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# Session based Core Test Scheduling for Minimizing the Testing Time of 3D SOC 

Surajit Roy, Payel Ghosh, Hafizur Rahaman and Chandan Giri


#### Abstract

Three dimensional (3D) VLSI integration based on through-Silicon-Via (TSV) is an emerging technology. It provides heterogeneous integration, higher performance, bandwidth, and lower power consumption. However, 3D-IC suffers from several challenges. The objective of this paper is to design the test access mechanism (TAM) architecture and test scheduling of different modules of an system-on-chip (SOC) such that the overall test time of that SOC gets reduced. In this paper we have used a session based heuristic approach to solve this problem. Experimental results have been tested on different ITC'02 benchmark SOCs that shows promising results for different TAM width allocation.


Keywords - 3D IC testing, test access mechanism, test scheduling.

## I. INTRODUCTION

Moores's law suggests that, for a given size of integrated circuit (IC), the number of transistors on IC gets doubled approximately in every one and half years. In case of 2 D IC, if the number of transistors increases, then the size will automatically increase. The gate delay and power consumption also gets increased. So for better performance the size of the IC must be kept as small as possible. Hence 3D integration for VLSI is the effective solution instead of 2D integration.


Figure 1. 3D SOC structure
An example of 3D SOC is shown in Figure 1. The entire chip is divided into number of blocks (called cores) which are placed on separate layers and these layers are stacked on

[^0]top of each other. Layers are connected by through silicon via (TSV) and have global interconnection through wires, resistances and capacitances. In 3D architecture, as the design blocks are stacked on top of each other, size of the chip can be kept small. 3D SOCs are also advantageous [2][8] for its scalability, cost, heterogeneous integration, shorter interconnection, power consumption, bandwidth etc. But in spite of all those benefits 3D-IC suffers from great challenge in testing. Testing the cores of an SOC test access mechanism (TAM) is required to transport test patterns and test responses between SOCs test pins and core I/Os. Proper allocation of TAMs to cores reduce this overall testing time of the SOC, which is assumed to be an NP-Hard problem.

In this work, we have proposed a session based heuristic approach for test architecture design and test time optimization problem of 3D SOCs. Experimental results on ITC'02 benchmark SOCs shows the effectiveness of the proposed method compared to already propose 3D test architecture and scheduling optimization methods.

The rest of this paper is organised as follows. In section 2, we have mentioned the related prior works. In section 3, problem formulation is described. Section 4 discusses the proposed method in details. Section 5 shows the experimental results and compared them with other existing approaches and finally section 6 , concludes this paper.

## II. Prior Work

The first work on TAM design for 3D-SoC [6] presented an integer linear programming (ILP) model. The method divides the total TAM wires into several test buses with fixed width and to assign modular cores to test buses so as to minimize the overall test time under the constraint of TSV count utilized by TAMs. In [1] authors have proposed an efficient thermal aware heuristics to resolve the testing problem for large and complex 3D-SoC devices. A flexible TAM architecture with thermal consideration is designed in [5] that maximize test concurrency by rearranging different sessions. In [3] authors have proposed a TAM optimization technique that does not impose any limits on the number of TSVs used for the TAM, but considers pre-bond testing considerations and wire length limits. A drawback of this approach is that since it does not limit the number of TSVs for the TAM, it ignores constraints related to the keep-out area that is associated with a TSV. In [6] authors have also been reported on the testing of TSVs and an optimization method for 3-D stacked ICs with die level test architecture. Jiang et al. [7] have proposed simulated annealing (SA) based algorithms to optimize modular SOC test architecture
considering both pre-bond tests and post-bond test. In this approach, the same TAMs that traverse multiple layers in post-bond testing are fully reused for pre-bond tests.

## III. PRoblem formulation

The objective in this work is to generate an efficient way of designing a test schedule with optimized testing time considering the maximum available TAM width and maximum available TSVs. So the problem can be formulated as follows:

Given a three dimensional SOC with i) n number of cores, ii) total TAM width limit $\left(\mathrm{TAM}_{\max }\right)$, iii) total TSV limit $\left(\mathrm{TSV}_{\max }\right)$, iv) number of input/outputs, number of scan chains and their lengths, iii) core placement details iv) layer details and $v$ ) testing time of each core for different TAM widths determine the scheduling order of cores in different sessions with the $\mathrm{TAM}_{\text {max }}$ such that the overall testing time is optimized with the constraints of $\mathrm{TSV}_{\text {max }}$.

## IV. PRoposed Algorithm with example

Figure 2 describes the proposed algorithm. Our proposed algorithm works in following manner. First sort all the cores of the SOC in ascending order of their test time for given TAM width, store them in cid and calculate the total test time. Then the scheduling mechanism is performed.

## Algorithm: Scheduling

1. cid=list the order of cores of the SOC under test with the increasing order of testing time for given maximum possible TAM width $\mathrm{TAM}_{\text {max }}$.
2. Calculate the overall test time as "t_time" by adding the test time (obtained in step 1 ) of all cores
3. While the 1st pare-to optimal point of the core with maximum testing time $\left(\mathrm{C}_{\mathrm{L}}\right)$ is not reached
a) While all cores in cid are not scheduled
i. Select the core from the non scheduled core list which have the maximum testing time for the maximum possible TAM for that core
ii. Schedule other possible unscheduled cores which have lesser or equal test time than the core chosen in step $a . i$ for remaining available TAM width for that session.
b) Record the order of scheduled core for different sessions.
c) Calculate the total test time as "time_new" by adding the maximum test time of each session
d) If the time_new < t_time,
then t_time=time_new
e) Update the TAM width of the core $C_{L}$ by decreasing its value by 1 and repeat from step3.
4. End

Figure 2. Proposed Heuristic Algorithm
First select the core $\left(\mathrm{C}_{\mathrm{L}}\right)$ with maximum testing time and assign to it the maximum possible TAM width. If all the TAM width are allocated to this core then the session is completed and we create a new session for the remaining cores.

If all the TAM is not used for that core then select the cores in the order as they are in cid such that they satisfy the remaining available TAM width as well as the testing time lesser or equal to $C_{L}$ for that session. Rest of the cores is scheduled in same fashion in different sessions. After scheduling of all cores of the given SOC the overall testing time is calculated by adding up the maximum test time of all sessions. Repeat the entire scheduling procedure until the first pareto optimal point [9] of $C_{L}$ is reached. The iteration which gives the optimum scheduling order of the cores, record the details of that iteration as the final scheduling order of the cores with respective TAM width and the corresponding overall test time is considered as the resultant overall test time of that SOC.


Figure 3. Intermediate Core test architecture with max TAM width 8 (a), Final Core test architecture with max TAM width 8 (b)

Assume an SOC having six cores, namely core1, core2, core3, core 4, core5 and core6 of a SOC are there for testing and the given maximum available TAM width is 8 . Assume the test time of the cores are $2507,1624,3305,8342,5829$, 64 respectively for maximum available TAM width. At first all these cores are sorted according to their minimum testing time for given TAM width in ascending order and get the order of cores as $6,2,1,3,5,4$. After that the actual scheduling process (Step 3) is started. At first, core 4 is chosen for scheduling in 1st session as it has the largest testing time. Then core 3 and 1 are selected respectively for scheduling
in that session as they have lesser or equal testing time than core 4 with remaining available TAM width. Hence cores 4, 3 and 1 can be tested parallel and this will be a test session with maximum available TAM width. The rest of the cores are scheduled in same fashion in $2^{\text {nd }}$ and $3^{\text {rd }}$ session as shown in Figure 3b. When all six cores are scheduled then the overall test time is calculated by adding up the maximum testing time of all the sessions. For further reduction of test time again the sessions are formed. This is done as follows: currently assigned TAM width of the largest core (as in previous session) is decreased by 1 and repeats the same scheduling Step 3. This process is continued until the TAM width of the largest core is reached to the $1^{\text {st }}$ pare-to optimal point of that core. Another scheduling architecture is shown in Figure 3a. Since it does not produce optimum results therefore the final configuration is the previous one (shown in Figure 3b).

## V. Experimental Results

The proposed algorithm is implemented using C programming language and GCC compiler in Linux platform is used here for simulation. The program is run in HP workstation with Core i7 processor and 4 GB RAM. Simulations are done on ITC'02 benchmarks SOC like p22810, 993791, p34392. Results are presented in Table I and Table II. $\Delta$ T represents the improvement in test time (in $\%$ ) with respect to our proposed method with other existing methods. $\Delta \mathrm{T}$ is calculated as follows:
$\Delta T=$ ( (Test time corresponding to Existing method - Test time corresponding to our method) / Test time corresponding to existing method) * $100 \%$.

The values of all testing times are in "Clock Cycles" unit.

Test time results for SOCs p22810, p34392 and p93791 are compared with [4] and [6] as no constraints like thermal, power etc. are presented. Table I shows the results of p22810 with existing methods and Table II presents the experimental results for the SOCs p93791 and p34392 with relative improvements in test time compared to the [4] and [6] respectively.

Table I
Experimental Results and Comparative Study of SOC p22810

| TAM <br> WIDTH | Our <br> Method | Method <br> [ 4 ] | $\boldsymbol{\Delta} \mathbf{T}_{\mathbf{1}}$ <br> $(\%)$ | Method <br> [ 6 ] | $\Delta \mathbf{T}_{\mathbf{2}}$ <br> $(\%)$ |
| :---: | :---: | :---: | :---: | :---: | :---: |
|  | 479211 | 959753 | 50.07 | 275537 | -73.92 |
|  | 357743 | 7387800 | 95.16 | 249274 | -43.51 |
| 32 | 243303 | 653060 | 62.74 | 205831 | -18.20 |
| 40 | 204687 | 611087 | 66.50 | 181687 | -12.66 |
| 48 | 186511 | 587328 | 68.24 | 169392 | -10.11 |
| 56 | 156391 | 563882 | 72.26 | 153282 | -2.03 |
| 64 | 134820 | 553497 | 75.64 | 142210 | 5.20 |

In p22810 our proposed method provides 68.03\% improvement in test time with compared to [4] for 64 TAM widths. In p93791 our proposed method provides 71.56\% improvement in test time with respect to [4] for 64 TAM widths and In p34392 our proposed method shows 70.07\% improvement in test time with respect to [4] for 56 TAM width.

But compared to the other method in [6] though our method does not perform well but it can be noted that for higher order TAM widths our proposed method performs better. Also it can be noted that with respect to the running time of the algorithm our proposed heuristic can do the simulation in a very negligible time compared to [6] as shown in Table III.

## VI. Conclusions

In this paper, we have implemented an efficient modular based approach for minimizing the overall test time of a 3D SOC considering the total TAM width and TSV as constraints. The comparative study shows that the obtained results are better than the existing algorithms in most of the cases in terms of testing time. As the TAM distribution and assignment of them to cores for testing is performed in a dynamic way therefore the algorithm works in a much more flexible manner.

Table II
Experimental Results and Comparative Study of SOC p93791 and p34392

| $\underset{\text { WIDTH }}{\text { TAM }}$ | p93791, $\mathrm{TSV}_{\text {max }}=80$ |  |  |  |  | p34392, $\mathrm{TSV}_{\text {max }}=80$ |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Our Method | $\begin{gathered} \text { Method } \\ {[4]} \end{gathered}$ | $\Delta \mathrm{T}_{1}$ | $\begin{gathered} \text { Method } \\ {[6]} \end{gathered}$ | $\Delta \mathbf{T}_{2}$ | Our Method | $\underset{[4]}{\substack{\text { Method }}}$ | $\underset{\Delta T_{1}}{ }$ | Method <br> [6] | $\underset{A T_{2}}{ }$ |
| 16 | 1824647 | 3726714 | 51.04 | 1779298 | -2.55 | 1024937 | 2088962 | 50.94 | 999543 | -2.54 |
| 24 | 1263957 | 2791223 | 54.72 | 1197683 | -5.53 | 692273 | 1791078 | 61.35 | 762841 | 9.25 |
| 32 | 898061 | 2390750 | 62.44 | 894463 | -0.4 | 625938 | 1595286 | 60.76 | 685445 | 8.68 |
| 40 | 763782 | 2153380 | 64.53 | 778296 | 1.86 | 549700 | 1538795 | 64.28 | 552231 | 0.46 |
| 48 | 680940 | 1946263 | 65.01 | 713347 | 4.54 | 544579 | 1567728 | 65.26 | 544579 | 0 |
| 56 | 624697 | 1842030 | 66.09 | 635095 | 1.64 | 544579 | 1819571 | 70.07 | 540069 | -0.84 |
| 64 | 494236 | 1737586 | 71.56 | 572342 | 13.65 | 544579 | 1758060 | 69.02 | 534212 | -1.94 |

TabLe III
Execution time of SOC p22810, 093791, p34392 COMPARING with [6]

| TAM <br> Width | P22810 <br> (ours) <br> (sec) | Method[6] <br> (sec) | $\boldsymbol{\Delta t}$ <br> (\%) | (ours) <br> (sec) | P93791 <br> Method[6] <br> (sec) | $\boldsymbol{\Delta t}$ <br> (\%) | (ours) <br> (sec) | P34392 <br> Method[6] <br> (sec) | $\boldsymbol{\Delta t}$ <br> (\%) |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 16 | 0.001407 | 20.24 | 99.99 | 0.000845 | 15.70 | 99.99 | 0.001049 | 12.2 | 99.99 |
| 24 | 0.001491 | 30.89 | 99.99 | 0.001754 | 18.70 | 99.99 | 0.001097 | 6.35 | 99.98 |
| 32 | 0.001549 | 48.53 | 99.97 | 0.001830 | 16.43 | 99.99 | 0.001129 | 7.26 | 99.98 |
| 40 | 0.00935 | 32.59 | 99.99 | 0.001951 | 40.59 | 99.99 | 0.001161 | 12.59 | 99.99 |
| 48 | 0.001005 | 53.82 | 99.99 | 0.002054 | 81.82 | 99.99 | 0.001212 | 23.82 | 99.99 |
| 56 | 0.001304 | 122.21 | 99.99 | 0.002108 | 180.67 | 99.99 | 0.001234 | 122.21 | 99.99 |
| 64 | 0.001664 | 33.71 | 99.99 | 0.002192 | 332.71 | 99.99 | 0.001261 | 33.71 | 99.99 |

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# Mathematical Model of Plasma Space for Electronic Technologies 

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#### Abstract

The paper is devoted to studying the plasma used in technologies of the electronic industry. It gives the characteristic of plasma space on the basis of a system of Maxwell-Boltzmann equations. Solving these equations is represented in the form of Fourier transformation and Green functions. Fluctuation-dissipative theorem and method of Longevin sources for calculating electric filed fluctuations are used.


Key words: electric field, correlation functions, fluctuationdissipative theorem, temperature.

## INTRODUCTION

In studying plasma systems researching electromagnetic properties is of great importance. Statistical theory (ST) of thermodynamic equilibrium is based upon the use of fluctuation-dissipative theorem. Thus, the problem of finding correlation functions of an electric field is reduced to calculating the function of the system response to external disturbance. One of the ST approaches is the method of Langevin sources. At that it is necessary to derive correlation functions and equations of the distribution of the fluctuations of the electric field. The present paper is devoted to developing a statistical model of a semi-infinite plasma being abut with a dielectric. Such a model is used in astrophysics, nuclear fusion, solid-state plasma of semiconductors, plasma spraying of thin films and gas-discharge plasma. The first section of the paper considers the problem of exciting electric waves in a dielectric on the basis on Maxwell equations and linearized kinetic equation with a collision integral in an $\vec{r}$-approximation. The solution of these equations is represented in the form of Fourier expansion. The second section uses the fluctuation-dissipative theorem for finding the correlation functions of a electric field which are expressed in terms of the linear response function. The distribution of Green functions along z -axis has been found.

[^1]The third section makes use of the Langevin approach to finding the correlation functions of the electric field.

## I. Distribution of Electric Field

Let us consider a homogeneous quasineutral plasma system taking up the semifinite space $(x, y<\infty, z>0)$. The exterior domain is filled with a dielectric of permittivity $\widetilde{\varepsilon}(\omega)$. We shall get equations for calculating the distribution of the fluctuation electric field established by arbitrarily distributed induced sources $\vec{J}(\vec{r} ; t)$ and $\overrightarrow{\widetilde{J}}^{e}(\vec{r}, t)$. The sought distributions can be found as a result of the joint solution of the Maxwell equations for the exterior domain and linearized system of Maxwell-Boltzmann equations for the plasma occupied domain [1]

$$
\begin{gather*}
\operatorname{rot} \vec{B}(\vec{r}, \omega)=-i \frac{\omega \varepsilon}{c} \vec{E}(\vec{r}, \omega)+4 \pi\left(\frac{\sum_{\sigma} \vec{J}(\vec{r}, \omega)+\vec{J}^{e}(\vec{r}, \omega)}{c}\right) \times \\
\times\left\{-i \omega+v \frac{\partial}{\partial \vec{r}}+\frac{e_{\sigma}}{m_{\sigma}}\left(\vec{E}+\frac{v \vec{B}}{c}\right) \frac{\partial}{\partial v}\right\} \times \delta f_{\sigma}(\vec{r}, v, \omega)+ \\
+\frac{e_{\sigma}}{m_{\sigma}}\left\{\vec{E}(\vec{r}, \omega)+\frac{v \vec{B}(\vec{r}, \omega)}{c}\right\} \times \frac{\partial f(v)}{\partial v}=L \delta f_{\sigma}(\vec{r}, v, \omega) \\
\operatorname{rot} \vec{E}(\vec{r}, \omega)=i \frac{\omega}{c} \vec{B}(\vec{r}, \omega) \tag{1}
\end{gather*}
$$

where $\vec{J}(\vec{r}, \omega)$ is the induced current of particles having charge $e_{\sigma}$, mass $m_{\sigma}$ and density $n_{\sigma} ; \varepsilon(\omega)$ is the plasma permittivity; $\delta f_{\sigma}(\vec{r}, v, \omega)$ is the deviation of particle distribution; $\vec{E}, \vec{B}$ are electric and magnetic fields; $L=-v$ is the linearized operator of particle collisions; $v$ is the frequency of particle collisions; " $\sim$ " is the exterior domain value. Let us consider the model of mirror reflection of charged particles from the interface region [2]. To harmonically analyze the sources $\vec{J}(\vec{r}, \omega), \vec{J}^{e}(\vec{r}, \omega)$, we shall make Fourier transform. After a transition from variables $\vec{r}$ to variables $\vec{k}$, we shall obtain [3-5]

$$
\begin{equation*}
A(\vec{r}, \omega)=\frac{1}{(2 \pi)^{3}} \int_{-\infty}^{\infty} d k \exp (i \vec{k} \vec{r}) A(\vec{k}, \omega) \tag{2}
\end{equation*}
$$

and the sought Fourier-components of an electric field can be represented in the form (Fig. 1)

$$
\begin{aligned}
& \Lambda(\vec{k}, \omega)=\varepsilon(\vec{k}, \omega)-\left(\delta-\frac{\vec{k}}{\vec{k}^{2}}\right) \frac{c^{2} \vec{k}^{2}}{\omega^{2}} ; \\
& \tilde{\Lambda}(\vec{k}, \omega)=\left(\delta-\frac{\vec{k}}{\vec{k}^{2}}\right) \overrightarrow{\tilde{A}}_{T}(\vec{k}, \omega) ; \\
& S(\vec{k}, \omega)=\frac{i}{\pi} \frac{c}{\omega} \int_{-\infty}^{\infty} d \vec{k} \tilde{\Lambda}^{-1}(\vec{k}, \omega) ;
\end{aligned}
$$

$\varepsilon(\vec{k}, \omega)$ is the permittivity tensor.


PRINT E NODAL SOLUTION PER NODE
POST1 NODAL ELECTRIC FIELD INTENSITY LISTING LOAD STEP=1 SUBSTEP=999999 TIME=1.0000 LOAD CASE=0 THE FOLLOWING $X, Y, Z$ VALUES ARE IN GLOBAL COORDINATES

| NODE | EX | EY | EZ | ESUM |
| ---: | :---: | :---: | :---: | :--- |
| 01 | -1229.6 | -1472.7 | 3476.3 | 4374.5 |
| 02 | -1327.7 | -1445.9 | 3655.1 | 4414.7 |
| 04 | -1379.3 | -1459.7 | 3543.9 | 4959.4 |
| 06 | -1394.4 | -1313.6 | 3627.4 | 4208.4 |
| 08 | -1389.7 | -1337.4 | 3425.5 | 3967.5 |
| 10 | -1395.9 | -1349.9 | 3246.7 | 3956.6 |
| 12 | -1356.7 | -1394.3 | 3276.8 | 3897.1 |
| 14 | -1482.8 | -1334.8 | 3284.8 | 3437.8 |
| 16 | -1367.2 | -1369.2 | 3524.6 | 3986.5 |
| 18 | -1354.3 | -1365.5 | 3412.6 | 3954.8 |
| 20 | -1334.8 | -1324.8 | 3434.3 | 3934.9 |
| 22 | -1382.6 | -1386.7 | 3487.8 | 3782.8 |
| 24 | -1327.8 | -1393.7 | 3482.3 | 3527.9 |
| 26 | -1325.7 | -1375.4 | 3385.5 | 3265.7 |
| 28 | -1306.8 | -1327.7 | 3575.2 | 3816.8 |
| 30 | -1358.9 | -1349.2 | 3476.9 | 3527.6 |
| 32 | -1380.5 | -1381.8 | 3554.7 | 3789.5 |
| 34 | -1359.7 | -1368.7 | 3417.5 | 3596.8 |
| 36 | -1307.3 | -1383.5 | 3747.6 | 3879.5 |
| 38 | -1320.7 | -1392.2 | 3834.8 | 3930.7 |
| 40 | -1306.4 | -1374.8 | 3752.2 | 3659.9 |
| 42 | -1357.6 | -1346.9 | 3974.8 | 3549.3 |
| 44 | -1325.9 | -1329.5 | 3841.4 | 3529.3 |
| 46 | -1427.8 | -1364.8 | 3862.2 | 3527.8 |
| 48 | -1456.4 | -1247.4 | 3879.7 | 3407.9 |
| 50 | -1145.3 | -1268.3 | 3843.4 | 3594.7 |

Fig. 1. Electric fluctuations in plasma

## II. Mathematical Model of a Thermodynamical EQUILIBRIUM SYSTEM

If a plasma is in the state of ST thermodynamic ecvilibrium, the correlation function has the form [6] in line with the fluctuation-dissipative theorem

$$
\begin{equation*}
\vec{E}(\vec{r}) \overrightarrow{\dot{E}}(\overrightarrow{\dot{r}})=-\theta(\omega, T) \times(G(\vec{r}, \overrightarrow{\dot{r}}, \omega)+\dot{G}(\vec{r}, \vec{r}, \omega)) \tag{4}
\end{equation*}
$$

where the average energy of a quantum harmonic oscillator

$$
\theta(\omega, T)=\frac{\hbar \omega}{2}+\frac{\hbar \omega}{\exp \left(\frac{\hbar \omega}{T}\right)-1}
$$

$G(\vec{r}, \overrightarrow{\dot{r}}, \omega)$ is the function of linear system response to the external disturbance.

As the system is homogeneous in $\vec{r}$, we shall pass over to variables $\vec{k}$.

$$
\begin{equation*}
\vec{E}(z) \overrightarrow{\dot{E}}(\dot{z})=-\theta(\omega, T) \times(G(\vec{k}, z, \dot{z}, \omega)+\dot{G}(\vec{k}, z, \dot{z}, \omega)) \tag{5}
\end{equation*}
$$

Let us find the distribution of Green functions of the Max-well-Boltzmann system along the axis $Z$

$$
\left\{\begin{array}{l}
G(\vec{k}, z, \dot{z}, \omega)=\frac{1}{(2 \pi)^{2}} \int_{-\infty}^{\infty} d \vec{k} \int_{-\infty}^{\infty} d \overrightarrow{\dot{k}} \exp (i(\vec{k} z-\overrightarrow{\dot{k}} \dot{z})) G(\vec{k}, \overrightarrow{\dot{k}}, \omega)  \tag{6}\\
\tilde{G}(\vec{k}, z, \dot{z}, \omega)=\frac{1}{(2 \pi)^{2}} \int_{-\infty}^{\infty} d \vec{k} \int_{-\infty}^{\infty} d \overrightarrow{\dot{k}} \exp (i(\vec{k} z-\overrightarrow{\dot{k}} \dot{z})) \tilde{G}(\vec{k}, \overrightarrow{\dot{k}}, \omega)
\end{array}\right.
$$

We shall obtain [7] (Fig.2) substituting the Fourier components of Green functions into the system (6)

$$
\left\{\begin{array}{l}
\vec{E}(\vec{k}, \omega)=\frac{1}{2 \pi} \int_{-\infty}^{\infty} d \overrightarrow{\dot{k}} G(\vec{k}, \overrightarrow{\dot{k}}, \omega) \vec{J}(\overrightarrow{\dot{k}}) ; \vec{J}(\vec{r}, t)=\overrightarrow{\widetilde{J}}^{e}(\vec{r}, t) ; \\
\overrightarrow{\widetilde{E}}(\vec{k}, \omega)=\frac{1}{2 \pi} \int_{-\infty}^{\infty} d \overrightarrow{\dot{k}} \widetilde{G}(\vec{k}, \overrightarrow{\dot{k}}, \omega) \vec{J}(\overrightarrow{\dot{k}}) ; \overrightarrow{\widetilde{J}}^{e}(\vec{r}, t)=0 \\
\vec{E}(\vec{k}) \overrightarrow{\dot{E}}(\overrightarrow{\dot{k}})=-\theta(\omega, T) \times(G(\vec{k}, \overrightarrow{\dot{k}}, \omega)+\dot{G}(\vec{k}, \overrightarrow{\dot{k}}, \omega)) ; \\
\overrightarrow{\widetilde{E}}(\vec{k}) \overrightarrow{\dot{E}}(\overrightarrow{\dot{k}})=-\theta(\omega, T) \times(\widetilde{G}(\vec{k}, \overrightarrow{\dot{k}}, \omega)+\stackrel{\tilde{G}}{ }(\vec{k}, \overrightarrow{\dot{k}}, \omega)) .
\end{array}\right.
$$

## III. Using the Method of Longevin Approach

The contribution to the correlation functions of electric fields is taking into account the heat radiation of external medium. The sources $\vec{J}^{e}(r, \omega), \overrightarrow{\widetilde{J}}^{e}(r, \omega)$ given in various space areas can be considered independent. Using the system of equations (3) of the problem of exciting by arbitrarily distributed sources, we will get the following equations [8]

$$
\begin{gather*}
\vec{E}(\vec{k}) \overrightarrow{\dot{E}}(\overrightarrow{\dot{k}})=\left(\frac{4 \pi}{\omega}\right)^{2} \Lambda^{-1}(\vec{k}, \omega) \dot{\Lambda}^{-1}(\overrightarrow{\dot{k}}, \omega) \times \\
\times\left\{\vec{J}^{e}(\vec{k}) \overrightarrow{\dot{J}}^{e}(\vec{k})+\left(\frac{c}{2 \pi}\right)^{2} \times \frac{\vec{E}^{e} \overrightarrow{\dot{E}}^{e}+\overrightarrow{\tilde{E}}^{e} \overrightarrow{\tilde{E}}^{e}}{S(\vec{k}, \omega) \dot{S}(\vec{k}, \omega)}+\frac{c \vec{J}^{e}(\vec{k}) \overrightarrow{\dot{E}^{e}}(\vec{k}, \omega)}{2 \pi \dot{S}(\vec{k}, \omega)}+\frac{\vec{E}^{e}(\vec{k}, \omega) \overrightarrow{\dot{J}^{e}}(\overrightarrow{\dot{k}})}{S(\vec{k}, \omega)}\right\} ; \tag{8}
\end{gather*}
$$

$$
\begin{align*}
& \overrightarrow{\tilde{E}}(\vec{k}) \overrightarrow{\dot{E}} \overrightarrow{\dot{k}})=\left(\frac{4 \pi}{\omega}\right)^{2} \tilde{\Lambda}^{-1}(\vec{k}, \omega) \tilde{\Lambda^{-1}}(\overrightarrow{\dot{k}}, \omega) \times \\
& \times\left\{\left(\overrightarrow{\tilde{J}}^{e}(\vec{k}) \overrightarrow{\tilde{J}^{e}}(\overrightarrow{\dot{k}})\right)+\left(\frac{c}{2 \pi}\right)^{2} \times \frac{\vec{E}^{e} \overrightarrow{\dot{E}}^{e}+\overrightarrow{\tilde{E}}^{e} \overrightarrow{\tilde{E}}^{e}}{S(\vec{k}, \omega) \dot{S}(\vec{k}, \omega)}-\frac{c \overrightarrow{\tilde{J}}^{e}(\vec{k}) \overrightarrow{\tilde{E}^{e}}(\vec{k}, \omega)}{2 \pi \dot{S}(\vec{k}, \omega)}+\frac{\overrightarrow{\tilde{E}}^{e}(\vec{k}, \omega)}{S(\vec{k}, \omega)}\right\} . \tag{9}
\end{align*}
$$

Setting Langevin sources in the external area to zero can result in erroneous results. When $T=\widetilde{T}$, equations (8) and (9) are reduced to equations for the correlation function of electric field Fourier-components. Introducing complimentary sources enables to calculate the distribution of an electric field in plasma. The equation for the energy of heat radiation from unit of plasma surface to the external area is determined by a normal component of the Umov-Pointing vector [9] (Fig. 2)

$$
\begin{equation*}
P(\omega) d \omega=\int_{\theta \leq 0.5 \pi} d \Omega \cos \theta I(\omega, \theta, T, \tilde{T}) d \omega \tag{10}
\end{equation*}
$$

where $I(\omega, \theta, T, \tilde{T})=I(\omega, \theta, T)-I(\omega, \theta, \tilde{T})$ is the intensity of heat radiation per unit of solid angle $d \Omega=\sin \theta d \theta d \varphi ; \theta$ is the vectorial angle from the outer normal to the plasma boundary.

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TIME= 1.0000 LOAD CASE= 0 THE FOLLOWING $X, Y, Z$ VALUES ARE IN GLOBAL

|  |  | COORDINATES |  |  |
| ---: | :---: | :---: | :---: | :---: |
| NODE | EX | EY | EZ | ESUM |
| 01 | 2529.8 | 2732.3 | 3672.8 | 5745.5 |
| 02 | 2585.4 | 2743.5 | 3655.1 | 5714.7 |
| 04 | 2339.9 | 2854.3 | 3543.9 | 5959.4 |
| 06 | 2394.5 | 2313.6 | 3627.4 | 5887.8 |
| 08 | 2379.7 | 2437.4 | 3625.5 | 5968.5 |
| 10 | 2495.9 | 2449.4 | 3646.7 | 5954.9 |
| 12 | 2456.6 | 2594.8 | 3676.6 | 6043.2 |
| 14 | 2582.3 | 2534.7 | 3684.3 | 6037.3 |
| 16 | 2567.2 | 2569.4 | 3687.6 | 6087.5 |
| 18 | 2564.3 | 2575.5 | 3712.6 | 6054.8 |
| 20 | 2634.5 | 2584.8 | 3734.3 | 6097.9 |
| 22 | 2682.6 | 2684.3 | 3789.4 | 6099.3 |
| 24 | 2627.8 | 2639.7 | 3782.3 | 6027.9 |
| 26 | 2525.7 | 2575.5 | 3685.5 | 5965.7 |
| 28 | 2576.2 | 2527.6 | 3575.2 | 5976.5 |
| 30 | 2558.3 | 2549.3 | 3586.5 | 5927.4 |
| 32 | 2575.3 | 2551.4 | 3554.7 | 5909.4 |
| 34 | 2589.7 | 2568.5 | 3527.6 | 5896.8 |
| 36 | 2577.2 | 2683.8 | 3570.5 | 5879.4 |
| 38 | 2520.7 | 2692.2 | 3435.8 | 5793.7 |
| 40 | 2486.4 | 2574.4 | 3452.2 | 5759.5 |
| 42 | 2457.3 | 2546.8 | 3445.8 | 5749.5 |
| 44 | 2425.9 | 2529.5 | 3438.4 | 5729.8 |
| 46 | 2427.8 | 2564.8 | 3439.2 | 5707.5 |
| 48 | 2457.4 | 2547.7 | 3494.7 | 5695.9 |
| 50 | 2428.2 | 2528.3 | 3443.5 | 5653.7 |

Fig. 2. Temperature distribution in plasma

The actuality of this scientific paper consists in the fact that its results are being used at Kharkov National University of Radio Electronics at accomplishing Ukraine’s Ministry of Education and Science (UMES) theme № 269 "SOLAR" for manufacturing thin films. Using the methods developed allows technological indices to be changed: oxygen concentration temperature at constant discharge power of 2.05 $\mathrm{W} / \mathrm{m}^{2}$ and chamber pressure of $5 \times 10^{-3}$ mega bars. It is found that glow - discharge plasma exerts a considerable energetic and heat effect on the film in the course of magnetron sputtering. It permits to produce films without special substrate heating.

## IV. Conclusion

The paper is of practical use as it has solved the problem of exciting a plasma system under thermodynamic equilibrium on the basis of a charged particle mirror reflection model. A method of developing plasma ST is suggested which takes into account external medium radiation. This method is based on the use of Langevin approach when random sources of fluctuations are introduced in plasma and external areas. To calculate the electric field the values of the Green functions of the Maxwell-Boltzmann equations system have been found and their harmonic analysis has been done. The results obtained on the base of the fluctua-tion-dissipative theorem and Langevin approach within the same temperatures of plasma and external medium are equivalent. The work has been done on UMES scientific theme №0107U002295.

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# Studying Physical Processes in Crystals without Inversion Centre 

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#### Abstract

The paper theoretically investigates the photogalvanic effect in optic transitions between spin subzones of Landau levels within an ultraquantum limit. A geometry is considered when polarization is perpendicular and the electric current is directed along the magnetic field. The effect is caused by cubic terms in the Hamiltonian function, which exist due to the absence of an inversion center. The considered magnetic field relation is of resonance character, the said relation having both odd and even field contributions. Such an effect character is related to the resonance in the intermediate state and interference of second order transition amplitudes in relativistic contributions in the Hamiltonian function.


Key words: photogalvanic effect, optic transitions, magnetic field, inversion center, polarization, relativistic contributions, Hamiltonian function, resonance.

## Introduction

The paper compares theory with experiment. Since the publication of the work by Blokh M.D. and Magarill L.I. [1], the phenomenon of combined resonance (light absorption at the expense of the electric component of an electromagnetic wave that is conditioned by electronic transitions with a spin flip) has remained in the sphere of solid-state physics interests. Thus, the phenomenon of interference of magnetic dipole and electric dipole resonances in the Vogt configuration in crystals without an inversion center has been found and studied. The research of the photo-galvanic effect (PGVE) has been of particular interest in this case as both light absorption and PGVE are defined by the non-center inversion state of a medium. The dependence on light polarization and crystal orientation helps to single it out among other photoelectric effects. The PGVE in a magnetic field was studied in a number of works [2-4], but the case of quantizing a field

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has not been considered prior to our paper. The aim of the paper is to investigate the PGVE within spin resonance as well as construction of mathematical model for calculating zone parameters, as the same components in the Hamiltonian can result both electric dipole transitions and PGVE current. The problems which are solved in the paper describe observed polarization relations in the considered magnetic field orientations related to crystallographic directions. The comparison of theoretical and experimental values of signals for an even resonance contribution to the PGVE allows to determine the parameters. The values of these parameters are in good agreement with their values calculated in Kane's model. The theoretical value of the contribution that is odd in $\Delta$ is almost by three orders of magnitude greater than the experimentally observed one. Partially it may be due to the fact that the nonuniformity of the magnetic field in the volume, occupied by a sample leads to the suppression of alternating signal and has a slight effect on the value of constant sign contribution. Other contributions are possible which are not taken into account by theory and which describe a peak, even in $\Delta$. The impurity pairs shown in Fig. 1 behave almost in the same way as the peak of spin resonance on free carriers does. Therefore free electrons emerge at the expense of auto ionization processes in such transitions.

## I. DISTRIBUTION OF ELECTRIC CURRENT

We will consider an electric current flowing along the direction of a magnetic field $H$ at propagation of light along the same direction (Faraday geometry). Light polarization and orientation $H$ with respect to crystallographic axes are considered random. Assume that the conditions are fulfilled which conform to the superquantum limit: $\omega_{s} \gg T ; \omega>E_{F}$ where $\omega_{s}=|q| \mu_{B} H$ is the energy of a spin transition, $E_{F}$ is the Fermi level calculated from the lower spin subzone, $\mu_{B}$ is Bohr's magneton, $\hbar=1$. $A_{0}, A(t)=\operatorname{Re} A e^{-i \omega t}$ are the vector potentials of a magnetostatic homogeneous field and electromagnetic wave, respectively [4].

$$
\begin{equation*}
U(r)=\sum_{i} u\left(r-r_{i}\right) \tag{1}
\end{equation*}
$$

is the potential energy of an interaction of electrons with chaotically distributed impurities ( $r_{i}$ is a coordinate of $r$-th impurity center).

The Hamiltonian function of the considered system has the form

$$
\begin{equation*}
H=H_{0}+H_{1}+H_{2}+H_{U}+U+F \tag{2}
\end{equation*}
$$

where $H_{0}$ is the Hamiltonian of a free electron in a parabolic approximation

$$
\left\{\begin{array}{l}
H_{0}=\frac{k^{2}}{2 m}+\frac{1}{2} q \mu_{B} H_{i} \sigma_{i}  \tag{3}\\
k=p+\frac{e}{c} A_{0}
\end{array}\right.
$$

The components $H_{1}, H_{2}, H_{U}$ correspond to three possible mechanisms with a spin flip [5]. The component $H_{1}=\delta_{0} \sigma \Phi \Omega$ is related with the absence of the center of inversion in the main axes of the crystal

$$
\begin{gather*}
\left\{\begin{array}{l}
\Omega_{1}=k_{2} k_{1} k_{2}-k_{3} k_{1} k_{3} ; \\
\Omega_{2}=k_{3} k_{2} k_{3}-k_{1} k_{2} k_{1} ; \\
\Omega_{3}=k_{1} k_{3} k_{1}-k_{2} k_{3} k_{2} .
\end{array}\right. \\
H_{2}=\bar{q} \mu_{B}\{(H k)(\sigma k)+(\sigma k)(H k)\},
\end{gather*}
$$

with the function of $q$-factor of a pulse, and the component

$$
\begin{equation*}
H_{U}=\alpha_{s}([\nabla U, k] \sigma) \tag{5}
\end{equation*}
$$

is a spin-orbital interaction of an electron with impurities. The terms in the Hamiltonian denoted by the letter $F$ define the interaction of electrons with an electromagnetic wave, at that

$$
\begin{align*}
& F=F_{0}+F_{1}+F_{2}+F_{3}+F_{U},  \tag{6}\\
& \left\{\begin{array}{l}
F_{0}=\frac{e}{m c}(k A) ; \\
F_{1}=i \frac{e \delta_{0}}{c}(\sigma \Omega) r A ; \\
F_{2}=2 q \frac{e}{c} \mu_{B}(\sigma A) H k ; \\
F_{U}=\alpha_{s} \frac{e}{c}(\sigma[\nabla U A]) .
\end{array}\right. \tag{7}
\end{align*}
$$

## II. Function of a longitudinal pulse

The existence of a current along the field $H$ direction requires the probability imparity of a transition as the function of a longitudinal pulse $p_{z}$. We will stem from the solution of the quantum kinetic equation of the form [6]

$$
\begin{equation*}
I f_{i}+G_{a}=0 \tag{8}
\end{equation*}
$$

where $f$ is an addition to the equilibrium distribution function, $I$ is an integral of collisions of an electron with impurities, $G_{a}$ is the generation probability, $i$ is a set of quantum numbers characteristic of the eigenstates of the Hamiltonian function $H_{0}$ in the range of $A_{0}, p$ is an electron pulse, $n$ is the level number, $\sigma= \pm 1$ (we will use the signs + and - to denote a projected spin). As we are interested in electron transitions within the Landau level $n=0$, we will omit this index in all the quantities. The part
of the distribution function that is potentially odd in pulse and that makes an attribute to the current can appear as a result of the oddness of the function of generalization and scattering probability (Figure). When neglecting the interaction with impurities in perturbation theory the asymmetric part of a transition probability can occur due to the interference of contributions $F_{1}$ and $F_{2}$

$$
\begin{equation*}
\omega_{i \beta}^{(1)}=\frac{\pi}{2} \operatorname{Re}\left[\left(F_{1}\right)_{\beta_{i}}\left(F_{2}\right)_{\beta_{i}}\right], \tag{9}
\end{equation*}
$$

where $i=p,+, \beta=p^{\prime},-$,

$$
\begin{equation*}
\left(F_{1}\right)_{\beta_{i}}=\frac{\sqrt{2} e E_{0} \delta_{0}}{i \omega a^{2}} e_{B}\left(a^{2} p_{z}^{2}-1 / 2\right) \delta_{p p^{\prime}} . \tag{10}
\end{equation*}
$$

Here $E_{o}$ is the field amplitude of an electromagnetic wave, $e$ is a polarization vector, $a=\sqrt{c \hbar / e H}$ is the function of the direction of a magnetic field with reference to crystallographic axes located in the coefficients $B_{i j k}$ ( $\Phi$ is an azimuth, $\Theta$ is polar angles).

$$
\left\{\begin{array}{l}
B_{133}=\cos 2 \Phi \cos 2 \Theta-i / 2 \sin 2 \Phi \cos \Theta\left(3 \cos ^{2} \Theta-1\right) \\
B_{233}=-3 i / 2 \sin 2 \Phi \sin \Theta \sin 2 \Theta \\
e_{B}=e_{-} B_{133}+e_{+} B_{233}
\end{array}\right.
$$



Calculation of distribution of concentration of
carriers of charge $n$ and $p$ type on X coordinate in GaAs at flowing a current $0,1 \mathrm{~A}$ and action of a 1 T magnetic field

## III. OdDNESSES OF SCATTERING PROBABILITY FUNCTION

The paper analyzes the components arising thanks to the oddness of the scattering probability in pulse at the availability of impurities. It was found that in the superquantum limit, unlike the case of the absence of a magnetic field, these components do not result in a photovoltaic effect. Besides, there is no oddness of generation function in the parabolic approximation for the spectrum of electrons. Taking into account the nonparabolic spectrum character we have calculated the space distribution of the current density [7].

$$
\begin{align*}
& j_{z}^{(1)}=-\frac{e^{3} \delta_{0} \tilde{q} \omega_{B}^{2} E_{0}^{2} m}{\pi a^{4}|q| \varepsilon_{q} \omega^{2}} \int d p_{z} f_{p z}^{(0)}+\frac{\partial}{\partial m}\left(\tau_{p_{z}},+v_{p z}^{2}\right) \times  \tag{11}\\
& \times p_{z}\left(a^{2} p_{z}^{2}-1 / 2\right) P \delta_{\eta}(\Delta) .
\end{align*}
$$

Here $P=\operatorname{Re}\left(e_{-} e_{+} B_{133}\right), \delta_{\eta}(\Delta)=\eta / \pi\left(\Delta^{2}+\eta^{2}\right)$ is the delta function that is fuzzy in the extension $\Delta=\omega-\omega_{\mathrm{s}}$ of resonance components.

$$
j_{z}^{(2)}+j_{z}^{(3)}=-\frac{4 \pi \alpha_{s} e^{3} n(\varepsilon)}{\alpha^{2} \omega^{2}} E_{0}^{2}\left(\delta_{\eta}(\Delta)-\frac{\tilde{q} \omega_{s}}{\alpha_{s}|q|} \delta_{\eta}^{\prime}(\Delta)\right) P^{\prime} .(12)
$$

Besides the considered contribution to the current there may be components depending on the interaction of electrons and impurities, the spin of electrons changing.

## Conclusion

The scientific novelty of the paper consists in modelling of PGVE shown on spin transitions in GaAs. The analysis of calculations has shown that the distribution of electric current density does not depend on the angle between the vector of linear polarization and crystallographic directions. A conclusion has been made in the paper that at the opposite directions of the light wave vector PGVE does not depend on the sign of the radiation wave vector. A symmetric combination of signals at the opposite light distribution is considered. The practical significance of the work lies in the obtained parameters that are dependent on a circular polarization magnetic field. The change of the sign of the magnetic field does not influence the value of the parameters.

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# Methodology of Two-Stage Masking Images in Information and Telecommunications Systems 

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#### Abstract

The questions of comparative evaluation of the most common methods of concealment. Demonstrates the use of previously-based measures quantify the quality of the detection and localization of the contours to compare methods. The results of the experiment on the use of masking. The need to apply the cascade methodology masking problems in image processing.


## I. Introduction

$\mathrm{I}^{\mathrm{R}}$n various application areas related to image processing, it is necessary to consider into account the semantic component of the image. The most semantically meaningful information about the contours, the edges of objects. One of the basic components of semantic processing is the concealment techniques. These technologies allow you to highlight informative details about the structural characteristics of objects in images. By masking the image we mean methods (algorithms, methods) discovery (search and localization) contours (boundaries of circuits) in the images by moving the mask (filter).

## II. STATEMENT OF THE PROBLEM

Detection contours there is a great variety of techniques and mask images. One effective approach for constructing concealment methods are methods based on building gradient [1-3, 6-8]. Gradient (differential) methods based on the detection at each point of the approximate values of the brightness gradient and direction of their greatest change, which serves to emphasize the position change of brightness. These methods are integrated methods for the edge detection, the direction of which is arbitrary.

There are no universal methods of concealment for different types of images [1, 6]. This leads to the fact that the existing methods are only effective within a narrow class of images. Therefore, the lack of reliable methods for evaluation of the device masking results in the restriction to

[^2]increase their effectiveness. In most cases, the evaluation of quality masking method is limited only by subjective assessment (visual assessment of the work quality). But this approach is only applicable in cases where the processing systems - the decision-maker. Thus, the task of quantifying the quality concealment methods in realistic image processing systems is the actual scientific - applied problem.

One solution to the problem is to construct a two-stage scheme of concealment. This will reduce the disadvantages of mutual concealment methods used in the first and second stages of the phased evaluation implementation of the concealment quality. Therefore, the purpose of research paper is to justify the approach to masking images based on two-stage technique using a quantitative assessment of the concealment methods quality for the formation of transformation operators in cascade on processing.

## III QUALITY ASSESSMENT METHOD FOR THE TWO-STAGE MASKING IMAGES TECHNOLOGY

Assessment of the work quality, study methods perform on the test images. As test images using GT-imagery, ground truth images - images that contain a common understanding of the researcher border with database of California Berkeley University, Computer Vision Group [4], and computer graphics laboratory of Moscow State University [5].

Key measurement concealment methods considered in the paper [1-3, 6-8]. In these studies suggest methods of theoretical and empirical evaluation of the detection and localization quality of the contours. Score concealment methods is carried out based on the following measures quality detection and localization of [1, 6-8]:

1) an error of first kind $\alpha$ - the ratio of incorrectly selected boundary pixels to total number of the pixels which are not boundary or its derivative - specificity $S_{p}$, as the ratio selected not boundary pixels to total number not boundary pixels of a GT-image;
2) an error of second kind $\beta$ - the ratio of not selected boundary pixels to total number of boundary pixels or its derivative sensitivity $S_{e}$ - the ratio of correctly selected boundary pixels to total number of boundary pixels of a GT-image;
3) an amount of correct certain pixels in comparison with an ideal contour - N corr.;
4) an amount of wrong certain pixels in comparison with an ideal contour - N incorr.;
5) mean squared error RMSE (Root Mean Square Error), defined as distance between two pixels of compared images [2, 3, 13];
6) the spades ratio of a signal/noise - PSNR.

As additional parameter it is offered to spend an estimation of handling time of the image $-t(\mathrm{~ms})$, the handling consisting of the method an operating time, time of measures calculation of qualities and a conclusion of processing outcomes. The metrics (1) - (4) allow spending an estimation of detecting quality of contours, metrics (5) and (6) estimation of quality of contours localization. The given metrics also allow to estimate the basic errors and distortions (ruptures, local displacement, spreading and thickenings of contours), brought by masking methods in the treated image [1-3].

Let's hold testing of the masking applied in systems methods of images automatic handling. Testing is understood as visualization of handling outcomes and a quantitative estimation of method quality masking (an evaluation of the offered metrics (1) - (7)). Were considered for testing the most widespread methods using a gradient of the image - operators of Prewitt, Sobel, Sharu, Laplace (2 aspects), Laplasian, a method of Hrjashchev and a mask of a method Canny (factors calculate for a mean squared deviation $\sigma=1$, 4) [1-3]. Matrixes of transformation for masking methods are known [1-6]. At an estimation of work quality of masking methods as the entering have been used: realistic images (color and half-tone) identical sizes and GT-images for the given realistic images.

In the calculation of metrics to compare images - the result of the masking method and a binary image of GT. When comparing the methods of concealment used in the proposed objective quality metrics (1) - (6), which, for all its shortcomings compared with subjective quality assessment (based on an assessment of the visual quality of the image processing) can be used in automatic image processing.

## IV. Result of testing

In the article the estimation of quality of masking methods (the entering image, outcome of handling, rated values of metrics) for the image " 37073 " of base [4, 5] is presented: color and half - tone realistic image with a natural background, a size - $481 \times 321$ pixels, a solution $300 \times 300$ dpi, depth of color 24 bit both 8 bit and corresponding to them GT - an image (fig. 1 a) and b)). For the realistic image "37073" outcome of handling is presented in drawing 1 , in table 1 the calculated values of quality indicators of masking methods (the bold type selects corresponding minimum and maximum values of metrics) are presented. During researches were the analysis more than 300 realistic images from databases $[4,5]$ is carried out.

As a result of the spent researches of widespread methods of masking it is possible to draw following conclusions:
a) the analysis of metrics shows insignificance values of images chromaticity for masking methods (the tendency in work of methods "better - worse" remains, values of quality indicators - no more than 5-8 \% slightly vary);
b) the best indicators of quality of contours search at a method of Sobel (N cor. = 150723, N incorr. = 2078, RMSE $=0,116616411531842$, PSNR $=18,6648065325059$ (values table 1);
c) the best indicators of quality from the point of view not to add false contours at a method of Hrjashchev (value of an error of first kind $\alpha=$,89383251944294E-5 and specificity $S_{p}=0,999971061674806$ ) with simultaneously worst values of performances of the real admission contours and origins of ruptures (an error of second kind $\beta=$ 0,955063117453348 and sensitivity $S_{e}=$ 0,044936882546652);
d) the best indicators of quality from the point of view do not miss real contours and origin of boundaries ruptures at a method Sharu (errors of second kind $\beta=0,001$ and sensitivity $S_{e}=0,999$ );
e) the best indicators of quality from the point of view unadmission real contours and origin of boundaries ruptures at a method to the Sharu (errors of second kind $\beta=0,001$ and sensitivity $S_{e}=0,999$ ).

The quantitative estimates are confirmed by the visualization of the processing realistic images results


TABLE I THE CALCULATED VALUES OF QUALITY INDICATORS OF MASKING METHODS

| Parameters | Methods of masking |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Sobel | Prewit | Sharu | Laplace 1 | Laplace 2 | Hrjashchev | Laplasian | matrix Canny |
|  | "37073", the half-tone image |  |  |  |  |  |  |  |
| Handling time, mc | 2416 | 2424 | 2430 | 2422 | 2415 | 5910 | 5854 | 5920 |
| Estimation of corr. pixels | 150723 | 146976 | 112435 | 138912 | 138367 | 138876 | 126618 | 117055 |
| Estimation of incorr. pixels | 2078 | 5825 | 40366 | 13889 | 14434 | 13925 | 26183 | 35746 |
| RMSE | 0,1166164115 | 0,195247223 | 0,5139782717 | 0,30148963828 | 0,30734790153 | 0,301880112862487 | 0,413948777771 | 0,48367164437 |
| PSNR | 18,66480653 | 14,18830267 | 5,781104806 | 10,414552186 | 10,2473949551 | 10,4033099262598 | 7,66106790743 | 6,30898745443 |
| Error of first kind | 0,0056719117 | 0,00343642612 | 0,2920311087 | 0,01281244348 | 0,056776994032 | 2,89383251944294E-5 | 0,165860010852 | 0,18473503346 |
| Specificity | 0,9943280883 | 0,996563574 | 0,7079688913 | 0,9871875565 | 0,94322300597 | 0,999971061674806 | 0,83413998915 | 0,81526496654 |
| Error of second kind | 0,08877607 | 0,632958288 | 0,001 | 0,831366630 | 0,4518386389 | 0,955063117453348 | 0,22344950604 | 0,700535126235 |
| Sensitivity | 0,9112239 | 0,367041712 | 0,999 | 0,1686333699 | 0,5481613611 | 0,044936882546652 | 0,776550494 | 0,299464873765 |
|  | "37073", the colour image |  |  |  |  |  |  |  |
| Handling time, mc | 2456 | 2426 | 2433 | 2409 | 2409 | 5880 | 5832 | 5914 |
| Estimation of corr. pixels | 150878 | 147566 | 112427 | 139864 | 139101 | 139714 | 127242 | 117272 |
| Estimation of incorr. pixels | 1923 | 5235 | 40374 | 12937 | 13700 | 13087 | 25559 | 35529 |
| RMSE | 0,11218287 | 0,185095237 | 0,51402920098 | 0,29097367 | 0,2994312928 | 0,292655676930907 | 0,408986367 | 0,482201319 |
| PSNR | 19,0014691 | 14,6520951 | 5,780244178 | 10,722922 | 10,4740563 | 10,6728609405908 | 7,765823385 | 6,33543212473 |
| Error of first kind | 0,00798142 | 0,004271138 | 0,290221682 | 0,012324463 | 0,056668081 | 3,5952341576E-5 | 0,1636838207 | 0,18590236782 |
| Specificity | 0,99201858 | 0,995728862 | 0,7097783179 | 0,98767553730 | 0,94333192 | 0,999964047658424 | 0,83631618 | 0,814097632179 |
| Error of second kind | 0,05922203 | 0,338068182 | 0,00087412587 | 0,81752622378 | 0,42387820513 | 0,95294289044289 | 0,203598485 | 0,704763986014 |
| Sensitivity | 0,94077797 | 0,661931818 | 0,999125874 | 0,1824737766 | 0,576121795 | 0,0470571095571096 | 0,7964015152 | 0,295236013986 |

(Fig. 1). Improve the quality of image processing in the following ways:

1) the preliminary analysis and the handling of images depending on outcome of the analysis (a filtration, a sharpness raise, noise reduction etc.).

Thus raise quality of handling by methods of Hrjashchev, Laplacian and a mask of a method Canny;
2) introduction of images intellectual processing:
a) carrying out of the preliminary analysis of the image fragments on saturation degree their contours (it is weak, middle and strongly sated);
b) use of the cascade scheme of contours allocation taking into account a class of fragments.

On the first stage - to use a method ensuring not the admission of real contours (minimum (maximum) value of an error of second kind (sensitivity)). At the second stage a method ensuring high localization and lack of ruptures in contours (exact allocation of boundary pixels and their unbiasedness), accordingly ensuring the minimum (maximum) value of an error of first kind (specificity) and minimum value RMSE.

For the first stage - use methods Sharu or the Laplacian (LoG), for the second stage - methods of Laplace 1, Sobel or Hrjashchev.

The method Canny on the average gives the highest value of metrics, however is not suitable for use in systems of images automatic processing.

## V. Conclusion

1. The testing methods for masking the performance quantification of the image processing quality the is justified, there is no universal method of masking, which has the same high values of the metrics for images with different content of their objects (contours). It is proved that the present methods are effective only within a narrow class of images. In most cases, the evaluation of quality masking method is limited only by subjective assessment (visual assessment of the work quality).
2. The experimental evaluation of the concealment methods quality revealed the following:
a) the irrelevance of the color images for concealment methods (values of quality - no more than 8 \% slightly change);
b) the best indicators of the search paths quality in the method of Sobel (on values of indicators N corr., N incorr., RMSE, PSNR);
c) the best indicators of quality in terms of nonpayment of false contours in Khryashchev method with simultaneously worst values of the admission characteristics of real contours and pass of the occurrence shocks;
d) the best indicators of quality from the point of view not the admission of real contours and occurrence of borders ruptures at a method Sharu.
3. Established methodology is applicable in automatic image processing and is based on an intelligent image processing, namely:
a) on analysis of images (or fragments) on saturation degree their contours with the subsequent classification: poorly, middle and strongly sated with contours;
b) use of the cascade scheme of contours detection and allocation in images taking into account saturation degree their contours.

Application of two-cascade technology of masking images allows to reduce processing time and to raise accuracy of masking, thus allows to eliminate lacks of separately used methods with preservation of advantages and advantages of masking technology as a whole.

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# Perforated with Technology of Description Massives Differential Representation in Delivery Compressed Images Systems 

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#### Abstract

The analysis of the minimum time to transmit video information. As a result, we show that for current and future aerospace monitoring systems using on-board telecommunications video delivery time up to several tens of minutes. This leads to the obsolescence of the information obtained, and the belated adoption of wrong decisions. It is proved that for solving this problem, we propose to use video compression technology. We justify the fact that the representation of an array of the perforation upper level elements in the differential polyadic space provides an additional reduction of combinatorial redundancy. It is shown that to avoid the disadvantages associated with a decrease in the lower limit of the differential polyadic space required for perforating technology further consider the binary mask wavelet elements of the upper and lower levels. Outlines the development of differentiated image compression method for increasing the availability of video data, which is based on the following technology solutions: derivation of images fragments on a combined scheme, the organization perforation arrays in a two-dimensional representation of the differential polyadic space, mask-dimensional block coding scheme.


## I. Introduction

TThe effectiveness of the strategic sectors depends on the security of information. Security of information is defined by three categories, namely: availability, integrity and confidentiality. The special value of the first two categories of particularly critical in the case of a decision on the timeliness and accuracy of the information. Special problems arise when the quality and accuracy of the solution depends on national issues. One such area is the prevention and elimination of emergency situations (ES). In this case, decisions must be made in real time and the delay before starting operation, emergency response should not exceed 10 minutes. This imposes strict requirements on availability of information. On the other hand the greatest complexities appear when want to use the sources of video

[^3]information. In such a situation, when the bandwidth of wireless communication channels are limited, unavoidable delays in delivery of information [1]. To solve the problem using existing image compression technology [2, 3]. At the same time, existing compression technologies typical drawbacks. Image compression is achieved by delaying the processing time and making distortion. Which in turn increases the risk of loss of data integrity. Therefore, research topics related to the advancement of technology compact representation of video data is relevant.

As shown in [4,5] direction of solving this problem is the combined use of a preliminary step the various mechanisms image conversion including differential representation. Effective option for further treatment approach is based on perforations of differential representation arrays (DRA) in polyadic space. Then, to further reduce the amount of compressed image by identifying the elements of the DRA, which have a high dynamic range is provided as a result of perforation. The point is that the perforations in the original array differential representation $\mathrm{H}=\left\{\mathrm{h}_{\mathrm{k} \ell}^{\prime}\right\}$ is divided into two components, depending on the value $\mathrm{d}_{\mathrm{k} \ell}$ belonging to one of two levels and the dynamic range of the DR array,
$\mathrm{K}\left(\mathrm{h}^{\prime}\right)_{\text {пор }}$
$\mathrm{H} \xrightarrow{\rightarrow}\left\{\mathrm{H}^{(0)} ; \mathrm{H}^{(1)}\right\}$, wherein $\mathrm{H}=\left\{\mathrm{h}_{\mathrm{k} \ell}^{\prime}\right\}, \mathrm{H}^{(1)}$ - the array of discrete elements comprise converting the upper and lower perforated layers. Then a further decline in the compressed image by identifying the elements of the DRA, which have a high dynamic range is achieved as a result of perforation $\left(\mathrm{K}\left(\mathrm{h}^{\prime}\right)_{\text {пор }}\right)$. Building a perforation of the differential representation of arrays are combined approach. This results to the formation of at least a binary representation of the structure of the differential dynamic range of the array. Consequently polyadic code structure formed without perforation dynamic range possess structural redundancy. Hence, the aim is to improve the image compression technology based on the space transforms a polyadic coding.

## II. THE MAIN PART OF INVESTIGATION

In $[4,5]$ proposed to increase the compression array is divided into two components, depending on one of two levels of the dynamic range, i.e. proposed to carry out the perforation of the differential representation of arrays (DRA). Then, to eliminate the lack of a large dynamic range of individual elements of the DRA is recommended to consider the properties constituting $\mathrm{H}^{(1)}$ the perforation of the upper level, consisting in the fact that:

- an array of top range of perforated presentation contains elements that are equal in value to an element contour images or the value of the basic background;
- the dynamic range of contour values and the values of the basic background images have a uniform structure.

Given these features you can go to the description of the differential representation of top-level perforation component [3, 4]. Where code-array number $\mathrm{H}^{(1)}$ will be determined by how the code array of polyadic numbers corresponding to the minimum level $\mathrm{M}^{(2)}$ of the differential space (fig. 1).


Fig. 1. Schematic of the formation of two-dimensional elements of the differential non-equilibrium position number

The minimum value of the vector formed in rows $M=\left\{\mu_{1}, \ldots, \mu_{m}\right\}$. Where the value $\mu_{i}$ is determined as a minimum value in the i-th row of the array $\mathrm{H}^{(1)}$, i.e. $\mu_{\mathrm{i}}=\min _{1 \leq \mathrm{j} \leq \mathrm{n}}\left\{\mathrm{h}_{\mathrm{ij}}^{(1)}\right\}, \quad \mathrm{i}=\overline{1, \mathrm{~m}}$.

This allows you to move from the original of dynamic range of the array $\mathrm{H}^{(1)}$ to reduced dynamic range described by vector $S$ constraints, i.e. $S=\left\{s_{1 j}, \ldots, s_{n j}\right\}$. Here $s_{i j}-$ the difference between the maximum $\mathrm{d}_{\mathrm{ij}}^{(1)}$ and minimal $\mu_{\mathrm{i}}$ value in i-th row of an array $\mathrm{H}^{(1)}$ the perforating of the upper level, i.e.

$$
\begin{equation*}
\mathrm{s}_{\mathrm{ij}}=\mathrm{d}_{\mathrm{ij}}^{(1)}-\mu_{\mathrm{i}} \tag{1}
\end{equation*}
$$

In view of (1) we obtain the following range the perforating of the upper level

$$
\begin{equation*}
\mu_{\mathrm{i}} \leq \mathrm{h}_{\mathrm{ij}}^{(1)} \leq \mathrm{d}_{\mathrm{ij}}^{(1)}-1, \quad \mathrm{i}=\overline{1, \mathrm{~m}}, \mathrm{j}=\overline{1, \mathrm{n}^{(1)}} \tag{2}
\end{equation*}
$$

where $\mathrm{n}^{(1)}$ - the number of columns in the array $\mathrm{H}^{(1)}$.
The lower level $\mathrm{M}^{(2)}$ the differential two-dimensional space is determined based on the values of the vector $\mathrm{M}=\left\{\mu_{1}, \ldots, \mu_{\mathrm{m}}\right\}$ and is polyadic number, the elements of which satisfy the constraints on dynamic range of the upper level of the perforating.

Given the constraints (1) and (2) the value of the codenumber as the length of the distance R between the current array $\mathrm{H}^{(1)}$ and the lower level $\mathrm{M}^{(2)}$ two-dimensional polyadic of the number is determined by the formula

$$
\begin{equation*}
\mathrm{R}=\sum_{\mathrm{i}=1}^{\mathrm{m}} \sum_{\mathrm{j}=1}^{\mathrm{n}^{(1)}}\left(\mathrm{h}_{\mathrm{ij}}^{(1)}-\mu_{\mathrm{i}}\right) \prod_{\xi=\mathrm{j}+1}^{\mathrm{n}^{(1)}} \mathrm{s}_{\mathrm{i} \xi} \prod_{\gamma=\mathrm{i}+1 \xi=1}^{\mathrm{m}} \prod_{\gamma \xi}^{\mathrm{n}^{(1)}} \mathrm{s}_{\gamma \xi} . \tag{3}
\end{equation*}
$$

Let us show that the consideration of the array $\mathrm{H}^{(1)}$ the two-dimensional differential polyadic the space of allows to reduce the interpretation thereof code-number relative to the original case. For that us justify that between the codenumber R as length distance in the differential polyadic space and source code-number of $\mathrm{N}^{(1)}$ the inequality

$$
\begin{equation*}
\mathrm{R} \leq \mathrm{N}^{(1)} \tag{4}
\end{equation*}
$$

The value of the code-number $\mathrm{N}^{(1)}$ in the source polyadic space is equal to $\mathrm{N}^{(1)}=\sum_{\mathrm{i}=1}^{\mathrm{m}} \sum_{\mathrm{j}=1}^{\mathrm{n}^{(1)}} \mathrm{h}_{\mathrm{ij}}^{(1)} \prod_{\xi=\mathrm{j}+1}^{\mathrm{n}^{(1)}} \mathrm{d}_{\mathrm{i} \xi}^{(1)} \prod_{\gamma=\mathrm{i}+1 \xi=1}^{\mathrm{m}} \prod_{\gamma \xi}^{\mathrm{n}^{(1)}} \mathrm{d}_{\gamma}^{(1)}$. We write the equation (3) taking into account formula (1), and we obtain

$$
\begin{equation*}
\mathrm{R}=\sum_{\mathrm{i}=1}^{\mathrm{m}} \sum_{\mathrm{j}=1}^{\mathrm{n}^{(1)}}\left(\mathrm{h}_{\mathrm{ij}}^{(1)}-\mu_{\mathrm{i}}\right) \prod_{\xi=\mathrm{j}+1}^{\mathrm{n}^{(1)}}\left(\mathrm{d}_{\mathrm{i} \xi}^{(1)}-\mu_{\mathrm{i}}\right) \prod_{\gamma=\mathrm{i}+1}^{\mathrm{m}} \prod_{\xi=1}^{\mathrm{n}^{(1)}}\left(\mathrm{d}_{\gamma \xi}^{(1)}-\mu_{\gamma}\right), \tag{5}
\end{equation*}
$$

In view then obtain the inequality (4).
We now prove that the code of number in the differential polyadic the space of will be less than the difference between the code-number polyadic of the number and the code-number of the lower level in the source perforated space, i.e.

$$
\begin{equation*}
\mathrm{R} \leq \mathrm{N}^{(1)}-\mathrm{N}_{\min }^{(1)} \tag{6}
\end{equation*}
$$

where $\mathrm{N}_{\text {min }}^{(1)}$ - value of the code-number PPN $\mathrm{M}^{(2)}$, which is the the lower level of the two-dimensional the differential polyadic space.

Really. We write the left side of (6) and we obtain

$$
\begin{gather*}
\mathbf{N}^{(1)}-\mathbf{N}_{m i n}^{(1)}=\sum_{i=1}^{m} \sum_{j=1}^{n^{(1)}} h_{i j}^{(1)} \prod_{\xi=j^{n}+1}^{n^{(1)}} d_{i \xi}^{(1)} \prod_{\gamma=\mathrm{i}+1 \xi=1}^{m} \prod_{\gamma \xi}^{\mathrm{n}^{(1)}} d_{\gamma}^{(1)}- \\
-\sum_{i=1}^{m} \sum_{j=1}^{n^{(1)}} \mu_{i} \prod_{\xi=j+1}^{n^{(1)}} d_{i \xi}^{(1)} \prod_{\gamma=i+1}^{m} \prod_{\xi=1}^{m} d_{\gamma \xi}^{(1)}=\sum_{i=1}^{m} \sum_{j=1}^{n^{(1)}}\left(h_{i j}^{(1)}-\mu_{i}\right) \prod_{\xi=j+1}^{n^{(1)}} d_{i \xi}^{(1)} \prod_{\gamma=i+1}^{m} \prod_{\xi=1}^{n^{(1)}} d_{\gamma \xi}^{(1)} . \tag{7}
\end{gather*}
$$

Whence comparing the right-hand side of (5) and (7) obtain the inequality (6).

Fulfillment of inequality (6) leads to a conclusion as to what to of elements of the array representation of the upper level of the perforating in the differential polyadic the space of provides an additional reduction of combinatorial redundancy.

The total number of $\mathrm{R}^{(2)}$ positional number admissible in the differential nonequilibrium the space of defined by the formula

$$
\begin{equation*}
\mathrm{R}^{(2)}=\prod_{\mathrm{i}=1}^{\mathrm{m}} \prod_{\mathrm{j}=1}^{\mathrm{n}^{(1)}}\left(\mathrm{d}_{\mathrm{ij}}^{(1)}-\mu_{\mathrm{i}}\right) \tag{8}
\end{equation*}
$$

Equation (8) determines the number of combinatorial redundancy, which could potentially be reduced by the perforating of the upper representation level array differential polyadic space.

For the separation of two constituting the DRA is used threshold perforation. In [4, 5] to estimate the threshold of perforation are encouraged to use

$$
\begin{equation*}
\mathrm{K}\left(\mathrm{~h}^{\prime}\right)_{\text {пор }}=\left(\sum_{\mathrm{k}=1 \ell=1}^{\mathrm{m}} \sum_{\mathrm{k} \ell}^{\mathrm{n}} \mathrm{~d}_{\mathrm{k} \ell}\right) / \mathrm{mn}, \tag{9}
\end{equation*}
$$

where $d^{(u)}$ - importance of the foundation of number polyadic to $u$-th a level of dynamic range; $v_{u}$ - number of bases polyadic of number, owned $u$-th level of dynamic range; U - the number of levels of dynamic range.

At the same time a perforation array option of a differential representation leads to the existence of the following drawbacks. Cases are possible when the dynamic range of the element $\mathrm{h}_{\mathrm{k} \ell}^{\prime}$ an array of the differential representation will be above the threshold perforation $\mathrm{K}\left(\mathrm{h}^{\prime}\right)_{\text {пор }}$, i.e. $\mathrm{d}_{\mathrm{k} \ell}>\mathrm{K}\left(\mathrm{h}^{\prime}\right)_{\text {пор }}$. But, on the other side the value itself will be the element below the threshold value, i.e. $\mathrm{h}_{\mathrm{k} \ell}^{\prime}<\mathrm{K}\left(\mathrm{h}^{\prime}\right)_{\text {пор }}$. This situation is possible when maximum values at the intersection of string $\mathrm{d}_{\mathrm{k}}$ and columns $\mathrm{d}_{\ell}$ have significantly higher values relative to the value $\quad \mathrm{h}_{\mathrm{k} \ell}^{\prime}, \quad$ i.e. $\quad \mathrm{h}_{\mathrm{k} \ell}^{\prime} \lll \max _{1 \leq \xi \leq \mathrm{n}}\left\{\mathrm{h}_{\mathrm{k} \xi}^{\prime}\right\}=\mathrm{d}_{\mathrm{k}}-1 \quad$ or $\mathrm{h}_{\mathrm{k} \ell}^{\prime} \lll \max _{1 \leq \mathrm{u} \leq \mathrm{m}}\left\{\mathrm{h}_{\mathrm{u} \ell}^{\prime}\right\}=\mathrm{d}_{\ell}-1$. Such a situation leads to the fact that a minimal boundary in the upper perforation array level will decline down to zero level. This leads the fact that the potential number of combinatorial reduced redundancy.

For exclusion disadvantages of the proposed conduct perforating an array of the differential representation with an additional view of the binary mask $\mathrm{P}^{(2)}$, singles out the items for which both of the following conditions): $\mathrm{d}_{\mathrm{k} \ell}>\mathrm{K}\left(\mathrm{h}^{\prime}\right)_{\text {пор }}$ and $\mathrm{h}_{\mathrm{k} \ell}^{\prime}<\mathrm{K}\left(\mathrm{h}^{\prime}\right)_{\text {пор }}$. Then the if for array element the differential representation the condition (9), at the corresponding position in the mask will be standing unit of. Conversely, if even one of the inequalities (8) is not satisfied, then the corresponding position in the mask will stand zero.

Consequently, the content of mask $\mathrm{P}^{(2)}$ is given as follows:

$$
\mathrm{p}_{\mathrm{k} \mathrm{\ell} \ell}=\left\{\begin{array}{l}
0, \rightarrow \mathrm{~d}_{\mathrm{k} \ell} \leq \mathrm{K}\left(\mathrm{~h}^{\prime}\right)_{\text {nop }} \vee \mathrm{h}_{\mathrm{kl}}^{\prime} \geq \mathrm{K}\left(\mathrm{~h}^{\prime}\right)_{\text {nop }} ; \\
1, \rightarrow \mathrm{~d}_{\mathrm{k} \ell}>\mathrm{K}\left(\mathrm{~h}^{\prime}\right)_{\text {nop }} \& \mathrm{~h}_{\mathrm{k} \mathrm{\ell} \ell}^{\prime}<\mathrm{K}\left(\mathrm{~h}^{\prime}\right)_{\text {nop }},
\end{array}\right.
$$

where $\mathrm{p}_{\mathrm{k} \ell}$ - mask element $\mathrm{P}^{(2)}$ at position $(\mathrm{k} ; \ell)$.
Availability such a mask enables array elements detect the upper perforating the level which results in decrease the degree of compression. Is suggested to elements of the array the differential representation, for which is equal to unity element of the mask, leave in an array of the lower level perforation with base $K\left(h^{\prime}\right)_{\text {пор }}$. Then the dynamic range $\mathrm{d}_{\mathrm{k} \ell}^{(0)}$ the lower level array elements of perforating following system:

$$
\mathrm{d}_{\mathrm{k} \ell}^{(0)}= \begin{cases}\mathrm{d}_{\mathrm{k} \ell}, & \rightarrow \mathrm{p}_{\mathrm{k} \ell}=0 \\ \mathrm{~K}\left(\mathrm{~h}^{\prime}\right)_{\text {пор }}, & \rightarrow \mathrm{p}_{\mathrm{k} \ell}=1\end{cases}
$$

Such transformations will: on the one hand increase the low the differential polyadic perforating the upper space of the array level, on the other side lower dynamic range of the masked the array elements of the lower level perforating. After all, the original value of dynamic range $\mathrm{d}_{\mathrm{k} \ell}$ an array of the upper-level perforating of perforation condition exceeds the value a threshold, i.e. $\mathrm{d}_{\mathrm{k} \ell}>\mathrm{K}\left(\mathrm{h}^{\prime}\right)_{\text {пор }}$. Amount $\mathrm{V}^{(0)}$ polyadic numbers for an of the lower level perforating array with the masked by elements is defined as

$$
\mathrm{V}^{(0)}=\left(\mathrm{K}\left(\mathrm{~h}^{\prime}\right)_{\text {пор }}\right)^{v} \prod_{\mathrm{i}=1}^{\mathrm{m}^{\prime}} \prod_{\mathrm{j}=1}^{\mathrm{n}^{\prime}} \mathrm{d}_{\mathrm{ij}}^{(0)}
$$

Here $v$ - number of masked by elements, $\mathrm{m}^{\prime}$, $\mathrm{n}^{\prime}$ perforating of the lower level array except for masked by elements.

From the analysis of the expression can be concluded that the number of valid polyadic numbers taking into account features dynamic range of camouflage of elements will be lower than without such accounting. Ultimately this will lead to an increase in the degree of compression the differential representation array.

## III. CONCLUSIONS

1. It is proved that the representation of the array elements of the top level perforating in the differential polyadic the space of provides an additional reduction of combinatorial redundancy caused by:

- reduction in of dynamic range perforating of the upper-level elements by identifying the minimum values;
- reduction of the number of polyadic numbers preceding the current number, but do not satisfy the condition the differential space.

2. To reduce the dynamic range of the differential representation arrays we demonstrate the use their perforating into two components, depending on the dynamic range of accessories one of the levels elements.
3. For exclusion limitations associated with lowering the lower bound the differential polyadic of the space substantiates and being developed an array of perforating technology with an additional the differential representation based binary mask. Such transformations will: on the one hand increase the low the differential polyadic perforating
the upper space of the array level, on the other side lower dynamic range of masked by the array elements of the lower level perforating.
4. It is proved that as a result of a one-dimensional polyadic coding block diagram shrinking a combinatorial redundancy caused on the one hand correlated areas of the images, on the other hand - the presence of a small objects limited number.

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# Method for Structure Coding Aperture Image Elements in Infocommunication Systems 

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#### Abstract

As a result of the conducted analysis of minimum time it is rotined on passing to videoinformation's, that for the existent and perspective systems of the aerospace monitoring with the use of side facilities of telecommunication it arrives at a few ten of minutes. It results in the obsolescence of the got information, acceptance of the belated and erroneous decisions. It is grounded, that for the decision of this problem it is suggested to utilize technologies of compression of videoinformation. It is rotined that existent technologies of compression on the basis of preliminary exposure of apertures, based on separate treatment of their constituents, that leads the decline of degree of compression of images. Forming of compact presentation of fragment of image is developed. Information technology of compression of images is created on the basis of the generalized encoding coordination-structural and line-by-line scaling constituents. The construction of twocomponent encoding is developed on the basis of the first code constituent, formed on the basis of elements of line of array of approximating sizes, presented as an adaptive position number with unequal elements. Grounded, that is arrived at additional increase of degree of compression of images due to the exception of statistical surplus, decline of psycho visual surplus and reduction of structural surplus.


## I. Introduction

TThe development of modern society is towards increasing automation and informatization in different fields. In this case is an increased knowledge intensity and criticality of integrable technologies. Therefore, in the framework of integrated security, the future development of information necessary to ensure the following: monitoring of strategic objects, monitoring the actions of the international values of, monitoring of emergency situations (ES) of natural and man-made disasters. It is necessary to improve existing and implement but new forms and methods of management of crisis situations. In particular this applies to improving the effectiveness of information security with the use of remote means of aerospace basing. The analysis showed that existing the possibility of onboard equipment data transmission, do not provide timely delivery of digitized images. There is a contradiction between the

[^4]desired characteristics of the processes of delivery of data, namely the time of processing, transmitting, the quality of the reconstructed image, and the actual characteristics of the existing systems of unmanned aircraft systems. In connection with this, it can be argued that there is a real scientific application task consists in reducing the time to bring the video aerospace monitoring system based on airborne systems. Improving the efficiency of bringing the information possible on the basis of the decrease of volumes processed and transferred video data. This approach is implemented on the basis of using compression technology. It is required to take into account the conditions of aerospace monitoring composed that: the predominant images are saturated realistic images, put forward higher requirements on the preservation of the information content of images, there are restrictions on the complexity of coding algorithms for onboard means of telecommunication. From this position it is effective technology that takes into account the preliminary identification of the components of aperture imaging. However, the existing data encryption technology does not allow you to fully eliminate the redundancy that is inherent components of the aperture image descriptions. In particular this applies to the low efficiency of known codes on the reduction of structural redundancy in the aperture components. Hence, the purpose of research paper is to develop a method for image compression based on coding, which allows eliminating the structural redundancy.

## II. DEVELOPMENT OF A TWO-COMPONENT METHOD OF COMPRESSION

It is appropriate to consider the main stages of constructing the two-component code.

Stage 1 is the formation of the coordinate-structural and line-by-line scaling components of a picture fragment. First of all it is necessary to select the required apertures and construct the corresponding arrays of approximating values $\Delta \mathrm{H}_{\mathrm{m}, \mathrm{n}}^{(\mathrm{v})}$ and aperture lengths $\Delta \mathrm{L}_{\mathrm{m}, \mathrm{n}}^{(\mathrm{v})}$. The procedure of revealing apertures is performed along the frame lines in the direction of the line scanning meeting the condition $\mathrm{X}_{\xi, \gamma+\mathrm{r}} \in\left[\mathrm{b}(\min )_{\xi} ; \mathrm{b}(\max )_{\xi}\right], \mathrm{r}=0, \ell_{\xi}-1$, where $\ell_{\xi}$ is the length of the current aperture, $b(\min )_{\xi}$ and $\mathrm{b}(\min )_{\xi}, \mathrm{b}(\max )_{\xi}$ - are the values of the lower and upper boundaries, respectively, of the $(\xi)$-th aperture, the boundaries being dependent on the aperture height b . On
the contrary, when $\mathrm{x}_{\xi, \ell \xi} \notin\left[\mathrm{b}(\min )_{\xi} ; \mathrm{b}(\max )_{\xi}\right]$, the next aperture is being constructed. The procedure of revealing apertures is finished when the final element $\mathrm{x}_{\mathrm{Z}_{\text {lin }}}, \mathrm{Z}_{\text {col }}$ of the frame of the pixel has been processed. The arrays $\Delta \mathrm{H}_{\mathrm{m}, \mathrm{n}}^{(v)}$ and $\Delta \mathrm{L}_{\mathrm{m}, \mathrm{n}}^{(v)}$ are formed in the direction of the lines, which permits revealing additional structural regularities and opens new potentialities for overcoming redundancy.

The integral reconstruction of a fragment of the pixel through a use of the structural and scaling components is achieved when the arrays $\Delta \mathrm{H}_{\mathrm{m}, \mathrm{n}}^{(v)}$ and $\Delta \mathrm{L}_{\mathrm{m}, \mathrm{n}}^{(v)}$ are equal in size and are formed in one-to-one correspondence. In this case we can avoid the use of auxiliary evidence and time delay in the process of positioning apertures and pixel fragments.

At Stage 2 we determine the bases of the pixel arrays $\Delta \mathrm{H}_{\mathrm{m}, \mathrm{n}}^{(v)}$ and $\Delta \mathrm{L}_{\mathrm{m}, \mathrm{n}}^{(\mathrm{v})}$, that are considered as an adaptive position number with nonequal neighboring pixels (APN) and a two-dimensional position number in the differential space (PNDS), respectively. The procedure is as follows:

1) a system of bases $w(h), W(h)=\left\{w^{\prime}(h) i\right\}, i=1, m$ of APN pixels is formed

$$
\begin{gathered}
w^{\prime}(h)_{i}=h_{i, \max }-h_{i, \min }+1-\operatorname{sign}(j-1), \\
h_{i, \max }=\max _{1 \leq j \leq n}\left\{h_{i, j}\right\}+1 ; h_{i, \min }=\min _{1 \leq j \leq n}\left\{h_{i, j}\right\} ;
\end{gathered}
$$

2) a system of bases $\mathrm{W}(\mathrm{l})=\left\{\mathrm{w}(\mathrm{l})_{\mathrm{i}}\right\}, \mathrm{i}=1, \mathrm{~m}$ of PNDS pixels is formed

$$
\begin{gathered}
\mathrm{w}^{\prime}(\mathrm{h})_{\mathrm{i}}=\mathrm{h}_{\mathrm{i}, \max }-\mathrm{h}_{\mathrm{i}, \min }+1-\operatorname{sign}(\mathrm{j}-1), \\
\ell_{\mathrm{i}, \max }=\max _{1 \leq \mathrm{j} \leq \mathrm{n}}\left\{\ell_{\mathrm{i}, \mathrm{j}}\right\}+1 ; \ell_{\mathrm{i}, \min }=\min _{1 \leq \mathrm{j} \leq \mathrm{n}}\left\{\ell_{\mathrm{i}, \mathrm{j}}\right\} .
\end{gathered}
$$

At Stage 3 the number of the pixels $v(h, i)_{\xi}$ and $v(\ell 1)_{\xi}$ of the two-component constituents are estimated for constructing the generalized two-component code. The length of the code word $\mathrm{D}_{\text {nec }}$ for constructing the current generalized two-component code is considered to be preassigned. According to the condition of the formation of the two-component code, the choice of the first component in terms of code construction is performed for the pixels of one line of the array $\Delta H_{m, n}^{(v)}$. As a result, we obtain $v(\mathrm{~h}, \mathrm{i})_{\xi}=\left[\mathrm{D}_{\text {nec }} / \log _{2}\left(\mathrm{w}(\mathrm{h})_{\mathrm{i}}-1\right)\right]$.

The second component is formed on the basis of the coding description of the pixels in the array $\Delta \mathrm{L}^{(\mathrm{v})}{ }_{\mathrm{m}, \mathrm{n}}$ which are located in different lines (general case).

For a compact representation of the arrays of aperture lengths $L^{(v)}{ }_{m, n}$ it is reasonable to perform encoding in the differential position space with different bases [5]. To do this, we form first the bases $\mathrm{w}(\ell)_{\mathrm{ij}}$. Note that in this case $0 \leq \ell_{\mathrm{ij}}^{\prime} \leq \mathrm{w}(\ell)_{\mathrm{ij}}<\ell_{\text {max }}$; Where $\mathrm{w}(\ell)_{\mathrm{ij}}$ is the difference between the minimum $\ell_{\mathrm{i}, \min }$ and the maximum $\ell_{\text {max }}$ in the i th line of the aperture length array.

In terms of the obtained bases $\mathrm{w}(\ell)_{\mathrm{ij}}$, the differential encoding of the aperture length array along the lines is determined by the equation

$$
\mathrm{E}(\ell)_{\mathrm{i}, \mathrm{n}}^{(\mathrm{i}, 1)}=\sum_{\mathrm{j}=1}^{\mathrm{n}}\left(\ell_{\mathrm{i}, \mathrm{j}}-\ell_{\mathrm{i}, \min }\right) \mathrm{V}(\ell)_{\mathrm{m}, \mathrm{n}}^{(\mathrm{i}, \mathrm{j})}
$$

where $V(\ell)^{(\mathrm{i}, \mathrm{j})}{ }_{\mathrm{m}, \mathrm{n}}$ is the weighting factor of the ( i ; j$)$-th PNDS pixel.

Since $\mathrm{w}(\ell)_{\mathrm{ij}}=\ell_{\mathrm{i}, \max }-\ell_{\mathrm{i}, \min }+1=\mathrm{w}(\ell)_{\mathrm{i}}$; the obtained expression becomes:

$$
\mathrm{E}(\ell)_{\mathrm{i}, \mathrm{n}}^{(\mathrm{i}, 1)}=\sum_{\mathrm{j}=1}^{\mathrm{n}}\left(\ell_{\mathrm{i}, \mathrm{j}}-\ell_{\mathrm{i}, \min }\right) \mathrm{w}(\ell)_{\mathrm{i}}^{\mathrm{n}-\mathrm{j}}
$$

The quantity of Eq. $\mathrm{E}(\ell)_{\mathrm{i}, \mathrm{n}}^{(\mathrm{i}, 1)}$ can be introduced into $\sum_{j=1}^{n}\left(\ell_{i, j}-\ell_{\mathrm{i}, \min }\right) \mathrm{w}(\ell)_{\mathrm{i}}^{\mathrm{n}-\mathrm{j}}$; as a code for the i -th onedimensional position number (line) in the differential space with different bases.

Thus, a compact representation of the non uniform coordinate structural component of the picture fragment was constructed on the basis of position coding in the differential space with different bases. The limited and non uniform character of the dynamic ranges of the pixels in aperture length arrays was taken into account and one-toone correspondence of such representation was ensured. This has a significant effect on the controllable character of the approximating distortions and on the quality of the reconstructed picture.

Step 4 is the construction of the two-component code. The first code component $\mathrm{E}(\mathrm{h})_{\mathrm{i}, \gamma+v(\mathrm{~h}, \mathrm{i})_{\xi}-1}^{(\mathrm{i}, \gamma)}$ formed on the basis of the pixels $\mathrm{v}(\mathrm{h}, \mathrm{i})_{\xi}$ in the line of the array of the approximating values is

$$
\begin{gathered}
E(h)_{\mathrm{i}, \gamma+v(\mathrm{~h}, \mathrm{i})_{\xi}-1}^{(\mathrm{i}, \gamma)}=\sum_{\mathrm{j}=\gamma}^{\gamma+v(\mathrm{~h}, \mathrm{i})_{\xi}-1}\left(\mathrm{~h}_{\mathrm{i}, \mathrm{j}}-\operatorname{sign}(1-\right. \\
\left.\left.-\operatorname{sign}\left(\mathrm{h}_{\mathrm{i}, \mathrm{j}-1}-\mathrm{h}_{\mathrm{i}, \mathrm{j}}\right)\right)\right)\left(\mathrm{W}(\mathrm{~h})_{\mathrm{i}}-1\right)^{v(\mathrm{~h}, \mathrm{i})_{\xi}+\gamma-1-\mathrm{j}}
\end{gathered}
$$

The recurrent expression for the formation of $\mathrm{E}(\mathrm{h})_{\mathrm{i}, \gamma+v(\mathrm{~h}, \mathrm{i})_{\xi}}^{(\mathrm{i},)^{2}}$ becomes $\mathrm{E}(\mathrm{h})_{\mathrm{i}, \gamma}^{(\mathrm{i}, \gamma)}=\mathrm{h}_{\mathrm{i}, \gamma}$;

$$
\begin{gathered}
E(h)_{i, \gamma+\mathrm{j}}^{(\mathrm{i}, \gamma)}=\mathrm{E}(\mathrm{~h})_{\mathrm{i}, \gamma+\mathrm{j}-1}^{(\mathrm{i}, \gamma)}\left(\mathrm{w}(\mathrm{~h})_{\mathrm{i}}-1\right)+\mathrm{h}_{\mathrm{i}, \gamma+\mathrm{j}}, \\
\mathrm{j}=\overline{1, v(\mathrm{~h}, \mathrm{i})_{\xi}-1},
\end{gathered}
$$

where $(\mathrm{i} ; \gamma),(\mathrm{i} ; \gamma+\mathrm{v}(\mathrm{h}, \mathrm{i}) \xi-1)$ are the coordinates of the starting and the final pixels, respectively, of the first component of the two-component code based on the i-th line of the approximating aperture array; $\mathrm{E}(\mathrm{h})^{(\mathrm{i}, \gamma)}{ }_{\mathrm{i}, \gamma+\mathrm{j}}$, $\mathrm{E}(\mathrm{h})^{(\mathrm{i}, \gamma)}{ }_{\mathrm{i}, \gamma+\mathrm{j}-1}$ stand for the code of the first component at the $(\gamma+\mathrm{j})$-th and the $(\gamma+\mathrm{j}-1)$-th steps of processing, respectively.

The code structure for the formation of the twocomponent code on the basis of the first component is determined by the expression:

$$
\begin{gathered}
\mathrm{E}(\mathrm{~h} ; \ell)_{\xi}=\mathrm{E}(\mathrm{~h})_{\mathrm{i}, \gamma+v(\mathrm{~h}, \mathrm{i})_{\xi}-1}^{(\mathrm{i}, \gamma)} \prod_{\phi=\alpha}^{\alpha+\beta} \mathrm{w}(\ell)_{\phi}^{v(\ell, \phi)_{\xi}}+ \\
+\Delta \mathrm{E}(\ell)_{\alpha+\beta, \tau}^{(\alpha, \gamma)},
\end{gathered}
$$

where $\mathrm{V}(\ell)_{\alpha+\beta, \tau}^{(\alpha, \gamma)}=\prod_{\phi=\alpha}^{\alpha+\beta} \mathrm{w}(\ell)_{\phi}^{\mathrm{v}(\ell, \phi)_{\xi}}$ is the weight factor of the first component $\mathrm{E}(\mathrm{h})^{(\mathrm{i}, \gamma)}{ }_{\mathrm{i}, \gamma+\mathrm{v}(\mathrm{h}, \mathrm{i})} \mathrm{\xi}_{\mathrm{g}}-1$ of the twocomponent code.

Here $\mathrm{V}(\ell)^{(\alpha, \gamma)}{ }_{\alpha+\beta, \tau}$ is taken as an accumulated product of the pixel bases in the aperture length array starting with the pixel base at the position $(\alpha ; \gamma)$ and ending with the pixel base at the position $(\alpha+\beta ; \tau)$.

In this case the following inequalities are obeyed

$$
\begin{gathered}
\Delta \mathrm{E}(\ell)_{\alpha+\beta, \tau}^{(\alpha, \gamma)}<\mathrm{V}(\ell)_{\alpha+\beta, \tau}^{(\alpha, \gamma)} \\
{\left[\log _{2}\left(\left(\mathrm{~W}(\mathrm{~h})_{\mathrm{i}}-1\right)^{v(\mathrm{~h}, \mathrm{i})_{\xi}} \prod_{\phi=\alpha}^{\alpha+\beta} \mathrm{w}(\ell)_{\phi}^{v(\ell, \phi)_{\xi}}\right)\right]+1 \leq \mathrm{D}_{\mathrm{nec}} .}
\end{gathered}
$$

If the final pixel of the array is processed, the current value of the code is the starting value of the two-component code and we pass over to process the pixels in the array of aperture lengths.

At Step 5 we calculate the second component $\Delta \mathrm{E}(\ell)^{(\alpha, \gamma)}{ }_{\alpha+\beta}$, of the code considering the of aperture length array as a position number in the differential space:

$$
\begin{aligned}
& \Delta \mathrm{E}(\ell)_{\alpha+\beta, \tau}^{(\alpha, \gamma)}=\sum_{\mathrm{j}=\gamma}^{\mathrm{n}}\left(\ell_{\alpha, \mathrm{j}}-\ell_{\alpha, \min }\right) \mathrm{w}(\ell)_{\alpha}^{\mathrm{n}-\mathrm{j}} \prod_{\chi=\alpha+1}^{\alpha+\beta-1} \mathrm{w}(\ell)_{\chi}^{\mathrm{n}} \times \\
& \quad \times \mathrm{w}(\ell)_{\alpha+\beta}^{\tau}+\sum_{\mathrm{i}=\alpha+1}^{\alpha+\beta-1} \sum_{\mathrm{j}=1}^{\mathrm{n}}\left(\ell_{\mathrm{i}, \mathrm{j}}-\ell_{\mathrm{i}, \min }\right) \mathrm{w}(\ell)_{\mathrm{i}}^{\mathrm{n}-\mathrm{j}} \times \\
& \prod_{\chi=\mathrm{i}+1}^{\alpha+\beta-1} \mathrm{w}(\ell)_{\chi}^{\mathrm{n}} \mathrm{w}(\ell)_{\alpha+\beta}^{\tau}+\sum_{\mathrm{j}=1}^{\tau}\left(\ell_{\alpha+\beta, \mathrm{j}}-\ell_{\alpha+\beta, \min }\right) \mathrm{w}(\ell)_{\alpha+\beta}^{\tau-\mathrm{j}}
\end{aligned}
$$

In the case of its recurrent computation the additional code $\Delta \mathrm{E}(\ell)^{(\alpha, \gamma)}{ }_{\alpha+\beta, \tau}$ is subdivided into three components:
$-\Delta \mathrm{E}(\ell)_{\alpha, \mathrm{n}}^{(\alpha, \gamma)}$ is a fraction code for the allowable pixels in the $\alpha$-th line of the array of aperture lengths

$$
\Delta \mathrm{E}(\ell)_{\alpha, \mathrm{n}}^{(\alpha, \gamma)}=\sum_{\mathrm{j}=\gamma}^{\mathrm{n}}\left(\ell_{\alpha, \mathrm{j}}-\ell_{\alpha, \min }\right) \mathrm{w}(\ell)_{\alpha}^{\mathrm{n}-\mathrm{j}}
$$

$-\Delta \mathrm{E}(\ell)_{\alpha+\beta-1, \mathrm{n}}^{(\alpha+1,1)}$ is the fraction code for the pixels of the complete lines starting with the $(\alpha+1)$-th line and ending with the $(\alpha+\beta-1)$-th line $\Delta \mathrm{E}(\ell)_{\alpha+\beta-1, \mathrm{n}}^{(\alpha+1,1)}=$

$$
=\sum_{\mathrm{i}=\alpha+1}^{\alpha+\beta-1} \sum_{\mathrm{j}=1}^{\mathrm{n}}\left(\ell_{\mathrm{i}, \mathrm{j}}-\ell_{\mathrm{i}, \min }\right) \mathrm{w}(\ell)_{\mathrm{i}}^{\mathrm{n}-\mathrm{j}} \times \prod_{\chi=\mathrm{i}+1}^{\alpha+\beta-1} \mathrm{w}(\ell)_{\chi}^{\mathrm{v}(\ell, \chi)_{\xi}} ;
$$

$\Delta \mathrm{E}(\ell)_{\alpha+\beta, \tau}^{(\alpha+\beta, 1)}$ is the fraction code based on the pixels allowable by the $(\alpha+\beta)$-th line

$$
\Delta \mathrm{E}(\ell)_{\alpha+\beta, \tau}^{(\alpha+\beta, 1)}=\sum_{\mathrm{j}=1}^{\tau}\left(\ell_{\alpha+\beta, \mathrm{j}}-\ell_{\alpha+\beta, \min }\right) \mathrm{w}(\ell)_{\alpha+\beta}^{\tau-\mathrm{j}}
$$

Then, the additional code of the second component is calculated using the known numbers of the pixels in the lines $\left\{\mathrm{v}(\ell, \alpha)_{\xi}, \ldots, \mathrm{v}(\ell, \alpha+\beta)_{\xi}\right\}$ of the aperture length array. The computation is performed on the basis of the following recurrent procedure:

1) computation of the code $\Delta \mathrm{E}(\ell)^{(\alpha, \gamma)}{ }_{\alpha, n}$;
2) formation of the accumulated code $\Delta \mathrm{E}(\ell)^{(\alpha, \gamma)}{ }_{\alpha+\beta-1, \mathrm{n}}$ using the equation $\Delta \mathrm{E}(\ell)_{\alpha+\beta-1, \mathrm{n}}^{(\alpha, \gamma)}=$

$$
\Delta \mathrm{E}(\ell)_{\alpha, \mathrm{n}}^{(\alpha, \gamma)} \prod_{\chi=\alpha+1}^{\alpha+\beta-1} \mathrm{w}(\ell)_{\chi}^{v(\ell, \chi)_{\xi}}+\Delta \mathrm{E}(\ell)_{\alpha+\beta-1, \mathrm{n}}^{(\alpha+1,1)}
$$

1) estimation of the sought-for quantity of the code of the second component

$$
\Delta \mathrm{E}(\ell)_{\alpha+\beta, \tau}^{(\alpha, \gamma)}=\Delta \mathrm{E}(\ell)_{\alpha+\beta-1, \mathrm{n}}^{(\alpha, \gamma)} \mathrm{W}(\ell)_{\alpha+\beta}^{v(\ell, \alpha+\beta)_{\xi}}+\Delta \mathrm{E}(\ell)_{\alpha+\beta, \tau}^{(\alpha+\beta, 1)}
$$

To simplify the obtained expressions, we introduce the following notations:

$$
\begin{gathered}
\mathrm{V}(\ell)_{\alpha+\beta, \tau}^{(\alpha, \gamma)}=\prod_{\phi=\alpha}^{\alpha+\beta} \mathrm{W}(\ell)_{\phi}^{v(\ell, \phi)_{\xi}} ; \mathrm{V}(\ell)_{\alpha+\beta-1, \mathrm{n}}^{(\alpha+1,1)}=\prod_{\chi=\alpha+1}^{\alpha+\beta-1} \mathrm{w}(\ell)_{\chi}^{v(\ell, \chi)_{\xi}} ; \\
\mathrm{V}(\ell)_{\alpha+\beta, \tau}^{(\alpha+\beta, 1)}=\mathrm{W}(\ell)_{\alpha+\beta}^{v(\ell, \alpha+\beta)_{\xi}}
\end{gathered}
$$

If we know the quantity $v(h, i)_{\xi}$ of the elements of the approximating value array and the quantity $v(\ell)_{\xi}$ of the elements of the aperture length array, the two-component coding $\mathrm{E}(\mathrm{h} ; \ell)_{\xi}$ can be found as

$$
\begin{aligned}
& \mathrm{E}(\mathrm{~h} ; \ell)_{\xi}=\sum_{\mathrm{j}=\gamma}^{\gamma+v(\mathrm{~h}, \mathrm{i})_{\xi}-1} \mathrm{~h}_{\mathrm{i}, \mathrm{j}}\left(\mathrm{~W}(\mathrm{~h})_{\mathrm{i}}-1\right)^{v(\mathrm{~h}, \mathrm{i})_{\xi}+\gamma-1-\mathrm{j}} \times \\
& \left.\times \mathrm{V}(\ell)_{\alpha+\beta, \tau}^{(\alpha, \gamma)}-\sum_{\mathrm{j}=\gamma}^{\gamma+v(\mathrm{~h}, \mathrm{i})_{\xi}-1} \operatorname{sign}\left(1-\operatorname{sign}\left(\mathrm{h}_{\mathrm{i}, \mathrm{j}-1}-\mathrm{h}_{\mathrm{i}, \mathrm{j}}\right)\right)\right) \times \\
& \times\left(\mathrm{w}(\mathrm{~h})_{\mathrm{i}}-1\right)^{v(\mathrm{~h}, \mathrm{i})_{\xi}+\gamma-1-\mathrm{j}} \mathrm{~V}(\ell)_{\alpha+\beta, \tau}^{(\alpha, \gamma)}+ \\
& +\sum_{\mathrm{j}=\gamma}^{\mathrm{n}}\left(\ell_{\alpha, \mathrm{j}}-\ell_{\alpha, \min }\right) \mathrm{w}(\ell)_{\alpha}^{\mathrm{n}-\mathrm{j}} \mathrm{~V}(\ell)_{\alpha+\beta-1, \mathrm{n}}^{(\alpha+1,1)} \mathrm{V}(\ell)_{\alpha+\beta, \tau}^{(\alpha+\beta, 1)}+ \\
& +\sum_{\mathrm{i}=\alpha+1}^{\alpha+\beta-1} \sum_{\mathrm{j}=1}^{\mathrm{n}}\left(\ell_{\mathrm{i}, \mathrm{j}}-\ell_{\mathrm{i}, \min }\right) \mathrm{w}(\ell)_{\mathrm{i}}^{\mathrm{n}-\mathrm{j}} \mathrm{~V}(\ell)_{\alpha+\beta-1, \mathrm{n}}^{(\mathrm{i}+1,1)} \mathrm{V}(\ell)_{\alpha+\beta, \tau}^{(\alpha+\beta, 1)}+ \\
& +\sum_{\mathrm{i}=\alpha+1}^{\alpha+\beta-1} \sum_{\mathrm{j}=1}^{\mathrm{n}}\left(\ell_{\mathrm{i}, \mathrm{j}}-\ell_{\mathrm{i}, \min }\right) \mathrm{w}(\ell)_{\mathrm{i}}^{\mathrm{n}-\mathrm{j}} \mathrm{~V}(\ell)_{\alpha+\beta-1, \mathrm{n}}^{(\mathrm{i}+1,1)} \mathrm{V}(\ell)_{\alpha+\beta, \tau}^{(\alpha+\beta, 1)}+ \\
& \\
& +\sum_{\mathrm{j}=1}^{\tau}\left(\ell_{\alpha+\beta, \mathrm{j}}-\ell_{\alpha+\beta, \min }\right) \mathrm{w}(\ell)_{\alpha+\beta}^{\tau-\mathrm{j}} .
\end{aligned}
$$

Here $(i ; \gamma),(\alpha ; \gamma)$ are the starting coordinates for the formation of the TCC in the arrays of approximating aperture values and aperture lengths, respectively. We can thus obtain the integral information about a fragment of the pixel. The generalized code combination is formed on the basis of the integrated two-component principle.

## III. CONCLUSION

1. A method of compressing pictures has been developed on the basis of constructing a generalized two-component code through a combined use of pixels of the coordinatestructural and line-by-line scaling representations of a picture fragment. In contrast to the bit-oriented principle, a supplementary group of bit positions is formed by weighted adding of the components of a picture fragment. The technique allows us:
1) to enhance the degree of compression by reducing the number of insignificant bit positions in code combinations;
2) to achieve the highest degree of compression by removing excessive bit positions;
3) to increase the efficiency of processing picture fragments;
4) to reduce elaborate computation in the course of processing;
5) to decrease the effects of errors upon the quality of reconstructed pictures in communication channels, in particular:

- the error appearing in the coding structure can propagate only within a local part of the picture fragment;
- on a distribution of aperture lengths over several twotype codes the error in the code representation of aperture lengths covers a smaller number of pixels in the coordinate-structural description of the picture fragment.

2. The arrays of the line-by-line scaling component of the picture fragment are represented as adaptive position numbers with unequal neighboring pixels (APN). In this case the lines of the arrays of approximating quantities are one-dimensional position numbers with non equal neighboring pixels.
3. A compact representation of a non uniform coordinate-structural component of a picture fragment has been constructed on the basis of two-dimensional polyadic coding in differential space. The limited and non uniform character of the dynamic ranges of pixels in the arrays of aperture lengths has been taken into account. The one-toone correspondence of such representation has been ensured, which improves considerably the control of approximating distortions and the quality of reconstructed pictures.

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# Matrix Manipulation Algorithms for Hasse Processor Implementation 

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#### Abstract

The processor is implemented in softwarehardware modules, which are based on the use of programming languages: $\mathrm{C}++$, Verilog, Python 2.7 and platforms: Microsoft Windows, $X$ Window (in Unix and Linux) and Macintosh OS X. HDL-code generator makes it possible to automatically synthesize HDL-code of the processor structure from 1 to 16 bits for parallel processing corresponding number of input vectors or words.


## I. InTRODUCTION

TThe binary coverage consists of finding the minimum lines combination in a matrix to make full one-units coverage. This task is very simple and doesn't require particular human effort for a small matrix. However this task becomes very difficult for a big matrix, for example considering a matrix of 1000 lines of 100 elements. In this case obviously we need a machine to do the job.

This paper will cover 2 methods that perform binary coverage with a reasonable speed performance for a matrix with up to $50000 \times 50000$ elements.

Those algorithms are coded in python for convenience reasons. This language is the optimal choice for algorithm prototyping. However, the final implementation of the algorithms will be coded in C++ for memory performance and multithreading.

## II. FORMATION OF THE MINIMUM COVERAGE FOR TWO-DIMENSIONAL MATRIX

### 2.1 Matrix to sub-matrices horizontal split

Solving practical problem for generating a binary coverage for unit matrix is to find the minimum combination of rows and columns, covering all unit values. Searching coverage for a small matrix is realized using simple techniques [1]. Searching binary coverage for a large

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matrix containing thousands of rows and columns requires a lot of time and money.

Horizontal partition of a matrix into submatrices is focused to divide the matrix M into a set of submatrices with a predetermined number of rows in accordance with the expression:

$$
\mathrm{M}\left(\mathrm{R}, \mathrm{~S}^{\mathrm{R}}\right)=\left\{\mathrm{M}_{\mathrm{i}}^{\prime}, \mathrm{M}_{\mathrm{i}+1}^{\prime}, \ldots \mathrm{M}_{\mathrm{i}+\mathrm{n}}^{\prime}\right\}
$$

where $n=R / S^{R}, M$ is the original matrix; $R$ is number of rows; $S^{R}$ is number $S$ of rows per sub-matrix; $M_{i}^{\prime}$ is the derivative matrix, resulting from horizontal split; i represents index of the matrix. For example, the matrix $M$ is:

|  | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 |
| 2 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 |
| 3 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 |
| 5 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 |
| 6 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| 7 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 |
| 8 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 |
| 9 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 1 |
| 10 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 |

Applying the method with horizontal split parameter $S^{R}=5$ will result on 2 matrixes:

| Matrix $\mathrm{M}_{1}^{\prime}$ |  |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 |
| 2 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 |
| 3 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 |
| 5 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 |



Applying this method we can considerably reduce binary coverage search time. In fact, when having two separate matrices $\mathrm{M}_{1}$ ' and $\mathrm{M}_{2}$, we can parallelize binary coverage search.

### 2.2. Matrix to sub-matrices horizontal vertical split

When solving the problem of binary coverage generation the most effective method is splitting M both horizontally and vertically into a set of submatrices with the specified number of rows and columns according to the expression:

$$
\begin{gathered}
M\left(\mathrm{R}, \mathrm{C}, \mathrm{~S}^{\mathrm{R}}, \mathrm{~S}^{\mathrm{C}}\right)=\left\{\mathrm{M}_{\mathrm{i}, \mathrm{j},}^{\prime}, \mathrm{M}_{\mathrm{i}, \mathrm{j}+1}^{\prime}, \mathrm{M}_{\mathrm{i}, \mathrm{j}+2}^{\prime}, \mathrm{M}_{\mathrm{i}+1, \mathrm{j},}^{\prime} \ldots \mathrm{M}_{\mathrm{i}+\mathrm{nj}+\mathrm{m}}^{\prime}\right\}, \\
\mathrm{j}=\mathrm{C} / \mathrm{C}^{\mathrm{R}},
\end{gathered}
$$

where $C$ is number of matrix columns; $C^{R}$ is number $C$ of columns per sub-matrix.

An example of horizontal-vertical partitioning of the matrix M when split-parameters have the following values $S^{R}=5$ и $S^{C}=5$ is represented below:
Matrix $\mathbf{M}_{1,1}^{I}$

|  | 1 | 2 | 3 | 4 | 5 |
| :--- | :--- | :--- | :--- | :--- | :--- |
| 1 | 0 | 0 | 0 | 0 | 0 |
| 2 | 1 | 0 | 1 | 0 | 0 |
| 3 | 1 | 0 | 1 | 0 | 0 |
| 4 | 1 | 1 | 1 | 1 | 1 |
| 5 | 0 | 0 | 0 | 0 | 1 |

Matrix $\mathbf{M}_{2,2}^{I}$

|  | 6 | 7 | 8 | 9 | 10 |
| :---: | :---: | :---: | :---: | :---: | :---: |
| 1 | 0 | 1 | 1 | 1 | 1 |
| 2 | 0 | 0 | 1 | 1 | 1 |
| 3 | 0 | 0 | 0 | 0 | 0 |
| 4 | 0 | 0 | 0 | 0 | 0 |
| 5 | 0 | 0 | 1 | 0 | 0 |

Matrix $\mathbf{M}_{2,1}^{I}$

|  | 1 | 2 | 3 | 4 | 5 |
| :---: | :---: | :---: | :---: | :---: | :---: |
| 6 | 1 | 0 | 0 | 1 | 1 |
| 7 | 0 | 0 | 0 | 0 | 0 |
| 8 | 1 | 1 | 1 | 1 | 1 |
| 9 | 1 | 1 | 1 | 1 | 0 |
| 10 | 0 | 0 | 0 | 0 | 0 |

Matrix $\mathbf{M}_{1,2}^{I}$

|  | 6 | 7 | 8 | 9 | 10 |
| :---: | :---: | :---: | :---: | :---: | :---: |
| 6 | 1 | 1 | 1 | 1 | 0 |
| 7 | 1 | 1 | 1 | 1 | 0 |
| 8 | 0 | 0 | 0 | 0 | 0 |
| 9 | 0 | 0 | 1 | 1 | 1 |
| 10 | 1 | 1 | 1 | 1 | 1 |

Partition of the matrix into submatrices can significantly reduce the search time of a binary coverage due to parallel processing submatrices.

### 2.3. Python matrix representation

In Python [2-4] bi-dimensional arrays (matrices) are not implemented; thereby a matrix is represented by an array of arrays. The class that implements the array interface in Python is List, so a matrix is represented by a list of lists. Let's consider the following matrix:

|  | 6 | 7 | 8 | 9 | 10 |
| :---: | :---: | :---: | :---: | :---: | :---: |
| 6 | 1 | 1 | 1 | 1 | 0 |
| 7 | 1 | 1 | 1 | 1 | 0 |
| 8 | 0 | 0 | 0 | 0 | 0 |
| 9 | 0 | 0 | 1 | 1 | 1 |
| 10 | 1 | 1 | 1 | 1 | 1 |

A simplified python representation of this matrix is shown in Listing 1.

Listing 1
matrix $=[[1,1,1,1,0]$,
$[1,1,1,1,0]$,
$[0,0,0,0,0]$,
$[0,0,1,1,1]$,
$[1,1,1,1,1]]$
In fact, a matrix is composed of a list of "Line" objects. A line object is a python matrix row representation. Bellow goes an example of matrix row and its python representation (Listing 2):

$$
\begin{array}{|l|l|l|l|l|}
\hline 1 & 1 & 1 & 1 & 1 \\
\hline
\end{array}
$$

Listing 2
print line
index :0
indexes :[]
values :[1, 1, 1, 1]
ones count :[1, 1, 1, 1]
The "Line" class members with the unique constructor are represented in Listing 3:

Listing 3
class Line(object):
def __init__(self, index $=0$, indexes $=[]$, values $=[]$,
ones_count = []):
self.index = index
self.indexes = indexes
self.values = values
self.ones_count = ones_count
if len(self.values) != len(self.ones_count): self.ones_count.extend(values)
end
Listing 4 involves some methods of the class Line:

Listing 4
class Line(object):
...

```
def ones_qnty(self):
```

    qnty \(=0\)
    for value in self.values:
                if value:
                    qnty \(+=1\)
        return qnty
    def binary_or(self, line):
        before_ones_qnty = self.ones_qnty()
        for key, value in enumerate(line.values):
            self_value = self.values[key]
            self.values[key] = self_value | value
            self.ones_count[key] += value
        if self.ones_qnty() > before_ones_qnty:
            for index in line.indexes:
                    self.indexes.append(index)
            self.indexes.append(line.index)
            return True
    return False
    def binary_xor(self, line):
    for key, value in enumerate(line.values):
        self.ones_count[key] -= value
        if self.ones_count[key] <= 0:
            self.ones_count[key] \(=0\)
            self.values[key] \(=0\)
        else:
            self.values[key] = 1
    self.indexes.remove(line.index)
    end

The method "ones_qnty" returns the quantity of one-unit in the line.

The method "binary_or" applies binary or transformation with the given line. A Boolean variable is returned:

- true if the binary or modified the line;
- false if the line was not modified.

The "ones_count" instance variable keeps ones count implied in binary or operation.

The method "binary_xor" performs a custom xor operation with a given line. For each element the "value" is subtracted from "ones_qnty". If the "ones_qnty" is equal to zero, the value field of the concerned line is set to zero too, otherwise it is set to one-unit.

A matrix set is represented as a container, which simplifies the manipulation of complicated matrices (Listing 5).

Listing 5
class ComplexMatrix(object):

```
def __init__(self, matrices):
    self.matrices = matrices
    self.columns = len(self.matrices[0].lines)
    self.rows = len(self.matrices) / self.columns
28
```

Listing 9
class MatrixUtils(object):
@staticmethod
def complexMatrixFromValues(values, horiz_max_lines = 10, vert_max_lines = 10):
matrices
MatrixUtils.rectSplitedMatricesFromValues(values, horiz_max_lines, vert_max_lines)

## return ComplexMatrix(matrices)

end
The method "RectSplitedMatricesFromValues" returns a set of matrices (Listing 10):

Listing 10
@staticmethod def
rectSplitedMatricesFromValues(values, horiz_max_lines = 10, vert_max_lines = 10):
horiz_splitted_lines = []
for hrz_line in values:
horiz_splitted_lines.append(MatrixUtils.split_array(hrz_line , horiz_max_lines))
result $=[]$
final_results = []
elements_count = len(horiz_splitted_lines[0])
print 'elements count: ' + str(elements_count)
for _ in range(elements_count):
result.append([])
line_count $=0$
for line in horiz_splitted_lines:
element_count $=0$
for element in line:
result[element_count].append(element)
element_count += 1
line_count $+=1$
if (not (line_count \% horiz_max_lines) and line_count):

> final_results.append(result)
result = []
for _ in range(elements_count):
result.append([])
print 'result: ' + str(result)
matrices = []
mat_counter $=0$
for res in final_results:
for val in res:
mat_index = [mat_counter / horiz_max_lines, mat_counter \% vert_max_lines]
print mat_index
matrices.append(Matrix(MatrixUtils.matrixLinesFromListV alues(val), mat_index))

$$
\text { mat_counter += } 1
$$

## return matrices

### 2.5. Matrix's binary coverage signature

The matrix's binary coverage signature represents a high level optimization, particularly for horizontal-vertical split. This method is not yet implemented.

The idea is about representing a matrix by a hash unique to matrix one-unit quantity and repartition. The goal is to avoid recalculating binary coverage for a same matrix. Bellow follows matrix signature representation:

$$
\mathrm{H}_{\mathrm{i}, \mathrm{j}}=\left\{\{\mathrm{R}, \mathrm{C}\},\left\{\mathrm{M}_{\mathrm{i}, \mathrm{j}}\right\}\right\}
$$

Matrix signature associated value:

$$
V_{i, j}=\left\{\left\{R_{i}\right\},\left\{M_{i, j}\right\}\right\}
$$

Let's consider the following example:

|  | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 |
| 2 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 |
| 3 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 |
| 5 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 |
| 6 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 |
| 7 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 |
| 8 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 |
| 10 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 |

Applying the method with horizontal split parameter $S^{\mathrm{R}}=5$ and vertical split parameter $\mathrm{S}^{\mathrm{C}}=5$ will result on 4 matrices:

| Matrix $\mathrm{M}_{1,1}^{V}$ |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: |
|  | 1 | 2 | 3 | 4 | 5 |
| 1 | 0 | 0 | 0 | 0 | 0 |
| 2 | 1 | 0 | 1 | 0 | 0 |
| 3 | 1 | 0 | 1 | 0 | 0 |
| 4 | 1 | 1 | 1 | 1 | 1 |
| 5 | 0 | 0 | 0 | 0 | 1 |

Matrix $\mathrm{M}_{2,1}^{I}$

|  | 1 | 2 | 3 | 4 | 5 |
| :---: | :---: | :---: | :---: | :---: | :---: |
| 6 | 0 | 0 | 0 | 0 | 0 |
| 7 | 1 | 0 | 1 | 0 | 0 |
| 8 | 1 | 0 | 1 | 0 | 0 |
| 9 | 1 | 1 | 1 | 1 | 1 |
| 10 | 0 | 0 | 0 | 0 | 1 |

Matrix $\mathbf{M}_{\mathbf{1}^{\prime} \text { 2 }}^{I}$

|  | 6 | 7 | 8 | 9 | 10 |
| :---: | :---: | :---: | :---: | :---: | :---: |
| 1 | 0 | 1 | 1 | 1 | 1 |
| 2 | 0 | 0 | 1 | 1 | 1 |
| 3 | 0 | 0 | 0 | 0 | 0 |
| 4 | 0 | 0 | 0 | 0 | 0 |
| 5 | 0 | 0 | 1 | 0 | 0 |

Matrix $\mathrm{M}_{2,2}^{I}$

|  | 6 | 7 | 8 | 9 | 10 |
| :---: | :---: | :---: | :---: | :---: | :---: |
| 6 | 0 | 1 | 1 | 1 | 1 |
| 7 | 0 | 0 | 1 | 1 | 1 |
| 8 | 0 | 0 | 0 | 0 | 0 |
| 9 | 0 | 0 | 0 | 0 | 0 |
| 10 | 0 | 0 | 1 | 0 | 0 |

Now we are going to calculate the hash for each matrix:
$\mathrm{H}_{1,1}^{\prime}=\{\{5,5\},\{0000010100101001111100001\}\}$
$\mathrm{H}_{1,2}^{\prime}=\{\{5,5\},\{0111100111000000000000100\}\}$ $\mathrm{H}_{2,1}^{\prime}=\{\{5,5\},\{0000010100101001111100001\}\}$ $\mathrm{H}_{2,2}^{\prime}=\{\{5,5\},\{0111100111000000000000100\}\}$

The values for those hashes:

$$
\begin{aligned}
\mathrm{V}_{1,1}^{\prime} & =\{\{4\},\{11111\}\} \\
\mathrm{V}_{1,2}^{\prime} & =\{\{1\},\{01111\}\} \\
\mathrm{V}_{2,1}^{\prime} & =\{\{9\},\{11111\}\} \\
\mathrm{V}_{2,2}^{\prime} & =\{\{6\},\{01111\}\}
\end{aligned}
$$

The hashes $\mathrm{H}_{1,1}^{\prime}, \mathrm{H}_{1,2}^{\prime}$ are respectively equal to $\mathrm{H}_{2,1}^{\prime}, \mathrm{H}_{2,2}^{\prime}$. This means that if we already know the binary coverage of $\mathrm{M}_{1,1}^{\prime}$ we can deduce the binary coverage result of $\mathbf{M}_{2,1}^{\prime}$ by simply calculating it's hash.

### 2.6. Methods comparison

Both methods goals are to parallelize binary coverage. The horizontal split is simple to realize. However, it does not consider the matrix columns count. For large matrices, where the columns count is considerably bigger than the rows count, this method can create time overhead because of linear complexity of binary coverage method.

The horizontal-vertical method is much harder to realize and the time to split the matrix into sub-matrices is considerably higher than for simple horizontal split. Also should be considered the time for reconstructing the matrices into the original matrix because of vertical split. The advantage of this method is high parallelizing. In fact, a large matrix can be split into matrices with smaller columns number. Moreover, a custom logic can be realized in order to processes particular matrices to speed up the coverage.

Profile test for both methods is presented in Listing 11, the result - in Listing 12.

Listing 11
"'
Created on 17.04.2013
@author: $\qquad$
from models.matrix_utils import MatrixUtils
from test_main import test_table_4
import cProfile
def linear_split_test():
for _ in range(100):
MatrixUtils.linearSplittedMatricesFromValues(test_table_4, 5)
def rect_split_test():
for _ in range(100):

MatrixUtils.rectSplitedMatricesFromValues(test_table_4, 5, 5)

```
if __name__== '__main__':
        cProfile.run('rect_split_test()')
        cProfile.run('linear_split_test()')
```

Listing 12
306104 function calls in 1.576 seconds
Ordered by: standard name
ncalls tottime percall cumtime percall
filename:lineno(function)
$\begin{array}{lllll}1 & 0.000 & 0.000 & 1.576 & 1.576 \text { <string>:1(<module>) }\end{array}$ $\begin{array}{lllll}56000 & 0.281 & 0.000 & 0.399 & 0.000 \\ \text { line.py: } & 9\left(\_ \text {init__) }\right.\end{array}$
$10.051 \quad 0.051 \quad 1.576 \quad 1.576$ main.py:17(rect_split_test) 112000.0290 .0000 .0290 .000 matrix.py:11(_init_) $\begin{array}{lllll}8100 & 0.078 & 0.000 & 0.112 & 0.000\end{array}$
matrix_utils.py:15(split_array)
$\begin{array}{lllll}100 & 0.300 & 0.003 & 1.525 & 0.015\end{array}$
matrix_utils.py:43(rectSplitedMatricesFromValues)
$\begin{array}{lllll}11200 & 0.404 & 0.000 & 0.910 & 0.000\end{array}$
matrix_utils.py:83(matrixLinesFromListValues)
$8200 \quad 0.015 \quad 0.000 \quad 0.015 \quad 0.000$ \{len\}
$\begin{array}{lllll}145500 & 0.276 & 0.000 & 0.276 & 0.000\end{array}$ \{method 'append' of 'list' objects\}
$\begin{array}{lllll}1 & 0.000 & 0.000 & 0.000 & 0.000\end{array}$ \{method 'disable' of '_Isprof.Profiler' objects\}
$\begin{array}{lllll}56000 & 0.118 & 0.000 & 0.118 & 0.000\end{array}$ \{method 'extend'
of 'list' objects\}
$9801 \quad 0.023 \quad 0.000 \quad 0.023 \quad 0.000$ \{range\}
188604 function calls in 1.069 seconds
Ordered by: standard name
ncalls tottime percall cumtime percall filename:lineno(function)
$\begin{array}{lllll}1 & 0.000 & 0.000 & 1.069 & 1.069 \text { <string>:1(<module>) }\end{array}$ $8100 \quad 0.035 \quad 0.000 \quad 0.054 \quad 0.000$ line.py: 9 (_init__) $\begin{array}{lllll}1 & 0.047 & 0.047 & 1.069 & 1.069\end{array}$ main.py:12(linear_split_test)

| 81950 | 0.256 | 0.000 | 0.256 | 0.000 |
| :---: | :---: | :---: | :---: | :---: |
| matrix.py:11(_init_) |  |  |  |  |
| 100 | 0.059 | 0.001 | 0.062 | 0.001 |
| matrix_utils.py:15(split_array) |  |  |  |  |
| 100 | 0.430 | 0.004 | 1.02 | 0.010 |

matrix_utils.py:31(linearSplittedMatricesFromValues) $\begin{array}{lllll}100 & 0.053 & 0.001 & 0.124 & 0.001\end{array}$
matrix_utils.py:93(matrixFromListValues)
$\begin{array}{llllll}100 & 0.000 & 0.000 & 0.000 & 0.000\end{array}$ \{len\}
$\begin{array}{llllll}89950 & 0.167 & 0.000 & 0.167 & 0.000 & \text { \{method 'append' }\end{array}$
of 'list' objects\}
$\begin{array}{lllll}1 & 0.000 & 0.000 & 0.000 & 0.000\end{array}$ \{method 'disable' of
'_Isprof.Profiler' objects\}
$\begin{array}{lllll}8100 & 0.019 & 0.000 & 0.019 & 0.000\end{array}$ \{method 'extend'
of 'list' objects\}
$\begin{array}{lllll}101 & 0.002 & 0.000 & 0.002 & 0.000\end{array}$ \{range\}
The linear method splits the original matrix on 17 submatrices. The rect-split method splits the matrix into 112 matrices but is $50 \%$ slower.

R\&I, 2014, N3

## III. MATRIX BINARY COVERAGE ALGORITHMS

### 3.1 Binary OR for first line algorithm

We take the first matrix line which contains at least 1 one-unit and apply binary or operation with the rest of the lines. If the first line is full of zeros (contains only zeros), we skip it and iterate to the next line. The operation is repeated until a non empty line is found. If the 5 lines of the sub-matrix are full of zeros, the entire sub-matrix is skipped and will not participate in further calculations. Each time we apply OR, we check if the operation changed the line, if yes we keep the result line and save the indexes of both lines.

For example, let us consider the following matrices M1, M2, and M3.

Matrix M1:

|  | 1 | 2 | 3 | 4 | 5 |
| :--- | :--- | :--- | :--- | :--- | :--- |
| 1 | 0 | 0 | 0 | 0 | 0 |
| 2 | 0 | 0 | 0 | 0 | 0 |
| 3 | 0 | 1 | 0 | 0 | 0 |
| 4 | 0 | 1 | 0 | 0 | 0 |
| 5 | 0 | 0 | 1 | 0 | 0 |

$l 1$ empty $\rightarrow l 1$ skipped
$l 2$ empty $\rightarrow l 2$ skipped
$l 3^{v} l 4 \rightarrow l 3^{=}=01000 \rightarrow l 4$ rejected
$l 3 \mathrm{v} l 5 \rightarrow l 3^{1}$ saved

We have skipped $\left\{l_{1}, l_{2}\right\}$ because they contain only zeros. Those lines are empty.

Matrix M2:

|  | 1 | 2 | 3 | 4 | 5 |
| :--- | :--- | :--- | :--- | :--- | :--- |
| 1 | 0 | 1 | 0 | 0 | 1 |
| 2 | 0 | 0 | 0 | 0 | 0 |
| 3 | 1 | 1 | 0 | 0 | 0 |
| 4 | 0 | 0 | 1 | 1 | 0 |
| 5 | 1 | 1 | 0 | 0 | 0 |

$l 1 \mathrm{v} l 2 \rightarrow l 1^{\square}=01001$ not changed $\rightarrow l 2$ rejected
$l_{1} \mathrm{v} l 3 \rightarrow l_{1}{ }^{1}=11001$ changed $\rightarrow l 3$ saved
$l_{1} \mathbf{1}^{\mathbf{v}} l 4 \rightarrow l_{1}=11111$ changed $\rightarrow l 4$ saved
Matrix M3:

|  | 1 | 2 | 3 | 4 | 5 |
| :--- | :--- | :--- | :--- | :--- | :--- |
| 1 | 0 | 0 | 0 | 0 | 0 |
| 2 | 0 | 0 | 0 | 0 | 0 |
| 3 | 0 | 0 | 0 | 0 | 0 |
| 4 | 0 | 0 | 0 | 0 | 0 |
| 5 | 0 | 0 | 0 | 0 | 0 |

[^5]Each OR operation we check if the binary coverage for 1 is full, in other words if the resulting line is full of oneunits. At state $l_{1} 2$ the line is full of one-units we no more perform OR operation. Let's make it clear with the following example:

Matrix M4:

|  | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 1 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| 4 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 |
| 5 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 |
| 7 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 0 |
| 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

$l 1 \mathrm{v} l 2 \rightarrow l \mathbf{1}^{1}=1101000000 \rightarrow l 2$ saved
$l_{1} \mathbf{1}^{v} l 3 \rightarrow l_{1}{ }^{\mathbf{2}}=1101100000 \rightarrow l 3$ saved
$l_{1} \mathrm{v}=l 4 \rightarrow l_{1}{ }^{2}=1101100000 \rightarrow l 4$ rejected
$l_{1} \mathbf{1}^{2}$ v $l 5 \rightarrow l_{1}{ }^{3}=1111100000 \rightarrow l 5$ saved
$l^{\mathbf{3}}$ v $l 6 \rightarrow l^{4}=1111101011 \rightarrow l 6$ saved
$l_{1}{ }^{\mathbf{4}} \mathrm{v} l 7 \rightarrow l_{1}{ }^{5}=1111111111 \rightarrow l 7$ saved
$l 1^{5}=\{l 1, l 2, l 3, l 5, l 6, l 7\}$

### 3.2 Binary OR for first line with reverse algorithm

This method consists of 3 steps:

1. First the matrix lines are sorted by one-units quantity descending. Consider the following example of the matrix M1:

|  | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 |
| 4 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| 5 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 |
| 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Bellow the sorted matrix $\mathrm{M}_{1 \mathrm{~s}}$ :

|  | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 5 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 |
| 2 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 |
| 4 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

2. Then we perform binary or for first line until we reach full coverage or the end of the matrix (if we reach the last line without full coverage the calculation is stopped):

$$
\begin{aligned}
& l 5 \cup l 2 \rightarrow l 5^{1}=0011001111 \rightarrow l 2 \text { saved } \\
& l 5^{1} \cup l 3 \rightarrow l 5^{2}=0011111111 \rightarrow l 3 \text { saved } \\
& l 5^{2} \cup l 4 \rightarrow l 5^{a}=0111111111 \rightarrow l 4 \text { saved } \\
& l 5^{3} \cup l 1 \rightarrow l 5^{4}=1111111111 \rightarrow l 1 \text { saved } \\
& l 5^{4}=\{l 5, l 2, l 3, l 4, l 1\}
\end{aligned}
$$

3. After that we begin deleting one line from $15^{4}$ each time. The lines are deleted starting from the penultimate line. Each time a line is deleted, we check if the binary coverage is still total. It is important to note that the algorithm is applied recursively. We can optimize binary coverage by deleting redundant lines. The following example demonstrates that fact:

$$
\begin{aligned}
& l s u l 2 \rightarrow l s^{1}=0011001111 \rightarrow l 2 \text { saved } \\
& l 5^{1} \cup l 3 \rightarrow l 5^{2}=001111111 \rightarrow l 3 \text { saved } \\
& \left.l 5^{2} v l 4 \rightarrow l 5^{2}=0111111111 \rightarrow l 4 \text { saved (line to delete }\right) \\
& l s^{2} v l 1 \rightarrow l 5^{4}=1111111111 \rightarrow l 1 \text { saved } \\
& l 5^{4}=\{l 5, l 2, l 3, l 4, l 1\}
\end{aligned}
$$

The result is represented below:

```
lsul2 ->ls'}=0011001111->l2 saved
l5
l5
l5*}={l5,l2,l3,l1
```

The binary coverage without row 14 is still total, 14 will be excluded from the final coverage. The row 14 is marked as primary redundant. Now, when we have found one redundant line, we begin applying this algorithm recursively, until we delete all redundant lines (rows). After there is no more redundant rows for the primary row 14 , the same algorithm is applied for the next primary row. In this case the next primary row is $l 3$. After the algorithm applied for all primary rows, the quantity of redundant rows is compared and the best result is considered.

Applying the algorithm for primary row l3:

$$
\begin{aligned}
& l 5 \cup l 2 \rightarrow l 5^{1}=0011001111 \rightarrow l 2 \text { saved } \\
& \left.l 5^{1} \cup l 3 \rightarrow l 5^{2}=0011111111 \rightarrow l 3 \text { saved(line to delete }\right) \\
& l 5^{\mathbf{3}} \cup l 1 \rightarrow l 5^{4}=1111111111 \rightarrow l 1 \text { saved } \\
& l 5^{4}=\{l 5, l 2, l 3, l 1\}
\end{aligned}
$$

The result is represented below:

$$
l 5 \text { ч } l 2 \rightarrow l 5^{1}=0011001111 \rightarrow l 2 \text { saved }
$$

$$
l 5^{1} \cup l 3 \rightarrow l 5^{2}=0011111111 \rightarrow l 3 \text { saved(line to delete) }
$$

$$
l 5^{a} \cup l 1 \rightarrow l 5^{4}=1111111111 \rightarrow l 1 \text { saved }
$$

$$
l 5^{4}=\{l 5, l 2, l 3, l 1\}
$$

Deleting the row $l_{3}$ makes the binary coverage not full. The row $l_{3}$ cannot be deleted.

Applying for row $l_{2}$ :

Listing 14
class Algorithm(object):
@staticmethod
def applyMatrixRecurtion(matrix):
matrix.sort_by_ones_qnty()
matrix.updateLinesMapping()
return matrix.binary_full_check_reverse()
end
Matrix class implements the algorithm (Listing 15).
Listing 15
class Matrix(object):
def binary_full_check_reverse(self): line =
self.binary_or_for_first_line_with_full_check() result_lines = []
for value in line.indexes:
newLine $=$ line.deepcopy ()
newLine.binary_xor(self.lineForIndex(value)) result_lines.append(newLine)
return result_lines
end
Bellow follows an example of input matrix and output values.

Input matrix is represented in Listing 16.
Listing 16
test_table $=$ [
$[0,1,0,0,1,1,0,0,0,1,0,0,0,0,0,0,0,0,0], \# 0$
$[0,0,0,0,1,0,1,0,1,0,0,0,0,0,0,0,0,0,0], \# 1$
$[0,0,1,0,0,0,0,0,0,0,1,0,0,0,0,0,0,0,0], \# 2$
$[0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0], \# 3$
$[0,0,0,0,1,1,0,0,0,0,0,0,0,0,0,0,0,0,0], \# 4$
$[0,0,0,0,0,0,0,0,0,0,0,1,0,0,0,0,0,0,0], \# 5$
$[0,0,0,0,0,0,0,1,0,0,0,0,0,0,0,0,0,0,0], \# 6$
$[0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0], \# 7$
$[0,0,0,0,0,0,0,0,0,0,0,0,1,0,0,0,0,0,0], \# 8$
$[0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0], \# 9$
$[0,0,0,0,0,0,0,0,0,0,0,0,0,1,0,0,0,0,0], \# 10$
$[0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0], \# 11$
$[0,0,0,1,0,0,0,0,0,0,0,0,0,0,1,0,0,0,0], \# 12$
$[0,0,1,0,0,0,0,0,0,0,0,0,0,0,0,0,1,0,0], \# 13$
$[0,1,0,0,0,1,0,0,0,0,0,1,0,0,0,0,0,0,0], \# 14$
$[0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,1,0,0,0], \# 15$
$[0,0,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0], \# 16$
$[1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0], \# 17$
$[0,1,0,1,0,0,0,0,0,0,0,0,0,0,0,0,0,1,1], \# 18$
]

Now goes the call that generates the output (Listing 17).
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Listing 17
$\qquad$
lines $=$ Algorithm.applyMatrixRecurtion(
MatrixUtils.matrixFromListValues(test_table)) for line in lines: print line

And finally the output (Listing 18):
Listing 18
index :0
indexes :[18, 1, 14, 2, 12, 13, 6, 8, 10, 15, 17]
values : $[1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1]$
ones count :[1, 3, 3, 2, 3, $3,1,1,1,1,1,2,1,1,1,1,1,1,1]$ index :0
indexes :[1, 14, 2, 12, 13, 6, 8, 10, 15, 17]
values : $[1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,0,0]$
ones count :[1, 2, 3, 1, 3, $3,1,1,1,1,1,2,1,1,1,1,1,0,0]$
index :0
indexes :[18, 14, 2, 12, 13, 6, 8, 10, 15, 17]
values :[1, 1, 1, 1, 1, 1, $0,1,0,1,1,1,1,1,1,1,1,1,1]$ ones count :[1, $3,3,2,2,3,0,1,0,1,1,2,1,1,1,1,1,1,1]$ index :0
indexes :[18, 1, 2, 12, 13, 6, 8, 10, 15, 17]
values : $[1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1]$
ones count :[1, 2, 3, 2, 3, 2, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1]
index :0
indexes :[18, $1,14,12,13,6,8,10,15,17]$
values :[1, 1, 1, 1, 1, 1, 1, 1, 1, 1, $0,1,1,1,1,1,1,1,1]$
ones count :[1, 3, 2, 2, 3, $3,1,1,1,1,0,2,1,1,1,1,1,1,1]$
index :0
indexes :[18, 1, 14, 2, 13, 6, 8, 10, 15, 17]
values :[1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, $0,1,1,1,1]$
ones count :[1, 3, 3, 1, 3, $3,1,1,1,1,1,2,1,1,0,1,1,1,1]$
index :0
indexes :[18, $1,14,2,12,6,8,10,15,17]$
values : $[1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,0,1,1]$
ones count :[1, 3, 2, 2, 3, $3,1,1,1,1,1,2,1,1,1,1,0,1,1]$
index :0
indexes :[18, 1, 14, 2, 12, 13, 8, 10, 15, 17]
values : $[1,1,1,1,1,1,1,0,1,1,1,1,1,1,1,1,1,1,1]$
ones count :[1, 3, 3, 2, 3, $3,1,0,1,1,1,2,1,1,1,1,1,1,1]$
index :0
indexes :[18, 1, 14, 2, 12, 13, $6,10,15,17]$
values :[1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, $0,1,1,1,1,1,1]$
ones count :[1, 3, 3, 2, 3, 3, 1, 1, 1, 1, 1, 2, $0,1,1,1,1,1,1]$
index :0
indexes :[18, 1, 14, 2, 12, 13, 6, 8, 15, 17]
values : $[1,1,1,1,1,1,1,1,1,1,1,1,1,0,1,1,1,1,1]$
ones count :[1, 3, 3, 2, 3, 3, 1, 1, 1, 1, 1, 2, 1, $0,1,1,1,1,1]$
index :0
indexes :[18, 1, 14, 2, 12, 13, 6, 8, 10, 17]
values : $[1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,0,1,1,1]$ ones count : $[1,3,3,2,3,3,1,1,1,1,1,2,1,1,1,0,1,1,1]$ index :0
indexes :[18, 1, 14, 2, 12, 13, 6, 8, 10, 15]
values : $[0,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1]$
ones count :[0, 3, 3, 2, 3, $3,1,1,1,1,1,2,1,1,1,1,1,1,1]$

### 3.5 Methods comparison

Methods called to profile algorithms performance (Listing 19):

```
Listing 19
def recurtion_test():
    for _ in range(100):
```

Algorithm.applyMatrixRecurtion(MatrixUtils.matrixFromL istValues(test_table))

```
def first_line_or_test():
    for _ in range(100):
```

Algorithm.applyMatrixFirstLineOR(MatrixUtils.matrixFro mListValues(test_table))

```
if ___name__ == '__main__':
    cProfile.run('first_line_or_test()')
    cProfile.run('recurtion_test()')
```

Profile results for first line or test are represented in Listing 20.

## Listing 20

21105 function calls in 0.146 seconds
Ordered by: standard name
ncalls tottime percall cumtime percall filename:lineno(function)
$1 \quad 0.000 \quad 0.000 \quad 0.146 \quad 0.146$ <string>: $1(<$ module $>$ )
$\begin{array}{lllll}100 & 0.001 & 0.000 & 0.103 & 0.001\end{array}$
algorithm.py:15(applyMatrixFirstLineOR)
$\begin{array}{lllll}5500 & 0.026 & 0.000 & 0.026 & 0.000\end{array}$
$\begin{array}{ccccc}\text { line.py:19(ones_qnty) } & & & \\ 1800 & 0.011 & 0.000 & 0.021 & 0.000\end{array}$
$\begin{array}{ccccc}\text { line.py:29(is_full_of_ones) } & & & \\ 100 & 0.001 & 0.000 & 0.001 & 0.000\end{array}$
$\begin{array}{ccccc}\text { line.py:34(is_full_of_zeros) } & & & \\ 1800 & 0.041 & 0.000 & 0.063 & 0.000\end{array}$

| line.py:39(binary_or) |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: |
| 100 | 0.002 | 0.000 | 0.005 | 0.000 |

line.py:78(deepcopy)
$2000 \quad 0.014 \quad 0.000 \quad 0.022 \quad 0.000$ line.py:9(__init__)
$\begin{array}{lllll}1 & 0.002 & 0.002 & 0.146 & 0.146\end{array}$
main.py:27(first_line_or_test)
$\begin{array}{lllll}100 & 0.000 & 0.000 & 0.000 & 0.000\end{array}$
matrix.py:11(__init__)

| 100 | 0.011 | 0.000 | 0.102 | 0.001 |
| :--- | :--- | :--- | :--- | :--- |

matrix.py:73(binary_or_for_first_line_with_full_check)
$\begin{array}{lllll}100 & 0.017 & 0.000 & 0.042 & 0.000\end{array}$
matrix_utils.py:93(matrixFromListValues)
$\begin{array}{lllll}100 & 0.000 & 0.000 & 0.000 & 0.000\end{array}$ \{iter\}
$5900 \quad 0.012 \quad 0.000 \quad 0.012 \quad 0.000$ \{len\}
$\begin{array}{lllll}3000 & 0.006 & 0.000 & 0.006 & 0.000\end{array}$ \{method 'append' of 'list' objects $\}$
$\begin{array}{lllll}1 & 0.000 & 0.000 & 0.000 & 0.000\end{array}$ \{method 'disable' of '_lsprof.Profiler' objects\}
$\begin{array}{lllll}301 & 0.002 & 0.000 & 0.002 & 0.000\end{array}$ \{method 'extend' of 'list' objects\}

```
100}00.000 0.000 0.000 0.000 {next
1}00.000 0.000 0.000 0.000 {range}
```

Profile results for recursion method are represented in Listing 21.

Listing 21
596943 function calls in 3.720 seconds
Ordered by: standard name
ncalls tottime percall cumtime percall filename:lineno(function)
$\begin{array}{lllll}1 & 0.000 & 0.000 & 3.720 & 3.720<\text { string>: } 1(<\text { module>) }\end{array}$
$\begin{array}{lllll}100 & 0.002 & 0.000 & 3.678 & 0.037\end{array}$
algorithm.py:52(applyMatrixRecurtion)
$\begin{array}{lllll}341792 & 1.177 & 0.000 & 1.177 & 0.000\end{array}$
$\begin{array}{rrrrr}\text { line.py:19(ones_qnty) } & & & \\ 41000 & 0.257 & 0.000 & 0.493 & 0.000\end{array}$
$\begin{array}{cccc}\text { line.py:29(is_full_of_ones) } \\ 100 & 0.000 & 0.000 & 0.001\end{array}$
$\begin{array}{cccc}\text { line.py:34(is_full_of_zeros) } \\ 41000 & 0.845 & 0.000 & 1.160\end{array}$
$\begin{array}{ccccc}\text { line.py:39(binary_or) } \\ 1100 & 0.021 & 0.000 & 0.024 & 0.000\end{array}$
line.py:57(binary_xor)
$\begin{array}{lllll}1200 & 0.020 & 0.000 & 0.043 & 0.000\end{array}$
line.py:78(deepcopy)
$3100 \quad 0.024 \quad 0.000 \quad 0.036 \quad 0.000$ line.py:9(__init__)
$\begin{array}{lllll}1 & 0.003 & 0.003 & 3.720 & 3.720\end{array}$
main.py:23(recurtion_test)
$\begin{array}{lllll}100 & 0.012 & 0.000 & 1.949 & 0.019\end{array}$
$\begin{array}{cccc}\text { matrix.py:102(binary_full_check_reverse) } & \\ 100 & 0.000 & 0.000 & 0.000\end{array}$
$\begin{array}{ccc}\text { matrix.py:11(_init__) } & & \\ 0.005 & 0.000\end{array}$
$\begin{array}{cccc}\text { matrix.py:18(sort_by_ones_qnty) } & & \\ 100 & 0.039 & 0.000 & 0.039\end{array}$
$\begin{array}{ccccc}\text { matrix.py:39(updateLinesMapping) } \\ 1100 & 0.003 & 0.000 & 0.003 & 0.000\end{array}$
matrix.py:45(lineForIndex)
$\begin{array}{lllll}100 & 0.210 & 0.002 & 1.869 & 0.019\end{array}$
matrix.py:73(binary_or_for_first_line_with_full_check) $\begin{array}{lllll}109346 & 0.720 & 0.000 & 1.426 & 0.000\end{array}$
matrix_utils.py:110(reverseLines)
$\begin{array}{lllll}100 & 0.013 & 0.000 & 0.038 & 0.000\end{array}$
matrix_utils.py:93(matrixFromListValues)
$\begin{array}{lllll}100 & 0.000 & 0.000 & 0.000 & 0.000\end{array}$ \{iter\} $\begin{array}{lllll}47300 & 0.089 & 0.000 & 0.089 & 0.000\end{array}$ \{len\}
$\begin{array}{lllll}4200 & 0.009 & 0.000 & 0.009 & 0.000\end{array}$ \{method 'append'
of 'list' objects $\}$
$100.000 \quad 0.000 \quad 0.000 \quad 0.000$ \{method 'disable' of '_lsprof.Profiler' objects\}
$\begin{array}{lllll}3601 & 0.008 & 0.000 & 0.008 & 0.000\end{array}$ \{method 'extend'
of 'list' objects\}
$\begin{array}{lllll}1100 & 0.003 & 0.000 & 0.003 & 0.000\end{array}$ \{method 'remove'
of 'list' objects \}
$\begin{array}{lllll}100 & 0.257 & 0.003 & 1.683 & 0.017\end{array}$ \{method 'sort' of 'list' objects\}

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```
100}00.000 0.000 0.000 0.000 {next
1
```

The second method is much slower, however more accurate because of binary xor recursion. Both methods are still subjects to optimization.

## III Conclusion

The processor is implemented in software-hardware modules, which are based on the use of programming languages: C++, Verilog, Python 2.7 and platforms: Microsoft Windows, X Window (in Unix and Linux) and Macintosh OS X. HDL-code generator makes it possible to automatically synthesize HDL-code of the processor structure from 1 to 16 bits for parallel processing corresponding number of input vectors or words.

Verification of HDL-processor code is executed on test examples of coverage problem using two optimization strategies: reversible algorithm to eliminate redundancy and partitioning the coverage matrix for the purpose of further parallel processing by Hasse processors.

The performance of the proposed two methods depends on the distribution of unit elements in the matrix; this information is important for large matrices. However, most of this information is not available. In this case, both the approaches can be used for logic optimization and increase the speed of the second method.

The best solution is a combination of two proposed methods: sorting matrix and its subsequent partitioning into submatrices; use of reverse algorithm of recursive method for submatrices containing more than one unit element, and a simple horizontal partitioning algorithm for the rest of the matrix; going to step 2 of the first recursive method.

## References

[1] Gorbatov V.A. Fundamentals of Discrete Mathematics / V.A. Gorbatov.- M.: Vysshaya Shkola.- 1986. - 311 p.
[2] http://www.python.org/
[3] http://www.eclipse.org/
[4] http://pydev.org/

# Radio-Frequency Identification Systems on Set of Quality Parameters 

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#### Abstract

General methodical approach to a choice of the best variant of radio-frequency identification (RFID) systems on quality parameters set is considered.


## I. Introduction

Modern RFID systems constantly become complicated, to them make inconsistent technical and economic demands which are characterized by set of indicators of quality. Now there is final and rather small set of RFID technologies [1], the final set of components of various firms for construction of RFID systems is considerable more, but besides (readers, antennas of readers, radiofrequency tags (RFT), RFT antennas, the software). However ready variants of RFID systems for variety of cases initially do not exist. It is connected by that there is a set of RFID systems of different function, for example, for monitoring systems and management of personnel access, for the safety control on highways, on the railway and many other things. Thus each RFID system has the specific lines and features and consequently is in own way unique.

At the big variety of components (hardware-software means), capable to provide performance of set of the technical and economic requirements shown to RFID systems, there is a problem of their rational choice. All available components are characterized by variety of the various indicators inherent in each of them which can influence in the various image system effectiveness RFID as a whole. Degree of influence of these indicators also is various. Thereupon there is a problem of a choice of the most rational variants for construction of RFID systems of different function. For the decision of this problem development of the general methodical approach to a choice of the best variant of RFID system from set of admissible variants is required.

[^6]
## II. Statement of problem

As starting positions for development of the methodical approach all set of factors of is standard-legal, technical and economic character, including documents of federal and departmental levels should be considered. To their number the governmental order of the Russian Federation from 28.11.2011 №977 «About federal state information system» Uniform system of identification and authentification in an infrastructure providing information-technological interaction of information systems, state for granting state and municipal services in the electronic form belongs, for example, etc.

The methodical approach includes: a substantiation of the list of requirements $\mathrm{T}-\left\{\mathrm{t}_{\mathrm{i}}\right\}$, shown to RFID system from its customers; definition of set of initial conditions $\mathrm{U}=\left\{\mathrm{u}_{\mathrm{i}}\right\}$ for designing, including possibilities and tendencies of development of RFID systems; working out of the general variants of construction and RFID system functioning, including its formalized representation as the difficult multicomponent system, allowing to describe its set of parameters $X=\{x i\}$; a choice of set of indicators of efficiency $Q=\left(q_{1}, q_{2}, \ldots, q_{m}\right)$ most influencing $a$ choice of the best variant of RFID system from set of admissible variants.

RFID system choice represents a multicriterion choice problem of alternative from some set of admissible alternatives on the basis of estimations criteria conformity of the given alternatives of the set of technical and economic requirements. Thus the main initial stage of a choice of a variant of RFID system is the proved formation of set of technical and economic requirements to chosen system. Then in a general view statement of a problem of a choice of a variant of RFID system on set of indicators of quality can be formulated as follows.

Let the choice of a variant of RFID system is made from set of alternatives $A=\left\{A_{i}, i=1,2, \ldots, n\right\}$ on the set of technical and economic requirements or criteria $Q=\left\{q_{j}, j=1,2, \ldots, m\right\}$. It is necessary to choose such alternative which in the best way corresponds to set of technical and economic requirements $Q$ from admissible set of RFID systems.

It is necessary to notice, that modern RFID systems are characterized by set of indicators of technical and economic character [2]. Thus for various types of systems of degree of importance of these indicators are various. It is necessary to note also, what not all indicators can be estimated quantitatively. The decision of the formulated problem includes two basic stages: formation of set of admissible alternative variants of systems; an estimation of alternative variants and a choice of the best variant.

In practice to find the strict decision of a task in view as optimizing in a general view it appears the extremely inconvenient. Therefore at a choice of the best variant of RFID system it is expedient to use the known hierarchical approach [2] consisting, first, in decomposition of the general problem on a number private, secondly, in proved application of various indicators of efficiency with the account of features of solved private problems. RFID system model in this case is represented in the form of hierarchy of models a component (systems, subsystems, elements) and models of relations a component. The choice of an optimum variant of system on model is carried out by means of consecutive search of optimum variants separate a component at different levels of hierarchy of system and their coordination for a finding optimum, from the point of view of the global purpose of system, combinations of variants a component. The hierarchy allows describing RFID system at various levels of abstraction, which is detail of reflexion of elements, properties and characteristics. Higher level differs more aggregation of system descriptions, and more bottom - more detailed elements of the description

At the description of a tree of subsystems most often use the functional approach: the general function of system is divided into the separate minorant functions solving private problems. Allocation of subsystems, thus, is carried out according to they should carry out what function. In other words, what way the subsystem carries out the given function the description of properties, characteristics of these elements and the description of signs and properties of all process is defined by model of a subsystem which includes the separate elements participating in process.

As root of a tree of subsystems the system of higher order, than the considered subsystem including also systems of environment, relevant in relation to chosen system can act. The tree is formed at the expense of consecutive decomposition of subsystems on more and more small subsystems. At decomposition each subsystem generates the subtotal. The generating subsystem is as though "parent", and the subsystems making a subtotal, - "affiliated".

Thus, it is possible to present hierarchical model of RFID system, as set of models of the subtotals connected by the treelike relation. Formation of any subtotal can be carried out by means of decomposition operation. The example of decomposition for RFID system is resulted on Fig. 1.


Fig. 1. Hierarchical representation of RFID system
It is obvious, that 1 basic components of RFID system presented on fig., in turn, by decomposition are represented by elements of hierarchy of lower level. For example, the transceiver divides on the receiver and the transmitter, etc.

RFID system consideration on any of hierarchy levels assumes not only allocation of subsystems, but also interrelations between them. For example, subsystems can be compatible among themselves or incompatible. Therefore besides models of subsystems in hierarchical model it is necessary to include model of interrelations, for example, in the form of compatibility model. As at transition from top levels to bottom the quantity of subsystems grows, so, the number of interrelations between subsystems grows also, consideration of all communications between all subsystems strongly complicates model. To avoid excessive complexity it is often expedient to consider only interrelations of subsystems of one subtotal. To each subtotal we will compare one or several models of relations of affiliated subsystems. Thus, the subtotal model includes set of models of affiliated subsystems and model of relations of subsystems.

## III. FORMATION AND CHOICE OF THE BEST VARIANTS OF RFID SYSTEMS

Formation of alternative variants of RFID systems when their decomposition on components is set, in a considered case is carried out by a method of the morphological analysis [2]. The method of the morphological analysis is characterized by following features: the strict formulation of a problem; revealing of as much as possible full list of the basic functions of system and decomposition on components to a functional sign; definition of various alternative ways of realization of each of a component and all morphological variants of considered system. Each of system variants as a whole consists of a chain containing on one way of realization of each subsystem (components).

Let functional decomposition of RFID system on some final set of subsystems (components) is executed

$$
\left\{A_{j}, j=1,2, \ldots, L, \bigcup_{j=1}^{L} A_{j}=A\right\}
$$

In the assumption that there is some set of alternative ways of realization of each subsystem $\mathrm{A}_{\mathrm{lk}}$, $\mathrm{k}=1,2, \ldots, \mathrm{~K}, \mathrm{l}=1,2, \ldots, \mathrm{~L}$, some morphological table (tab. 1 see) can be set.

| TABLE I. THE MORPHOLOGICAL TABLE |  |  |
| :--- | :---: | :---: |
| System components | Possible methods of <br> realizations of components <br> of system | Number of <br> methods |
| 1. Reader | $\left[\mathrm{A}_{11}\right], \mathrm{A}_{12}, \ldots, \mathrm{~A}_{1 \mathrm{~K}_{1}}$ | $\mathrm{~K}_{1}$ |
| 2. RFID tag | $\mathrm{A}_{21},\left[\mathrm{~A}_{22}\right], \ldots, \mathrm{A}_{2 \mathrm{~K}_{2}}$ | $\mathrm{~K}_{2}$ |
| 3. Antenna reader | $\mathrm{A}_{31}, \mathrm{~A}_{32}, \ldots,\left[\mathrm{~A}_{3 \mathrm{~K}_{3}}\right]$ | $\mathrm{K}_{3}$ |
| 4. Antenna tag | $\left[\mathrm{A}_{41}\right], \mathrm{A}_{42}, \ldots, \mathrm{~A}_{4 \mathrm{~K}_{4}}$ | $\mathrm{~K}_{4}$ |
| 5. The software | $\left[\mathrm{A}_{51}\right], \mathrm{A}_{52}, \ldots, \mathrm{~A}_{5 \mathrm{~K}_{5}}$ | $\mathrm{~K}_{5}$ |

In turn it is possible to present each subsystem of considered system in the form of the morphological table. Morphological tables are an effective remedy of representation of knowledge of RFID system. They allow systematizing enough great volume of knowledge of morphology of RFID systems in a compact kind. Working out of the morphological table gives the chance to formalize process of ordering of set of prisoners in it of alternative variants of systems.

The purposes of the morphological approach at the decision of problems of formation and a choice of a variant of RFID system are:

1) System research of all possible variants of the decision of the problem, following from laws of a structure (morphology) of improved RFID system that allows considering, except known, unusual variants which at simple search could be lost sight the designer.
2) Realization of set of operations of search on morphological set of variants of the description of the functional systems corresponding to initial requirements, i.e. problem conditions.

In morphological tab. 1 by a chain of the connected alternatives in square brackets one of variants of considered system is shown. The general number of the every possible variants $N$ forming morphological set, is defined as the Cartesian product of sets of the alternatives formed in each line of the morphological table:

$$
\begin{equation*}
\mathrm{N}=\prod_{\mathrm{l}=1}^{\mathrm{L}} \mathrm{~K}_{1} \tag{3}
\end{equation*}
$$

In the resulted expression (3) following designations are accepted: $K_{l}$ - number of ways (alternatives) of realization $l$ th functions (components) or the generalized subsystem; $L$ number of all functions. The generated variant of system (subsystem) represents sample of alternatives on one of every line morphological table and in a general view registers as follows:

$$
\begin{equation*}
\mathrm{A}_{\mathrm{i}}=\left\{\mathrm{A}_{1 \mathrm{i}}, \mathrm{~A}_{2 \mathrm{j}}, \ldots, \mathrm{~A}_{\mathrm{Ln}}\right\}, \tag{4}
\end{equation*}
$$

where $\quad i=1,2, \ldots, K_{1} ; \quad j=1,2, \ldots, K_{2}, \quad \ldots$, $\mathrm{n}=1,2, \ldots, \mathrm{~K}_{\mathrm{L}}$.

Rules of generation of variants of investigated systems it is that, that each complete variant differs from any other variant of considered morphological set at least one alternative $\mathrm{A}_{\mathrm{lm}}$. For example, for typical RFID system with RFT on surface acoustic waves (SAW) known ways of realization of components of system define $5 \times 3 \times 5 \times 4 \times 3=900$ various variants of construction of system, i.e. alternatives.

Now in the foreign and domestic markets there is a considerable quantity of various components for construction of RFID systems. Saturation of the market by foreign and domestic element base, the big variety of conditions in which work RFID systems, specificity of the requirements, shown to them, reliability and durability questions, presence of the big number of constructive types complicate a choice of the best variant of these systems for concrete conditions of operation. Besides, in practice such choice very often becomes complicated also because of impossibility to receive trustworthy information about indicators of quality of components, for example, or because of unwillingness of manufacturers to estimate production on offered indicators of quality, or because of concealment or deliberate distortion of real indicators for the purpose of deception of competitors. Therefore in a considered case a multicriterion choice problem (MC) RFID system variant to have to solve in the conditions of uncertainty.

## IV. CHOICE OF RFID SYSTEM VARIANTS

For the decision of MC problem of variants of RFID systems in [2] the complex of the algorithms constructed on a basis is offered: the modified method of the analysis of hierarchies (MMAH); theories of indistinct sets (IS); the modified method of streamlining of preferences through similarity to the ideal decision (MMSID); estimations of necessary and possible levels of conformity (MENPLS) variants to the set requirements.

The basic features of the specified algorithms are following possibilities: for MMAH algorithm simultaneously to work with quantitative, qualitative and interval criteria; for algorithm on the basis of the IS theory use of the accessible expert information on quality of variants in the form of pair comparisons on Saati scale; for algorithm on the basis of MMSID - a choice of the alternative having the shortest distance to the positive ideal decision (the leader of the market) and the greatest distance to the negative ideal decision (the outsider of the market); for algorithm on the basis of MENPLS - an alternative choice in which decrease in superfluous requirements occurs at the expense of increase of the requirements realized not enough.

The technique of a choice of variants системотехнических decisions of construction of RFID systems consists of following basic steps.

Step 1. A substantiation of the list of technical and economic requirements shown to RFID system by the customer.

Step 2. Allocation of some typical alternative RFID technologies $\mathrm{V}=\left\{\mathrm{V}_{\mathrm{i}}\right\}, \mathrm{i}=1,2, \cdots, \mathrm{r}$ which are applied to construction of modern RFID systems.

Step 3. A choice of possible indicators for comparison purposes technologies.

Step 4. Carrying out of a comparative estimation of RFID technologies and a choice of the best variant MMAH [3].

Step 5. For chosen the best for the given concrete case of a variant of RFID technology sets of alternative components of various firms - manufacturers are defined.

Step 6. We range components of each class in decreasing order of preference on set of their indicators of quality, and then it is deleted the components worst and-or not meeting set requirements in each class of components.

Step 7. We form the morphological table from remained alternative a component.

Step 8. We delete from the morphological table incompatible variants of RFID systems.

Step 9. From all turned out set of variants of RFID systems set $G=\left\{G_{i}\right\}, i=1,2, \ldots, n$ such variants which are capable to provide performance of shown technical and economic requirements is defined.

Step 10. From all set of the indicators characterizing chosen variants of RFID systems, a number of technical and economic indicators $Q=\left\{q_{j}\right\}, j=1,2, \ldots, m$ is defined having paramount value at a choice of the best variant [4, 5].

Step 11. We solve a problem of a choice of a variant from set of admissible alternatives and the best variant [6] is defined.

The offered approach is used at a choice of variants of RFID systems on set of indicators of quality.

Thus, at the initial stage of designing of modern RFID systems there is a problem of a choice of the best variant of their construction. It is difficult enough system problem, the important place at which decision occupies a choice of criteria of efficiency. Such criteria should be clear enough and allow to carry out unequivocal quantitative and the quality standard of a system effectiveness reflecting, on the one hand, degree of performance of problems assigned to it, and with another - financial expenses on creation,
introduction and system development. As such criteria the most important indicators of technical and economic character with which the system should satisfy, as a rule, are used. For various types of RFID systems in connection with their specificity such indicators will be various.

Besides, not all indicators give in to a quantitative estimation.

## V. Conclusion

The offered approaches to a choice of variants of RFID systems on set of indicators of quality and the considered technique of a choice constructed on their basis, allow enough reasonable with attraction of knowledge of the qualified experts to solve at the initial stages of designing a problem of a rational choice of the best variant of these systems.

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## VI. References

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Fig. 1. Magnetization as a function of applied field. Note that "Fig." is abbreviated. There is a period after the figure number, followed by two spaces. It is good practice to explain the significance of the figure in the caption.

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TABLE I
UNITS FOR MAGNETIC PROPERTIES

| Symbol | Quantity | Conversion from Gaussian and CGS EMU to SI ${ }^{\text {a }}$ |
| :---: | :---: | :---: |
| Ф | magnetic flux | $1 \mathrm{Mx} \rightarrow 10^{-8} \mathrm{~Wb}=10^{-8} \mathrm{~V} \cdot \mathrm{~s}$ |
| B | magnetic flux density, magnetic induction | $1 \mathrm{G} \rightarrow 10^{-4} \mathrm{~T}=10^{-4} \mathrm{~Wb} / \mathrm{m}^{2}$ |
| H | magnetic field strength | $1 \mathrm{Oe} \rightarrow 10^{3} /(4 \pi) \mathrm{A} / \mathrm{m}$ |
| $m$ | magnetic moment | $\begin{aligned} & 1 \mathrm{erg} / \mathrm{G}=1 \mathrm{emu} \\ & \quad \rightarrow 10^{-3} \mathrm{~A} \cdot \mathrm{~m}^{2}=10^{-3} \mathrm{~J} / \mathrm{T} \end{aligned}$ |
| M | magnetization | $\begin{aligned} & 1 \mathrm{erg} /\left(\mathrm{G} \cdot \mathrm{~cm}^{3}\right)=1 \mathrm{emu} / \mathrm{cm}^{3} \\ & \rightarrow 10^{3} \mathrm{~A} / \mathrm{m} \end{aligned}$ |
| $4 \pi M$ | magnetization | $1 \mathrm{G} \rightarrow 10^{3} /(4 \pi) \mathrm{A} / \mathrm{m}$ |
| $\sigma$ | specific magnetization | $1 \mathrm{erg} /(\mathrm{G} \cdot \mathrm{g})=1 \mathrm{emu} / \mathrm{g} \rightarrow 1 \mathrm{~A} \cdot \mathrm{~m}^{2} / \mathrm{kg}$ |
| $j$ | magnetic dipole moment | $\begin{aligned} & 1 \mathrm{erg} / \mathrm{G}=1 \mathrm{emu} \\ & \rightarrow 4 \pi \times 10^{-10} \mathrm{~Wb} \cdot \mathrm{~m} \end{aligned}$ |
| $J$ | magnetic polarization | $\begin{aligned} & 1 \mathrm{erg} /\left(\mathrm{G} \cdot \mathrm{~cm}^{3}\right)=1 \mathrm{emu} / \mathrm{cm}^{3} \\ & \rightarrow 4 \pi \times 10^{-4} \mathrm{~T} \end{aligned}$ |
| $\chi$ к к | susceptibility | $1 \rightarrow 4 \pi$ |
| $\chi_{\rho}$ | mass susceptibility | $1 \mathrm{~cm}^{3} / \mathrm{g} \rightarrow 4 \pi \times 10^{-3} \mathrm{~m}^{3} / \mathrm{kg}$ |
| $\mu$ | permeability | $\begin{aligned} & 1 \rightarrow 4 \pi \times 10^{-7} \mathrm{H} / \mathrm{m} \\ & =4 \pi \times 10^{-7} \mathrm{~Wb} /(\mathrm{A} \cdot \mathrm{~m}) \end{aligned}$ |
| $\mu_{\mathrm{r}}$ | relative permeability | $\mu \rightarrow \mu_{\mathrm{r}}$ |
| w, W | energy density | $1 \mathrm{erg} / \mathrm{cm}^{3} \rightarrow 10^{-1} \mathrm{~J} / \mathrm{m}^{3}$ |
| N, D | demagnetizing factor | $1 \rightarrow 1 /(4 \pi)$ |

Vertical lines are optional in tables. Statements that serve as captions for the entire table do not need footnote letters.
${ }^{\text {a }}$ Gaussian units are the same as cgs emu for magnetostatics; $\mathrm{Mx}=$ maxwell, $\mathrm{G}=$ gauss, $\mathrm{Oe}=$ oersted; $\mathrm{Wb}=$ weber, $\mathrm{V}=$ volt, $\mathrm{s}=$ second, $\mathrm{T}=$ tesla, $\mathrm{m}=$ meter, $\mathrm{A}=$ ampere, $\mathrm{J}=$ joule, $\mathrm{kg}=$ kilogram, $\mathrm{H}=$ henry.
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The SI unit for magnetic field strength $H$ is $\mathrm{A} / \mathrm{m}$. However, if you wish to use units of $T$, either refer to magnetic flux density $B$ or magnetic field strength symbolized as $\mu_{0} H$. Use the center dot to separate compound units, e.g., "A•m²."

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Figure axis labels are often a source of confusion. Use words rather than symbols. As an example, write the quantity "Magnetization," or "Magnetization M," not just " $M$." Put units in parentheses. Do not label axes only with units. As in Fig. 1, for example, write "Magnetization (A/m)" or "Magnetization (A $\cdot \mathrm{m}^{-1}$ )," not just "A/m." Do not label axes with a ratio of quantities and units. For example, write "Temperature (K)," not "Temperature/K."

Multipliers can be especially confusing. Write "Magnetization (kA/m)" or "Magnetization ( $10^{3} \mathrm{~A} / \mathrm{m}$ )." Do not write "Magnetization $(\mathrm{A} / \mathrm{m}) \times 1000$ " because the reader would not know whether the top axis label in Fig. 1 meant $16000 \mathrm{~A} / \mathrm{m}$ or $0.016 \mathrm{~A} / \mathrm{m}$. Figure labels should be legible, approximately 8 to 12 point type.

## B. References

Number citations consecutively in square brackets [1]. The sentence punctuation follows the brackets [2]. Multiple references [2], [3] are each numbered with separate brackets [1]-[3]. When citing a section in a book, please give the relevant page numbers [2]. In sentences, refer simply to the reference number, as in [3]. Do not use "Ref. [3]" or "reference [3]" except at the beginning of a sentence: "Reference [3] shows ... ." Please do not use automatic
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$$
\begin{array}{rl}
\int_{0}^{r_{2}} & F(r, \varphi) d r d \varphi=\left[\sigma r_{2} /\left(2 \mu_{0}\right)\right]  \tag{1}\\
& \cdot \int_{0}^{\infty} \exp \left(-\lambda\left|z_{j}-z_{i}\right|\right) \lambda^{-1} J_{1}\left(\lambda r_{2}\right) J_{0}\left(\lambda r_{i}\right) d \lambda .
\end{array}
$$

Be sure that the symbols in your equation have been defined before the equation appears or immediately following. Italicize symbols ( $T$ might refer to temperature,

[^7]but T is the unit tesla). Refer to "(1)," not "Eq. (1)" or "equation (1)," except at the beginning of a sentence: "Equation (1) is ... ."

## E. Other Recommendations

Use one space after periods and colons. Hyphenate complex modifiers: "zero-field-cooled magnetization." Avoid dangling participles, such as, "Using (1), the potential was calculated." [It is not clear who or what used (1).] Write instead, "The potential was calculated by using (1)," or "Using (1), we calculated the potential."

Use a zero before decimal points: " 0.25 ," not ". 25 ." Use " $\mathrm{cm}^{3}$," not "cc." Indicate sample dimensions as " $0.1 \mathrm{~cm} \times$ 0.2 cm ," not " $0.1 \times 0.2 \mathrm{~cm}^{2}$." The abbreviation for "seconds" is "s," not "sec." Do not mix complete spellings and abbreviations of units: use "Wb/m" or "webers per square meter," not "webers $/ \mathrm{m}^{2}$." When expressing a range of values, write "7 to 9 " or " $7-9$," not "7~9."

A parenthetical statement at the end of a sentence is punctuated outside of the closing parenthesis (like this). (A parenthetical sentence is punctuated within the parentheses.) In American English, periods and commas are within quotation marks, like "this period." Other punctuation is "outside"! Avoid contractions; for example, write "do not" instead of "don't." The serial comma is preferred: "A, B, and C" instead of "A, B and C."

If you wish, you may write in the first person singular or plural and use the active voice ("I observed that ..." or "We observed that ..." instead of "It was observed that ..."). Remember to check spelling. If your native language is not English, please get a native English-speaking colleague to carefully proofread your paper.

## VI. Some Common Mistakes

The word "data" is plural, not singular. The subscript for the permeability of vacuum $\mu_{0}$ is zero, not a lowercase letter "o." The term for residual magnetization is "remanence"; the adjective is "remanent"; do not write "remnance" or "remnant." Use the word "micrometer" instead of "micron." A graph within a graph is an "inset," not an "insert." The word "alternatively" is preferred to the word "alternately" (unless you really mean something that alternates). Use the word "whereas" instead of "while" (unless you are referring to simultaneous events). Do not use the word "essentially" to mean "approximately" or "effectively." Do not use the word "issue" as a euphemism for "problem." When compositions are not specified, separate chemical symbols by en-dashes; for example, "NiMn" indicates the intermetallic compound $\mathrm{Ni}_{0.5} \mathrm{Mn}_{0.5}$ whereas " $\mathrm{Ni}-\mathrm{Mn}$ " indicates an alloy of some composition $\mathrm{Ni}_{\mathrm{x}} \mathrm{Mn}_{1-\mathrm{x}}$.

Be aware of the different meanings of the homophones "affect" (usually a verb) and "effect" (usually a noun), "complement" and "compliment," "discreet" and "discrete," "principal" (e.g., "principal investigator") and "principle" (e.g., "principle of measurement"). Do not confuse "imply"
and "infer."
Prefixes such as "non," "sub," "micro," "multi," and "ultra" are not independent words; they should be joined to the words they modify, usually without a hyphen. There is no period after the "et" in the Latin abbreviation "et al." (it is also italicized). The abbreviation "i.e.," means "that is," and the abbreviation "e.g.," means "for example" (these abbreviations are not italicized).

An excellent style manual and source of information for science writers is [9]. A general IEEE style guide and an Information for Authors are both available at http://www.ieee.org/web/publications/authors/transjnl/index.html

## VII. Editorial Policy

Submission of a manuscript is not required for participation in a conference. Do not submit a reworked version of a paper you have submitted or published elsewhere. Do not publish "preliminary" data or results. The submitting author is responsible for obtaining agreement of all coauthors and any consent required from sponsors before submitting a paper. IEEE TRANSACTIONS and Journals strongly discourage courtesy authorship. It is the obligation of the authors to cite relevant prior work.

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## VIII. Publication Principles

The contents of IEEE Transactions and Journals are peer-reviewed and archival. The Transactions publishes scholarly articles of archival value as well as tutorial expositions and critical reviews of classical subjects and topics of current interest.

Authors should consider the following points:

1) Technical papers submitted for publication must advance the state of knowledge and must cite relevant prior work.
2) The length of a submitted paper should be commensurate with the importance, or appropriate to
the complexity, of the work. For example, an obvious extension of previously published work might not be appropriate for publication or might be adequately treated in just a few pages.
3) Authors must convince both peer reviewers and the editors of the scientific and technical merit of a paper; the standards of proof are higher when extraordinary or unexpected results are reported.
4) Because replication is required for scientific progress, papers submitted for publication must provide sufficient information to allow readers to perform similar experiments or calculations and use the reported results. Although not everything need be disclosed, a paper must contain new, useable, and fully described information. For example, a specimen's chemical composition need not be reported if the main purpose of a paper is to introduce a new measurement technique. Authors should expect to be challenged by reviewers if the results are not supported by adequate data and critical details.
5) Papers that describe ongoing work or announce the latest technical achievement, which are suitable for presentation at a professional conference, may not be appropriate for publication in a TrANSACTIONS or Journal.

## IX. Conclusion

A conclusion section is not required. Although a conclusion may review the main points of the paper, do not replicate the abstract as the conclusion. A conclusion might elaborate on the importance of the work or suggest applications and extensions.

## APPENDIX

Appendixes, if needed, appear before the acknowledgment.

## Acknowledgment

The preferred spelling of the word "acknowledgment" in American English is without an "e" after the "g." Use the singular heading even if you have many acknowledgments. Avoid expressions such as "One of us (S.B.A.) would like to thank ... ." Instead, write "F. A. Author thanks ... ." Sponsor and financial support acknowledgments are placed in the unnumbered footnote on the first page, not here.

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