average voltages (6) can be estimated in the practical conditions as

(35) $$K_a = \frac{U^{(-)}_{a,a}}{U^{(+)}_{a,a}} \simeq 2\, \frac{C_c + C_a}{G_a T_0}\, \mu_G \sim (1 \div 5) \cdot 10^2.$$

Using these estimations, we can be convinced in the considerable increase of the ratio signal/noise

(36) $$\frac{N^{(-)}}{N^{(+)}}\, 2\, \mu_G\, \frac{(C_c + C_a)}{G_a T_0}\, \frac{\sqrt{\overline{U^2_{Na}}}}{\sqrt{\overline{U^2_{N\Sigma}}}} \sim (0{,}5 \div 1) \cdot 10^3.$$

The FFPS design with the purpose of implementing C_- and G_- with necessary absolute values can be made using the formulae (25) and (26).

For all possible real parameters of FFPS with advanced elements the sensitivities defined by Eqns. (29)—(31) are in the following limits: $S_A \sim 10$—15, $S_\omega \sim 100$—150, $S_E \sim 20$—25. For example, if $\delta_{A_p} = 10^{-4}$, $\delta_{\omega_p} = 10^{-6}$ and $\delta_E = 10^{-4}$ (the case of common fluctuations without taking spacial actions), the total instability of C_- is $\frac{\Delta C_-}{C_-} \lesssim 1\%$.

The estimation of the minimum trap collector current, which can be reliably registered with an instability of conversion gain less than 1 %, is $i_{c\,min} \sim 10^{-14}$ A.

A general theory of the trapping multielectrode-modulation sensor of Solar-wind with an added stage based on four-frequency parametric system (FFPS) has been developed. The conditions for the advisability of FFPS utilization as one-port with negative parameters have been derived.

The investigation made shows that the utilization of FFPS considerably increases the signal level at the preamplifier input and to a great extent improves system sensibility by increasing the ratio signal/noise.

References

1. Солнечный ветер и околоземные процессы (под ред. А. Д. Шевнина). М., Наука, 1987.
2. Научная аппаратура для космических исследований (Под ред. В. М. Балебанова). М., Наука, 1987.
3. Северный, А. Б. Некоторые проблемы физики солнца. М., Наука, 1988.
4. Шкловский, И. С. Проблемы современной астрофизики. М., Наука, 1988.
5. Космическая физика (под ред. Д. П. Ле Гэлли и А. Розена). М., Мир, 1976.
6. Емельянов, С. Л., В. И. Старцев, В. Соколов. — Радиотехника, 33, 1978, № 4, 78—79.

7. Дамгов, В. Н. Параметрическая RC-система как двухполюсник с отрицательной проводимостью. — Болг. физ. ж., 5, 1978, 519—534.
8. Дамгов, В. Н. Авторски свидетелства №№ 25959, 25960, 25961, 28971, 29260, 29993, 45821.
9. Дамгов, В. Н. Индуктивен датчик — спектроанализатор. Авторско свидетелство № 30009.
10. Карпов, Ю. С., Ю. М. Лукин, В. И. Фомичев. — Радиотехника и электроника, 22, 1977, № 12, 2638—2641.
11. Damgov, V. N. Injection-locked self-oscillating system as one-port with controlled parameters. — IEE Proceedings, Part G: Electronic Circuits and Systems, 131, 1984, No 1, 1-9.
12. Damgov, V. N. Design and Application of One-port Exhibiting Negative R, C and L Based on Four-Frequency Parametric Systems. — In: Proc. IEEE Int. Symposium on Circuits and Systems, Rome, May 10-12, 1982, 1, 1982, 190-193.

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Метод для повышения чувствительности датчика солнечного ветра

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(Резюме)

Предложен метод повышения чувствительности датчика солнечного ветра. Метод продемонстрирован на базе многоэлектродного модуляционного измерителя солнечного ветра. Сущность метода заключается в использовании сформулированного принципа обратимости модуляционно-параметрических взаимодействий и в его материализации в разработанных четырехчастотных параметрических системах. Эти системы позволяют получить широкополосные малошумящие отрицательные емкости (C_-) и отрицательные активные проводимости (G_-). Чувствительность модуляционного датчика солнечного ветра увеличивается существенно за счет компенсации собственной емкости его коллектора и активной проводимости предусилителя применением эффективных малошумящих C_- и G_-.

Проведен анализ предложенной четырехчастотной параметрической системы, позволяющей получить малошумящие широкополосные (в видеочастотной полосе) отрицательные C_- и G_-. Получены выражения для динамических характеристик системы. Представлены результаты экспериментального исследования.

Теоретически и экспериментально исследованы шумовые свойства системы, определяющие чувствительность датчика. Сформулированы общие критерии целесообразности применения в подобных системах параметрических двухполюсников с отрицательными параметрами.

Теоретически и экспериментально рассмотрена стабильность системы на базе диаграммы внутренних связей всех влияющих факторов.