UDC 621.317.365:621.372 (045)
DOI: 10.18372/1990-5548.56.12929

[1]Yu. F. Zinkovsky,
[2]A. I. Vytiaganets

MAGNETORESISTIVE TRANSFORMER ON THIN FILMS

[1,2]Department of Design and Production of Radio Electronic Equipment,
National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute", Kyiv, Ukraine
E-mails: [1]kivra@kpi.ua, [2]vytiaganets@gmail.com

Abstract—*The statistical processing of the results for a three-time measurement of active power by a magnetoresistive converter is given. In the statistical processing of the threefold result of measuring the active power by a magnetoresistive converter, two problems were solved. First, some approximate value of the measured value (estimation) is determined, which best corresponds to the obtained results. Secondly, the probable deviation of the measurement results from the estimation of the measured value is determined.*

Index Terms—Magnetoresistive converter; active power; statistical processing; magnetoresistive susceptibility; thin films.

I. INTRODUCTION

One of the most important energy characteristics, which is measured in electronics is power. The most promising means of measuring the active power mode "in situ" is a magnetoresistive measuring transformer on the basis of the anomalous Hall effect and anisotropic magnetoresistance in thin ferromagnetic films [1]. Such measuring transformer, as compared with semiconductors, are 2 orders of magnitude higher sensitivity, a small measurement error of 3 orders of magnitude smaller values thermoelectromotive forces and the absence of rectifying contacts, which are the basis for selecting of the magnetoresistive measuring transformer for further investigation [2] – [5].

II. PROBLEM STATEMENT

A three-fold measurement of the active power was carried out by a magnetoresistive converter, the results are given in Table I.

We perform the verification of the adequacy of the electric model of the measuring transducer using the criteria of Student and Fisher [3].

The hypothesis about the adequacy of the mathematical model is not rejected if the residual variance S^2_{res} of the output value $\hat{X}_{0m}$, calculated on the model, in relation to the experimental $\hat{X}_{0p}$ does not exceed the statistically error of the experiment, which is determined by the dispersion of the reproducibility S_0^2.

The residual variance is defined as:

$$S^2_{\text{res}} = \frac{m}{f_1}\sum_{n=1}^{N}\left(\overline{X}_{0p} - \hat{X}_{0p}\right)^2,$$

where $f_1 = (N_m - l)$ is the number of degrees of freedom; N-number of groups of parallel experiments $(N_m - 19)$; m is the number of parallel experiments in one group $(m = 3)$; l is the number of links $(l = n^* + 1)$; n^* is the number of factors (number of external influences) $(n^* = 4,\ l = 5)$; $\overline{X}_{0p} = \frac{1}{m}\sum_{\text{k}=1}^{m} X_{0p_k}$ -average value of the output parameter on the results of parallel experiments $(m = \overline{1,3})$, $(n = \overline{1,19})$.

To determine the variability of reproducibility S_0^2, it is necessary to have several values of the output parameter measured under the same conditions. Experimental values X_{0p_k} are obtained in three parallel studies, and the value of the output value, calculated from the model $\overline{X}_{0p} = \frac{1}{m}\sum_{\text{k}=1}^{m} X_{0p_k}$ $\hat{X}_{0m}$, are presented in Table II.

$$S_0^2 = \frac{1}{N}\sum_{n=1}^{N} S_n^2,$$

where $S_n^2\ (n = \overline{1,19})$ is the sample dispersions.

$$S^2_{\text{n}} = \frac{1}{m-1}\sum_{k=1}^{m}\left(X_{0p_k} - \hat{X}_{0p}\right)^2$$

Determine the point estimates of the received distributions of experimental data (arithmetic mean, median, arithmetic mean of the boundaries of the variation series), scattering (dispersion and mean square deviation of the measurement results), asymmetry and sharpness. The results of calculating the characteristics of the position of point estimates are classified in Table III.

From Table III it is seen that the largest variance of the result of the experiment (mean square deviation) is the 3rd measurement group. From the estimation of the asymmetry, we can conclude that the distribution density curve of the 1st group with negative asymmetry lies to the left of the symmetric probability distribution, whose asymmetry is equal to zero, and the 2nd and 3rd groups with positive asymmetry – to the right. Excesses in probability distribution laws will be close to zero if their probability density curve will have a ringing form. Curves with a more acute peak have a positive excess (2nd measurement group), and with a more stable one there is a negative excess (1st and 3rd measurement groups).

Since the excess E is in the range $-1 < E < 1$, that is, the distribution is close to normal ($E = 0$), then for the estimation of the distribution we take the arithmetic mean.

Define the boundaries of the random error of the measurement results given in Table I for the probability of probability $P_d = 0.9973$ and the level of significance of the coherence criteria $\alpha = 0.05$.

To determine the limits of random error based on the results of triple observations, perform the following operations:

1) We will exclude from the results of observation gross errors.
2) Calculate the arithmetic mean of the corrected observational results or estimate the mathematical expectation that is taken for the measurement result.
3) Calculate the mean square deviation of the measurement result and its estimation.
4) Let's check the hypothesis that the results of observations belong to the chosen distribution law.
5) Calculate the confidence limits of the random error of the measurement results.

By the type of histograms and cumulative curves, Fig. 1, as well as obtained point results of asymmetry and excesses, Table. III, we accept the hypothesis that the measurement results are distributed according to normal law.

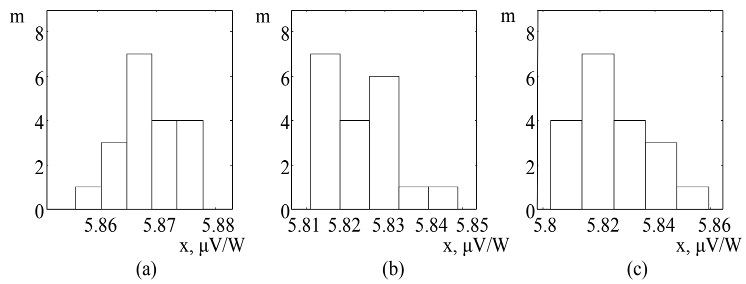

Fig. 1. Histograms: (a) is 1 measurement group; (b) is 2 measurement group; (c) is 3 measurement group

III. Determination of Gross Errors and Misses According to Wright's Criterion

The measurement result k_i ($k_{\max}$ or $k_{\min}$) does not belong to the normal distribution with the given probability P, if

$$\frac{|k_i - M_K|}{\sigma_K} > t_p, \quad (1)$$

where t_p is the confidence coefficient, Table 2.1 [7].

That is, if k_i goes beyond the interval $(M_K - t_p\sigma_K;\ M_K + t_p\sigma_K)$ and substituting (1) instead M_K and σ_K to their estimation $\bar{k}$ and $\hat{\sigma}_K$, taking into account that for a normal distribution law $t_p = 3.0$ (for the probability $P = 0.9973$), intervals at the border are defined (Table IV).

Outside the intervals, there is no measurement result as seen in Table IV. That is, there are no blunders and gross errors.

IV. Determination of Gross Errors and Misses According to Smirnov's Criterion

By the Smirnov criterion, the measurement result k_i does not belong to a given distribution with a given probability P, if

$$\frac{|k_i - \bar{k}|}{\hat{\sigma}_K} > \beta,$$

where β is a random variable that depends on P and the number of observations n.

For the number of observations $n = 19$ and the level of significance $\alpha = 0.05$, $P = 1 - \alpha = 0.95$, the value of β according to Table B.1 [7] is 2.75.

From Table IV shows that all the results of the measurement k_i belong to the normal distribution.

V. Pearson's Test

For previously obtained values of middle of intervals histogram $k_{\mathrm{res}j}$($j = 1, \ldots, L$), value probability density theoretical distribution are obtained using the formula [7]

$$p(k_{\text{mid}\,j}) = \frac{1}{\sqrt{2\pi}\hat{\sigma}_K} e^{-\frac{(k_{\text{mid}\,j}-\bar{k})^2}{2\hat{\sigma}_K^2}}.$$

Frequency hits measurement results $m_{j\text{d}}$ are obtained, which are subject to a theoretical distribution:

$$m_{j\text{d}} = p(k_{\text{mid}\,j}) n \,\Delta k .$$

For each interval j value are calculated

$$\chi_j^2 = \frac{(m_j - m_{j\text{d}})^2}{m_{j\text{d}}}.$$

The total value of the coefficient for each measurement group is determined:

$$\chi^2 = \sum_{j=1}^{L} \chi_j^2.$$

We obtain that χ_1^2 = 1.4826, χ_2^2 = 4.7397, χ_3^2 = 1.0029.

In Table B.3 [7] for the probability P = 0.95 and the number of degrees of freedom k = 5 – 3 = 2 the value are obtained χ_0^2= 5.99.

Since $\chi_1^2 < \chi_0^2$, $\chi_2^2 < \chi_0^2$, $\chi_3^2 < \chi_0^2$, we assume that the hypothesis about the normal distribution of experimental data is reliable.

VI. Check by Kolmogorov's Criterion

In the Table V contains the previously obtained values of the cumulative curve at the boundaries of the interval k_j.

For previously obtained estimates of mathematical expectation $\hat{\sigma}_K$ and mean square deviation integral formula for normal distribution function value $F_{j\text{d}}$ (Table 2.4 [7]) at the points k_j are defined

$$F_{j\text{d}} = \frac{1}{\sqrt{2\pi}\hat{\sigma}_K} \int_{-\infty}^{k_j} e^{-\frac{(z-\hat{M}_K)^2}{2\hat{\sigma}_K^2}} dz$$

$$= \begin{cases} 0.5 - \Phi\left(\dfrac{k_j - \hat{M}_K}{\hat{\sigma}_K}\right), & \text{if } k_j < \hat{M}_K, \\ 0.5 + \Phi\left(\dfrac{k_j - \hat{M}_K}{\hat{\sigma}_K}\right), & if\ \ k_j > \hat{M}_K, \end{cases}$$

where $\Phi\left(\dfrac{k_j - \hat{M}_K}{\hat{\sigma}_K}\right) = \Phi(t_p)$ is the value of the Laplace function.

Maximum values of D_j calculated from the number of $D_{j\max 1}$ = 0.0435, $D_{j\max 2}$ = 0.0850, $D_{j\max 3}$ = 0.1121 are defined. The values are obtained as

$$\lambda = D\sqrt{n}\ ,$$

λ_1= 0.1895, λ_2= 0.3705, λ_3= 0.4884.

According to Table B.2 [7] respectively calculated probability value λ P_{01}=1.000, P_{02}=0.998, P_{03}=0.997 are obtained. Since $P_{01}>P$=0.95, $P_{02}>P$=0.95, $P_{03}>P$=0.95. Thus, the hypothesis of the normal distribution law is considered correct.

VII. Component Criterion Check

Calculated value of the coefficient (Table V).

$$d = \frac{\frac{1}{n}\sum_{i=1}^{n}\left|k_i - \hat{M}_K\right|}{\sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(k_i - \hat{M}_K\right)^2}}.$$

According to Table B.4 [7], for a given probability P=0.95, the value of the coefficient d should be in the range of 0.7304 to 0.8768, i.e. all measurement results (Table V) satisfy the first part of the component criteria.

To check the "tails" of the empirical distribution in the second part of the criterion, the confidence intervals are defined by the formula $\varepsilon = t_p \hat{\sigma}_K$.

For a normal distribution t_p = 3.0 (Table 2.2 [7]), and the boundaries of the confidence interval will be equal to:

$$k_{\min} = \hat{M}_X - \varepsilon,\ \ k_{\max} = \hat{M}_X + \varepsilon.$$

No measurement result exceeds the specified limits, so the second part of the criterion is satisfied. Thus, the results of measurements belong to the normal distribution law.

VIII. Determination of Boundaries of Random Error of Measurement Results

The boundaries of the random error of the measurement results will be determined as:

$$\varepsilon' = \pm t_p \hat{\sigma}_K .$$

From [8] for the probability P_d= 0.9973 and normal distribution t_p= 3.0 are obtained.

Boundaries of random error of measurement results (arithmetic mean), Table VI:

$$\varepsilon_{\bar{k}} = \pm t_p \hat{\sigma}_{\bar{k}} = \pm t_p \hat{\sigma}_K / \sqrt{n}.$$

Consequently, the magnetoresistive transformer has a measurement error ±1.163% in the frequency range from 200 Hz to 200 kHz in scattering of the measurement result 0.37%.

TABLE I. RESULTS OF MEASUREMENT OF ACTIVE POWER BY A MAGNETORESISTIVE TRANSFORMER ON THIN FILMS

No	*f*, Hz	k_1, µV/W	k_2, µV/W	k_3, µV/W	No	*f*, Hz	k_1, µV/W	k_2, µV/W	k_3, µV/W
1	200	5.8735	5.8328	5.8379	4	10000	5.8685	5.8185	5.8077
2	500	5.8675	5.8318	5.8283	5	50000	5.8612	5.8163	5.8142
3	3000	5.8636	5.8299	5.8141	6	200000	5.8741	5.8489	5.8590

TABLE II. OUTPUT AND RESULTS OF CALCULATING THE ADEQUACY OF MATHEMATICAL MODEL OF TRANSFORMER

No	*f*, Hz	$\hat{X}_{0m}$, µV	Experimental data, X_{0p_k}, µV			X_{0p}, µV	$\left(\hat{X}_{0m} - X_{0p}\right)^2$, µV·$10^2$	$S_n^2 \cdot 10^4$
			1	*2*	*3*			
1	200	5.9459	5.8735	5.8328	5.8379	5.8481	0.9571	4.9164
2	500	5.9459	5.8675	5.8318	5.8283	5.8425	1.0685	4.7056
3	3000	5.9459	5.8636	5.8299	5.8141	5.8359	1.2107	6.3926
4	10000	5.9459	5.8685	5.8185	5.8077	5.8316	1.3072	10.5221
5	50000	5.9457	5.8612	5.8163	5.8142	5.8306	1.3256	7.0490
6	200000	5.9420	5.8741	5.8489	5.8590	5.8607	0.6615	1.6084

TABLE III. POINT ESTIMATES OF THE RECEIVED DISTRIBUTIONS OF EXPERIMENTAL DATA

Point estimates	Measurement group		
	1	*2*	*3*
Arithmetic mean $\bar{x}$	5.8685	5.8241	5.8245
The arithmetic mean of the boundaries of the variation series x_{mid}	5.8671	5.8149	5.8084
Median Me	5.8675	5.8239	5.8220
Estimation of the dispersion of the measurement result $\hat{D}_X$	$2.9381 \cdot 10^{-5}$	$9.1148 \cdot 10^{-5}$	$2.0654 \cdot 10^{-4}$
Standard deviation $\hat{\sigma}_X$	0.0054	0.0095	0.0144
Estimation of standard deviation $\hat{\sigma}_{\bar{X}}$	0.0012	0.0022	0.0033
Estimation of asymmetry $\hat{A}$	-0.3599	0.5870	0.5176
Estimation of excess $\hat{E}$	-0.6076	0.0566	-0.4515

TABLE IV. INTERVAL BOUNDARIES

	Measurement group		
	1	*2*	*3*
$(\bar{k} - t_p\hat{\sigma}_K;\ \bar{k} + t_p\hat{\sigma}_K)$	(5.8523; 5.8848)	(5.7955; 5.8528)	(5.7814; 5.8677)
$(\bar{k} - \beta\hat{\sigma}_K;\ \bar{k} + \beta\hat{\sigma}_K)$	(5.8536; 5.8834)	(5.7979; 5.8504)	(5.7850; 5.8641)

TABLE V. RESULTS OF CALCULATION

Measurement group	*j*	$K_{\text{mid}\,j}$	$p(k_{\text{mid}\,j})$	m_{jd}	m_j	χ_j^2	k_j	F_j	F_{jd}	D_j
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
1	1	5.8585	13.2928	1.0856	1	0.0068	5.8563	0	0.0130	0.0130
	2	5.8628	42.0950	3.4379	3	0.0558	5.8606	0.0526	0.0740	0.0214
	3	5.8671	71.0780	5.8049	7	0.2460	5.8649	0.2105	0.2540	0.0435
	4	5.8714	63.9925	5.2263	4	0.2877	5.8692	0.5789	0.5550	0.0239
	5	5.8757	30.7194	2.5088	4	0.8863	5.8735	0.7895	0.8230	0.0335
	6						5.8778	1	0.9570	0.0430
2	1	5.8149	26.0687	3.7415	7	2.8379	5.8111	0	0.0850	0.0850
	2	5.8224	41.1134	5.9008	4	0.6123	5.8186	0.3684	0.2850	0.0834
	3	5.8300	34.6711	4.9761	6	0.2107	5.8262	0.5789	0.5830	0.0041
	4	5.8375	15.6341	2.2439	1	0.6895	5.8338	0.8947	0.8420	0.0527
	5	5.8451	3.7696	0.5410	1	0.3894	5.8413	0.9474	0.9640	0.0166
	6						5.8489	1	0.9950	0.0050

CONTINUATION OF THE TABLE V

1	2	3	4	5	6	7	8	9	10	11
3	1	5.8084	14.7575	3.1521	4	0.2281	5.8028	0	0.0650	0.0650
	2	5.8196	26.1831	5.5925	7	0.3543	5.8140	0.2105	0.2310	0.0205
	3	5.8309	25.1945	5.3813	4	0.3546	5.8252	0.5789	0.6910	0.1121
	4	5.8421	13.1482	2.8083	3	0.0131	5.8365	0.7895	0.7950	0.0055
	5	5.8534	3.7214	0.7949	1	0.0529	5.8477	0.9474	0.9460	0.0014
	6						5.8590	1	0.9910	0.0090

TABLE VI. RESULTS OF CALCULATION

	Measurement group		
	1	*2*	*3*
Coefficient *d*	0.8153	0.7885	0.8310
Value ε	0.0163	0.0286	0.0431
$(\hat{M}_X - \varepsilon;\ \hat{M}_X + \varepsilon)$	(5.8523; 5.8848)	(5.7955; 5.8528)	(5.7814; 5.8677)
Value ε'	± 0.0163	± 0.0286	± 0.0431
Value $\varepsilon_{\bar{k}}$	± 0.0037	± 0.0066	± 0.0099

IX. CONCLUSIONS

In the statistical processing of the threefold result of measuring the active power by a magnetoresistive converter, two problems were solved. First, some approximate value of the measured value (estimation) is determined, which best corresponds to the obtained results. Secondly, the probable deviations of the measurement results from the measured value are determined.

REFERENCES

[1] A. I. Vytiaganets and V. S. Vountesmeri, "Means of measurement of active power at low and medium frequencies "in situ," *Newsletter NTUU "KPI". Radiotekh. Radio equipment building*, 34: pp. 112–118, 2007.

[2] V. S. Vountesmeri, and A. I. Vytiaganets, "Investigation of existing magnetoresistive effects and features of implementation of devices based on them," *Newsletter NTUU "KPI". Radiotekh. Radio equipment building*, 37: pp. 97–101, 2008.

[3] A. I. Vytiaganets, "Broadband magnetoresistive active power measuring transducer middle frequencies", in *11-th Intern. youth. forum "Electronics and youth in the XXI century"*, Univ. Kharkov, Ukraine, Apr. 2007, 334 p.

[4] V. S. Vountesmeri and A. I. Vytiaganets, "Frequency response investigation of magnetoresistive low frequency active power measuring transducer," *Radioelectronics and Communications Systems*, 50: pp. 680–682, 2007.

[5] V. S. Vountesmeri, V. G. Smolianinov, and A. I. Vytiaganets, "Magnetoresistive measuring transformer of active power," in *18th International Crimean Conf. CriMiCo*, SevNTU, Ukraine, Sept. 2008, pp. 688–689.

[6] P. M. Talanchuk, M. N. Fomin and V. V. Sergeev, *Modeling and optimization of measuring converters by computers*, Kyiv: Vyshcha shkola, 1991, 250 p. (in Ukrainian).

[7] I. P. Zakharov, *Processing of measurement results: training. allowance*, Kharkov: Publishing House of NEUR, 2002, 126 p.

[8] V. A. Granovskii and T. N.Syraya, *Methods of processing experimental data for measurements*, Leningrad: Energoatomizdat, 1990, 288 p.

Received February 09, 2018.

Yuriy Zinkovsky. Doctor of Engineering Science. Professor.

Department of Design and Production of Radio Electronic Equipment, National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute", Kyiv, Ukraine.

Education: Kyiv Polytechnic Institute, Kyiv, Ukraine, (1956).

Research area: radio electronics, microelectronics; technical protection of information; computer design of electronic equipment, technology of electronic apparatus building; pedagogy of higher education.

Publications: more than 300 papers.

E-mail: kivra@kpi.ua

Andrii Vytiaganets. Post-graduate student.

Department of Design and Production of Radio Electronic Equipment, National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute", Kyiv, Ukraine.

Education: National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute", Kyiv, Ukraine, (2006).

Research area: radio electronics, microelectronics, ferromagnetism, thin films.

Publications: more than 20 papers.

E-mail: vytiaganets@gmail.com

Ю. Ф. Зіньковський, А. І. Витяганець. Магніторезистивний перетворювач на тонких плівках
Проведено трикратне вимірювання активної потужності магніторезистивним перетворювачем. Виконана перевірка адекватності електричної моделі магніторезистивного перетворювача, використовуючи критерії Стьюдента і Фішера. Перевірено гіпотезу про адекватність математичної моделі реальному магніторезистивному перетворювачу активної потужності. Прийнято гіпотезу про те, що результати вимірювання розподілені по нормальному закону. Перевірка за критеріями Райта, Смирнова, Пірсона, Колмогорова та багатоскладовому критерію підтвердила дане припущення. При статистичній обробці трикратного результату вимірювання активної потужності магніторезистивним перетворювачем було вирішено дві задачі. По-перше, визначено деяке наближене значення виміряної величини (оцінку), що найкращим чином відповідає отриманим результатам. По-друге, визначено імовірні відхилення результатів вимірювань від оцінки виміряної величини. У результаті досліджень визначені точкові оцінки отриманих розподілів експериментальних даних та побудовані гістограми для експериментальних даних магніторезистивного перетворювача.
Ключові слова: магніторезистивний перетворювач; активна потужність; статистична обробка; тонкі плівки.

Зіньковський Юрій Францевич. Доктор технічних наук. Професор.
Кафедра радіоконструювання та виробництва радіоапаратури, Радіотехнічний факультет, Національний технічний університет України «Київський політехнічний інститут імені Ігоря Сікорського», Київ, Україна.
Освіта: Київський політехнічний інститут, Київ, Україна, (1956).
Напрям наукової діяльності: радіоелектроніка, мікроелектроніка; технічний захист інформації; комп'ютерне проектування радіоелектронної апаратури, технологія електронного апаратобудування; педагогіка вищої освіти.
Кількість публікацій: понад 300.
E-mail: kivra@kpi.ua

Витяганець Андрій Іванович. Аспірант.
Кафедра радіоконструювання та виробництва радіоапаратури, Національний технічний університет України «КПІ ім. Ігоря Сікорського», Київ, Україна.
Освіта: радіотехнічний факультет КПІ ім. Ігоря Сікорського, Київ, Україна, (2006).
Напрям наукової діяльності: радіоелектроніка, мікроелектроніка, феромагнетизм, тонкі плівки.
Кількість публікацій: понад 20.
E-mail: vytiaganets@gmail.com

Ю. Ф. Зиньковский, А. И. Вытяганец. Магниторезистивный преобразователь на тонких пленках
Проведено трехкратное измерение активной мощности магниторезистивным преобразователем. Выполнена проверка адекватности электрической модели магниторезистивного преобразователя, используя критерии Стьюдента и Фишера. Подтверждена гипотеза об адекватности математической модели реальному магниторезистивному преобразователю активной мощности. Принято гипотезу о том, что результаты измерения распределены по нормальному закону. Проверка по критериям Райта, Смирнова, Пирсона, Колмогорова и многосложном критерию подтвердила данное предположение. При статистической обработке трехкратного результата измерения активной мощности магниторезистивным преобразователем было решено две задачи. Во-первых, определены некоторое приближенное значение измеренной величины (оценку), что наилучшим образом соответствует полученным результатам. Во-вторых, определены возможные отклонения результатов измерений от оценки измеренной величины. В результате исследований определены точечные оценки полученных распределений экспериментальных данных и построены гистограммы для экспериментальных данных магниторезистивного преобразователя.
Ключевые слова: магниторезистивный преобразователь; активная мощность; статистическая обработка; тонкие пленки.

Зиньковский Юрий Фронцевич. Доктор технических наук. Профессор.
Кафедра радиоконструирования и производства радиоаппаратуры, Радиотехнический факультет, Национальный технический университет Украины «КПИ им. Игоря Сикорского», Киев, Украина.
Образование: Киевский политехнический институт, Киев, Украина, (1956).
Направление навигация и управление движением.
Количество публикаций: более 300.
E-mail: kivra@kpi.ua

Вытяганец Андрей Иванович. Аспирант.
Кафедра радиоконструирования и производства радиоаппаратуры, Радиотехнический факультет, Национальный технический университет Украины «КПИ им. Игоря Сикорского», Киев, Украина.
Образование: радиотехнический факультет, Национальный технический университет Украины «КПИ имени Игоря Сикорского», Киев, Украина, (2006).
Направление радиоэлектроника, микроэлектроника, ферромагнетизм, тонкие пленки.
Количество публикаций: более 20.
E-mail: vytiaganets@gmail.com