

# Two-Dimensional Correlation as a Search Method of Relationship between Pattern Image and Compromising Emanation

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**Abstract-** In the era of technological advance in development of electronic equipment and its widespread application for everyday use, the issues related to protection of information against electromagnetic penetration become the matters of key importance. Each piece of equipment that is used for processing confidential information may happen to be a source of undesired emissions. However, due to design solutions applied to engineering of such devices, the levels of compromising emission signals are very low. To evaluate vulnerability of such equipment to eavesdropping, it is necessary to apply methods that enable picking up substantial information that is hidden in noise. In particular, it refers to signals that are correlated with signals of graphic transmission tracks of computers since capturing such signals enables reproduction of images that are displayed on the screen of the “eavesdropped” computer. Use of the methods that are suitable for digital processing of images, even modified for needs of successful electromagnetic infiltration, is insufficient to achieve the desirable results. Hence, it is necessary to seek for other more powerful and efficient methods, where the method of two-dimensional correlation between the pattern image and fragments of the images subjected to the analysis seems to be the most promising one, where the images can be reproduced from the compromising emanation with use of the half-tone screening method. For such cases, the correlation factor never reaches the levels that correspond to a strong or even a weak correlation since its values for those fragments of the images under the analysis that comprise signs consistent with signs of the pattern reach the values of about 0.07. Therefore, one has to adopt a certain criterion that makes it possible to classify recognized fragments of images.

The paper outlines the opportunities offered by application of the Zeroing Filter. The approach bases on the analysis of the amplitude value for the pixel that indicates potential position of the pattern image in the image under analysis and comparison of that amplitude against the average amplitude of adjacent pixels. When the differential amplitude exceeds the predefined threshold  $D$  the methods assumes that the location within the analyzed image with the desired sign of the pattern image is detected. The studies with the aim to confirm legitimacy of the assumed method were carried out for real images that had been acquired from signals of compromising emanation recorded for the special unit under test.

**Keywords-** *Electromagnetic Infiltration; Protection of Information; Compromising Emanation*

## I. INTRODUCTION

The paper deals with issues related to electromagnetic protection of confidential information processed by IT equipment, particularly the method for evaluation and classification of hardware means that are used to exchange and display such information. In pace with continuous progress in technologies and design solutions for such equipment the topics covered by this study are getting more and more important. It is also associated with increasing capabilities in detection and measurements of very weak signals. Mechanical typewriters have been substituted with electronic appliances that are commonly used nowadays for keying in and displaying of information. Before such a device is approved for application it must undergo a long-term process of laboratory examination that enables assessment whether it is designed and manufactured in an appropriate manner. Such tests are chiefly focused on possibility and efficiency of the electromagnetic infiltration attack, i.e. whether the device is insensitive to such attempts and the images presented on displays that are safe from being retrieved.

As everybody knows, operation of IT equipment is associated with generation of variable electromagnetic fields with pulsations that are often directly correlated with the processed information. Non-invasive recording of such signals, referred to as signals of compromising emission, makes it possible to reproduce confidential information with no awareness of the information holder. Since such signals are emitted unintentionally and the generating devices are purposefully modified to diminish levels of electromagnetic emission, quality of recorded information is very poor. It means that distinctive features contained in such signals are hardly distinguishable on the background of associated noise and interferences. Eventually, images that are reproduced by means of the half-tone screening method from the original video signal (the graphic path of the computer or a printer) are unclear and graphic components comprised therein are undistinguishable for human eye. Thus, all related analyses must be supported with digital methods that enable detailed analysis of recorded information even in cases when the Signal to Noise Ratio (SNR) is much less than zero. However, the methods for digital processing must be subject to continuous improvements and development.

The objectives for reproduction of graphic information are the following:

- reproduction of the entire image to enable recognition of nearly all graphical components comprised therein,

- finding out that any characteristic component is really included into the reproduced image, which classifies the image for further processing.

The process aimed at reproduction of graphic information benefits from methods for digital processing of images. In particular, the following solutions are applied:

- median filtration [1];
- superposition of images [1];
- conversions that enable detection of edges [1];
- thresholding of amplitudes for image pixels [1];
- histogram smoothing;
- histogram extension.

Each of the foregoing methods needs some modification of the operational algorithm to make it really efficient for very specific cases associated with signals of compromising emission. Moreover, signals suitable for processing must be free of overburdening noise and interferences and their distinctive features must enable reproduction of at least general contours, typical for graphic components sought.

Unfortunately, the electromagnetic environment in the surrounding space is affected by so much additional sources of disturbances that processing of signals recorded for compromising emission is getting inefficient for the great number of cases. The interferences are generated by components of printers (motors, heaters, sensors of all types, cooling systems) and desktop computers (signals of horizontal or vertical deflection in displays, a computer mouse).

When to seek for an efficient method for equipment that is used by organizations that are entrusted to process confidential information and when the aforementioned methods prove fruitless one can consider the analysis based on the two-dimensional correlation. Such an analysis needs no attempts to improve quality of the recorded images but the focus is placed on the analyses that are aimed at determination how much the fragments of reproduces images (signals) are similar (correlated) with the standard pattern. Searching for an already predefined graphic component (text) included in the specific image not always lead to reproduction of information. However, the method enables determination that a certain characteristic component (e.g. "TOP SECRET") is really comprised in the image and detection of that component may be the first phase of the information reproduction process since only the selected images can be then pre-classified for further digital processing that can be very time consuming but may end up with extraction of a great volume of desired information. However, such a method is impaired by some constraints, since infiltration is only possible when an appropriate standard pattern is available, but that constraint is not a problem under laboratory conditions. In such a case the pattern image is compared against subsequent fragments of the reproduced image. Finally, the maximum peak of the correlation coefficient is sought since such peaks may indicate locations where the pattern is comprised in the reproduced image. One has to be aware that similarity of e.g. two images is considered as detectable when the correlation coefficient reaches the level of 0.2 or more. In such a case only so called weak interrelationship is manifested and any less values of the mentioned parameter indicate that no correlation exists between the fragments under analysis.

Due to very poor quality of signals recorded for compromising emission the commonly acceptable threshold of the correlation coefficient  $R$  (0.2) that usually indicates similarity between the pattern image and the fragment of reproduced image proves impractical. The study demonstrates that  $R$  parameter for the processes that are typical for electromagnetic infiltration is at the magnitude of 0.07 and even such low value may serve as the proof of correlation between individual signs. However, due to such low value of the correlation coefficient it is mandatory to fulfill an additional condition that shall finally classify the location indicated by the  $R$  parameter as exactly the one where the desired sign corresponding to the predefined pattern really exists. If the additional criterion is not met the decision can be made that there is no correlation between the pattern images and the reproduced fragments of the image recorded.

As for needs of this paper, the additional criterion that must be fulfilled to certify the correct decision is proposed as the outcome from the zeroing filter procedure. The idea of the zeroing filter ( $ZF$ ) consists in analysis of the signal amplitude for the pixel that indicates possible location of the pattern image and comparison of that amplitude against the average amplitudes for pixels within the vicinity. When the differential amplitude exceeds the predefined threshold  $D$  the assumption is made that a desired pattern sign really exists at the certain location of the image under analysis. The study reveals the outcome from analyses that were carried out for real images obtained from signals of compromising emission emitted by a special device and that outcome confirmed adequacy of the proposed method. Results from operation of the zeroing filter can be depicted on graphs, which have also been done in the presented paper, where numbers of rows (lines) and columns of the images under analysis unambiguously indicate locations of the desired sign. The presented method is really efficient and can be considered as an alternative to other solutions that let down frequently and fail to support the correct decision.

II. APPLICATION OPPORTUNITIES

A. Theoretical Grounds

The cross correlation is one of the parameters that indicate similarity, e.g. between one and another signal waveform, even with mutual displacement of these waveforms, e.g. down the time axis. Such correlation is referred to as a one-dimensional one. However, seeking for and identification of graphic signs within images is only possible with use of two-dimensional correlation that is capable of determining the similarity degree between the pattern image and fragments of the image under analysis with taking account that the image under analysis can be translated down rows and columns of the image matrix.

$$R_{j,i} = \frac{\sum_{j=0}^{N_a-N_w+1} \sum_{i=0}^{M_a-M_w+1} \sum_{n=j}^{N_w+j} \sum_{m=i}^{M_w+i} (x_{n,m} - \bar{x}_{j,i}) \cdot (y_{n,m} - \bar{y})}{\sqrt{\sum_{j=0}^{N_a-N_w+1} \sum_{i=0}^{M_a-M_w+1} \sum_{n=j}^{N_w+j} \sum_{m=i}^{M_w+i} (x_{n,m} - \bar{x}_{j,i})^2 \cdot \sum_{n=0}^{N_w-1} \sum_{m=0}^{M_w-1} (y_{n,m} - \bar{y})^2}} \tag{1}$$

$$\bar{x}_{j,i} = \frac{1}{N_w \cdot M_w} \sum_{j=0}^{N_a-N_w+1} \sum_{i=0}^{M_a-M_w+1} \sum_{n=j}^{N_w+j} \sum_{m=i}^{M_w+i} x_{n,m} \tag{2}$$

$$\bar{y} = \frac{1}{N_w \cdot M_w} \sum_{n=0}^{N_w-1} \sum_{m=0}^{M_w-1} y_{n,m} \tag{3}$$

where

- $x_{n,m}$ – pixel amplitude within the image under analysis;
- $y_{n,m}$ – pixel amplitude within the pattern image;
- $M_a$ – number of columns for the image under analysis;
- $N_a$ – number of rows for the image under analysis;
- $M_w$ – number of columns for the pattern image;
- $N_w$ – number of rows for the pattern image;
- $i$ – current column number for the image under analysis;
- $m$ – current column number for the pattern image;
- $j$ – current row number for the image under analysis;
- $n$ – current row number for the pattern image.

For the cross-correlation factor  $R$  defined in the foregoing manner one has to carry out a series of computations for  $(M_a - M_w) \cdot (N_a - N_w)$  fragments of the image under analysis, where each fragment shall correspond to the  $M_w \cdot N_w$  size of the standard pattrer as shown in Fig. 1.

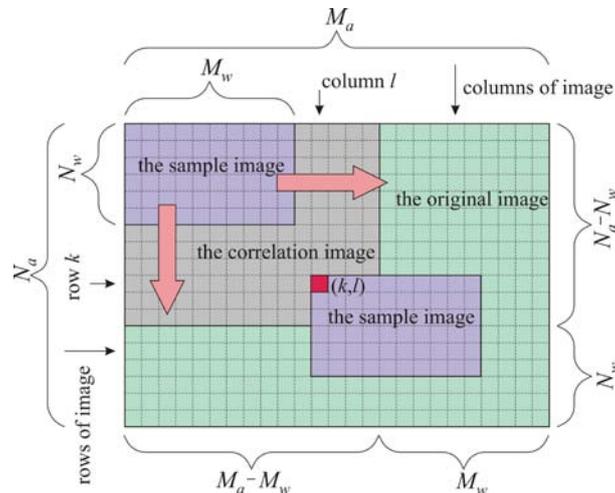


Fig. 1 The method for calculation of cross-correlation between a pattern image and fragments of the image under analysis

Upon conversion of the correlation factors  $R$  according to the formula:

$$Z_{j,i} = 255 \cdot \frac{R_{j,i} - \min_a}{\max_a - \min_a} \tag{4}$$

where

$$0 \leq j \leq N_a - N_w - 1;$$

$$0 \leq i \leq M_a - M_w - 1;$$

$\min_a$ – the minimum for the correlation factor  $R$ ;

$\max_a$ – the maximum for the correlation factor  $R$ ;

It is possible to obtain correlation image  $Z$  for the pattern image and the image under analysis, where the  $Z$  image contains full palette of colours and grey shades, which enable visual analysis of individual image fragments. The brightest points of that image indicate possible location of the graphic sign that corresponds to the pattern image with the relevant probability of  $R$ .

Let the matrix of pixels:

$$[N_w \times M_w] = \begin{bmatrix} 0,0 & 0,1 & \dots & 0, M_w - 1 \\ 1,0 & 1,1 & \dots & 1, M_w - 1 \\ \vdots & \vdots & & \vdots \\ N_w - 1,0 & N_w - 1,1 & \dots & N_w - 1, M_w - 1 \end{bmatrix}, \tag{5}$$

stands for the pattern image, while for the correlation image  $Z$ :

$$Z = \begin{bmatrix} 0,0 & 0,1 & \dots & 0,l & \dots & 0, M_a - M_w \\ 1,0 & 1,1 & \dots & 1,l & \dots & 1, M_a - M_w \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ k,0 & k,1 & \dots & k,l & \dots & k, M_a - M_w \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ N_a - N_w,0 & N_a - N_w,1 & \dots & N_a - N_w,l & \dots & N_a - N_w, M_a - M_w \end{bmatrix}, \tag{6}$$

exists one bright point with coordinates  $(k,l)$  and that point is distinguishable on the background of the adjacent area. If so, the number of the first row and the first column of the pattern image that indicate location of the graphic sign detected in the image under analysis (Fig. 1) adopts the coordinate values  $(k,l)$ :

$$[N_w \times M_w] = \begin{bmatrix} k,l & k,l+1 & \dots & k, M_w - 1 + l \\ k+1,l & k+1,l+1 & \dots & k+1, M_w - 1 + l \\ \vdots & \vdots & & \vdots \\ N_w - 1 + k,l & N_w - 1 + k,l+1 & \dots & N_w - 1 + k, M_w - 1 + l \end{bmatrix}, \tag{7}$$

Therefore, superposition of the pattern image and the primary (original) images makes it possible to find out location of the sought graphic sign, which is the pattern image.

**B. Analysis of Actual Signals for Compromising Emanation**

The related calculations and the analysis of the opportunity to apply the two-dimensional correlation  $R$  to the process of electromagnetic infiltration were carried out for real images achieved from signals of compromising emanation correlated with the video signals corresponding to operation of a computer display in the mode 800 x 600 x 60 Hz as shown in Fig. 2.

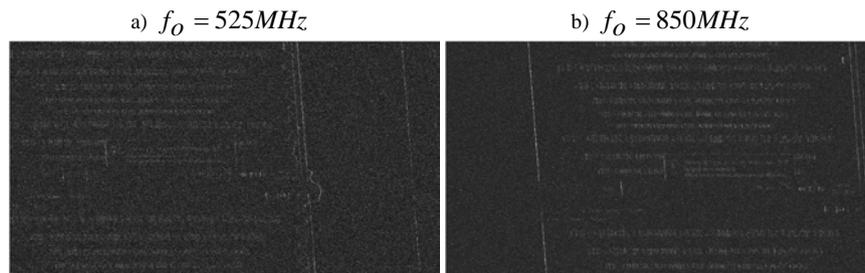


Fig. 2 Images acquired from signals of radiations emitted by a computer display, measured at two different frequencies of reception and then subjected to the analysis

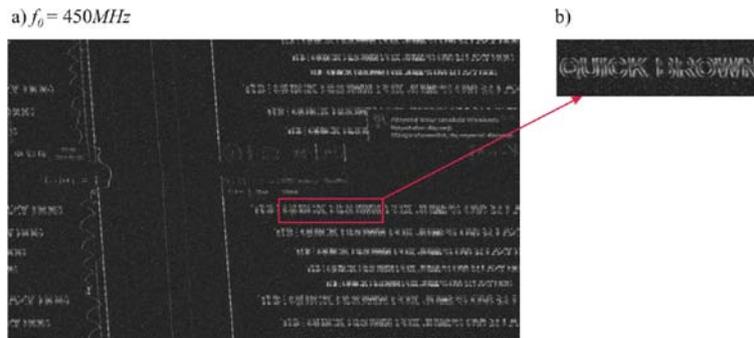


Fig. 3 Pattern image a) and its fragment b) used as a pattern to seek for corresponding graphic components in primary (original) images

The *b)* fragment of the *a)* image shown in Fig. 3 has been adopted as the pattern and presence of that pattern was subsequently sought for in all aforementioned images. It is the image that had been recorded from the signal of compromising emanation dissipated by a computer display without any means that would make it secured against electromagnetic infiltration. The quality of the recorded image was relatively good as for electromagnetic infiltration and subsequent application of two-dimensional correlation enabled extraction of a fragment that had been already adopted as a pattern. When images of the pattern are reproduced one has to remember that only such images can be considered as replicas of the pattern that demonstrate features of the original signal after passing through the Channel of Information Penetration. When primary signals are used for that purpose, i.e. video signals measured directly in the graphic path of the computer the recorded replicas of the pattern have distinctive properties that are not in line with those of the compromising signals.

TABLE 1 THE MAXIMUM CORRELATION FACTORS CALCULATED FOR PRIMARY IMAGES FROM FIG. 2 AND THE PATTERN IMAGES OF FIG. 3B BY MEANS OF THE (1) RELATIONSHIP

No.	Figure number	Maximum value of the correlation factors <i>R</i>
1	Fig. 2a	0.21121355891
2	Fig. 2b	0.29502096772

Fig. 4 and Fig. 5 present correlation images *Z* obtained with use of the relationship (1) for calculation of correlation factors. The analysis of each image make it possible to reveal points of more intense brightness than the adjacent vicinity and these points are visible on the background of various *Z* values presented as a wide spectrum of grey shades. These points indicate locations associated with higher values of the correlation factors as shown in Table 1, hence these are locations where the sought graphic pattern occurs as a pattern image as shown in Fig. 3b. The correlation levels exceeding 0.2 directly indicate that at least weak interrelationship exists between fragments of the image under analysis and the pattern image.

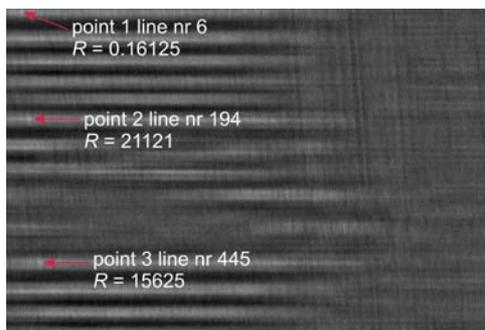


Fig. 4 The correlation image *Z* for the signal of compromising emanation measured at the frequency of  $f_0=525\text{ MHz}$  along with locations where the sought graphic components (pattern image) occurs in the image under analysis

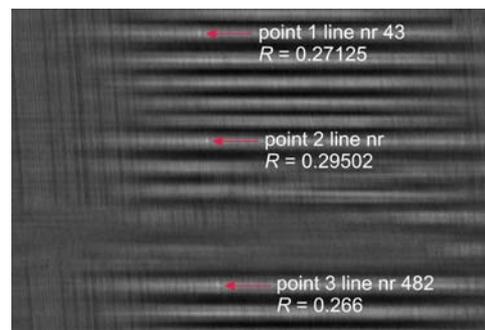
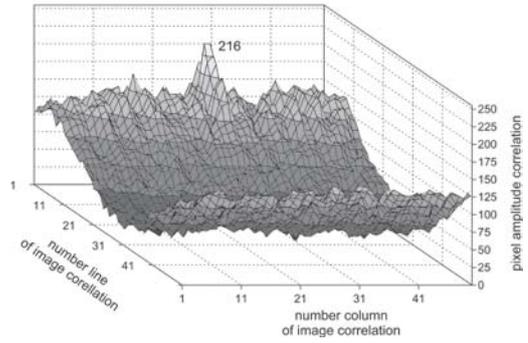
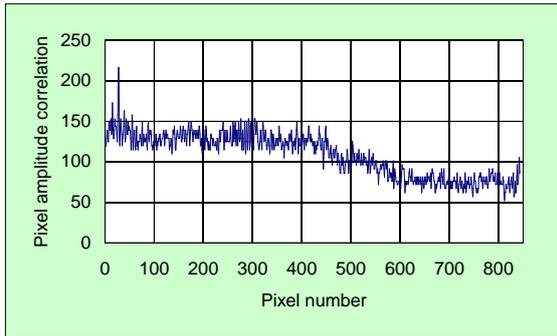


Fig. 5 The correlation image *Z* for the signal of compromising emanation measured at the frequency of  $f_0=850\text{ MHz}$  along with locations where the sought graphic components (pattern image) occurs in the image under analysis

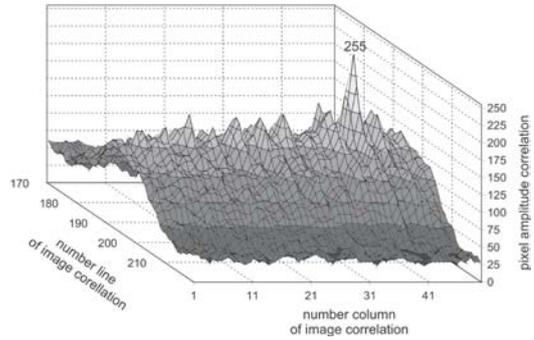
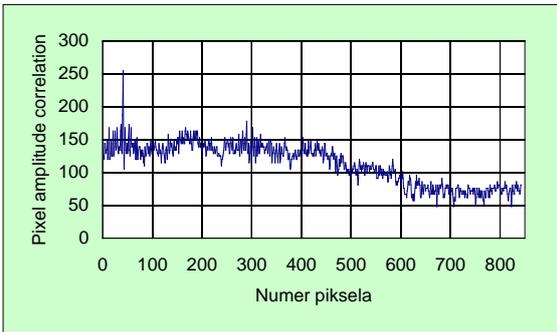
Each of the pictures in Fig. 4 and 5 comprises three characteristic points that provide information about possible occurrence of a sought graphic component. The detailed analysis of them as well as the correlation levels indicate clear peak of the pixel amplitude for the correlation image *Z* as well as the correlation factor itself. The above is shown in Fig. 6 below.

a)  $f_o = 525MHz$

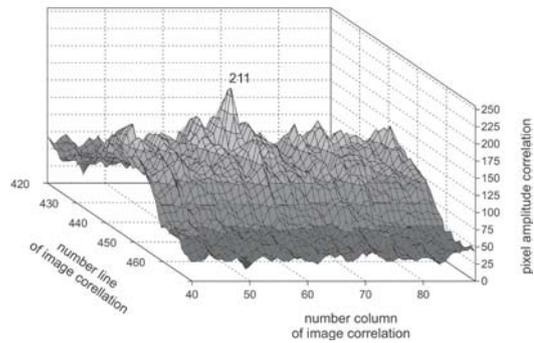
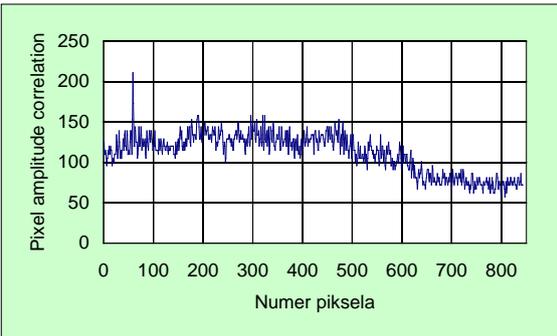
line number: 6



line number: 194

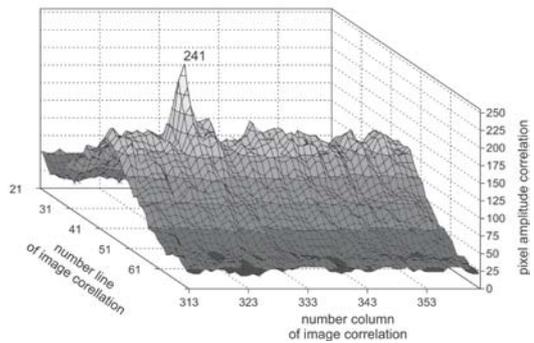
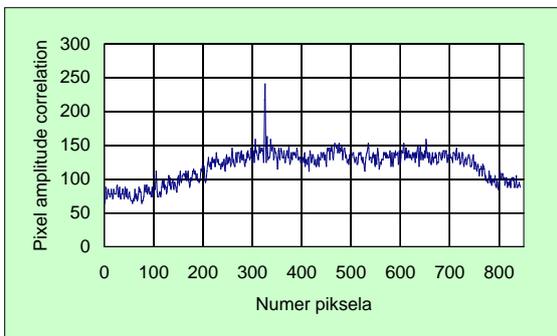


line number: 445

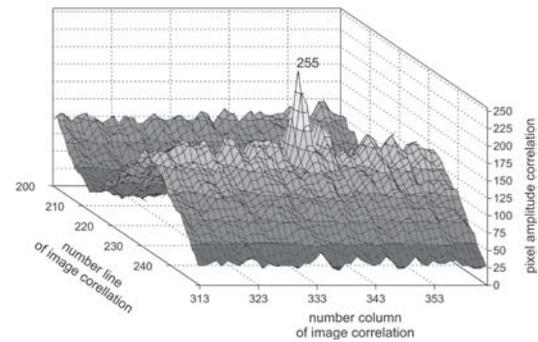
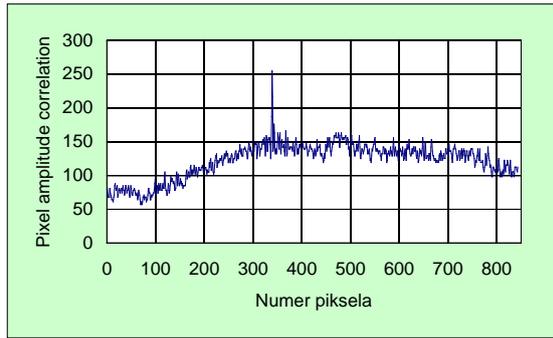


b)  $f_o = 850MHz$

line number: 43



line number: 231



line number: 482

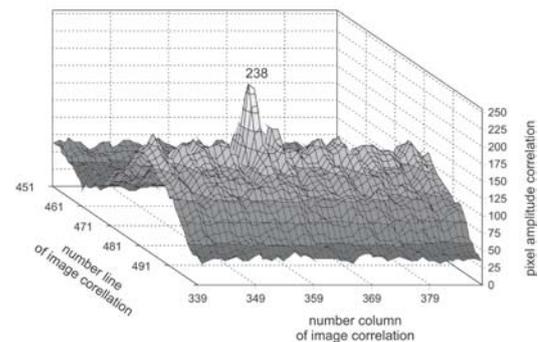
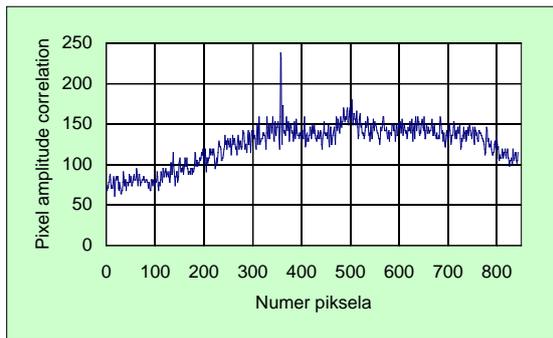


Fig. 6 Rows of correlation images with maximum values for pixel amplitudes (the maximum peaks of the correlation factor  $R$ )

### III. SIGNAL TO NOISE RATIO AGAINST THE TWO-DIMENSIONAL CORRELATION FOR THE ELECTROMAGNETIC INFILTRATION PROCESS

The foregoing considerations referred merely to the cases where possible occurrence of pixels with amplitudes exceeding the background levels could be detected by visual observation. It is expected that such pixels represent data that are correlated with the information depicted on the computer display that is the source of compromising emanation. Although direct readouts of such data was impossible due to interference signals and noise but the method of two-dimensional correlation could be successfully applied to find out locations where the desired graphic signs could potentially occur. The values achieved for these points for the correlation factor  $R$  oscillate around 0.2, which demonstrates correlation between these two images. However, the final decision whether or not the sought component is present in the analysed image can be burdened by a certain error and that decision may be incorrect. It is why further questions appear: how much the two-dimensional correlation is useful for analysis of images with high noise level (e.g. when the compromising information is acquired from a significant distance from the emission source) and for which boundary limits of the SNR the method of two-dimensional correlation can be really efficient.

The presence of noise in the image under analysis along with other disturbing factors leads to much less levels of two-dimensional correlation factor calculated for such circumstances. Numerous correlation images no longer contain clear bright points that distinguish them from the adjacent background. In such cases, the mere visual analysis is insufficient and use of computer-aided methods is necessary to support the decision-making process. Therefore, the analysis was carried out dedicated to application of a criterion that makes it possible to take unambiguous decisions about presence of sought components in primary images. For that purposes it was assumed that the SNR is defined by the following relationship:

$$SNR_{[dB]}_{j,i} = 10 \log_{10} \frac{P_s}{P_{sz_{j,i}}} \tag{8}$$

where:

$$P_s = \sum_{n=0}^{N_w-1} \sum_{m=0}^{M_w-1} (y_{n,m})^2, \tag{9}$$

$$P_{sz_{j,i}} = \sum_{j=0}^{N_a-N_w+1} \sum_{i=0}^{M_a-M_w-1} \sum_{n=j}^{N_w+j} \sum_{m=i}^{M_w+i} (x_{n,m})^2, \tag{10}$$

For our case the signal is understood as the pattern image, whilst the noise is represented by those fragments of the image under analysis that correspond to sizes of the pattern image. For the SNR defined in the foregoing way its values for individual correlation points from Fig. 4 and 5 are summarized in Table 2. The visual analysis of primary images (Fig. 2a and Fig. 2b) for which the two-dimensional correlation factors were calculated make it possible to state that these images comprise some, maybe sought, graphic signs that resemble the pattern image.

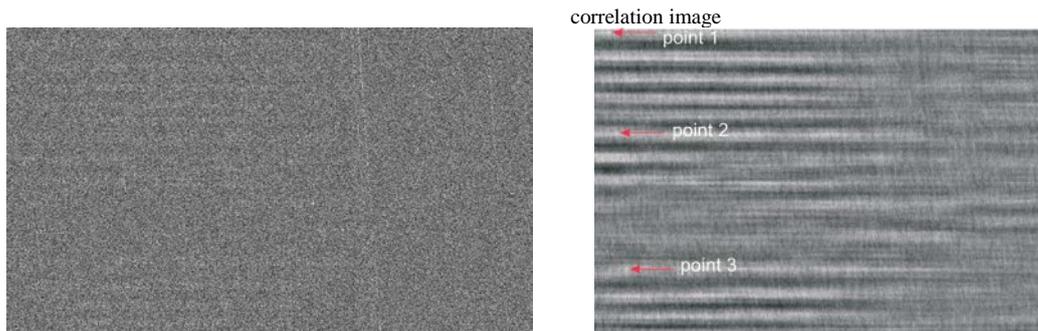
TABLE 2 VALUES OF SNR FOR INDIVIDUAL POINTS OF CORRELATION IMAGES

Figure number	Point number	R value	SNR [dB]
Fig. 4	point 1	0.165218	0.756495
	point 2	0.211214	0.741570
	point 3	0.157720	0.857778
Fig. 5	point 1	0.274072	0.786089
	point 2	0.295021	0.810788
	point 3	0.270380	0.759281

Now let us have a look at Fig. 7. It presents images that comprise similar graphic signs as images from Fig. 2. However, the images are noisy and the visual method is insufficient to unambiguously state whether or not the sought graphic signs are present in these images.

Further steps of deliberations shall be dedicated to verify how much the two-dimensional correlation is efficient for the process of seeking for desired graphic signs when the SNR is less than 0. The pattern image for these considerations is shown in Fig. 3b.

a)  $f_o = 525MHz$



b)  $f_o = 850MHz$

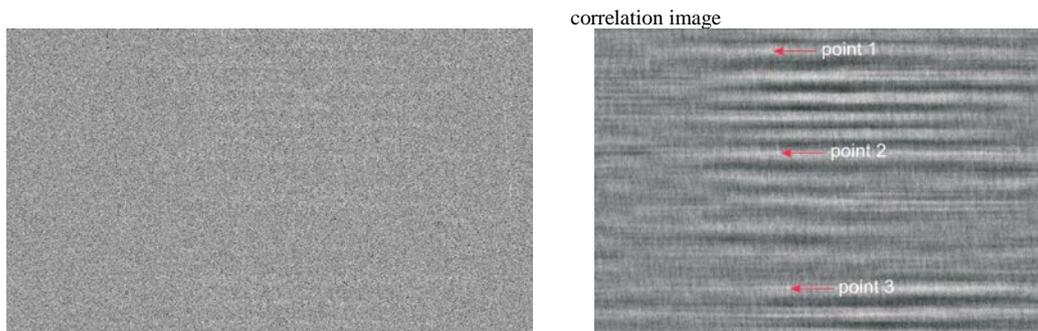


Fig. 7 Investigated images acquired from signals of emitted radiation measured at three different frequencies of reception

TABLE 3 THE R AND SNR PARAMETERS FOR INDIVIDUAL POINTS OF THE CORRELATION IMAGES AND THE IMAGE UNDER ANALYSIS

Figure number	Point number	R value	SNR [dB]
Fig. 7a	point 1 (row 6)	0.075750	-7.25614
	point 2 (row 193)	0.075981	-7.27844
	point 3 (row 445)	0.069104	-7.27597
Fig. 7b	point 1 (row 43)	0.065170	-9.41527
	point 2 (row 231)	0.073215	-9.46181
	point 3 (row 482)	0.062833	-9.48117

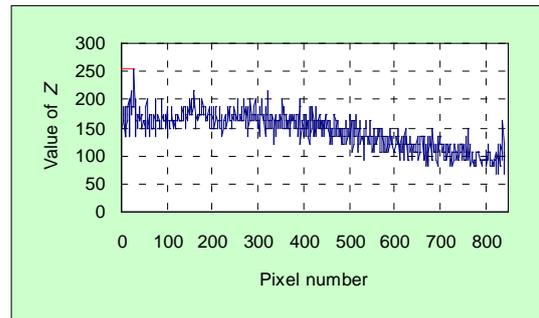
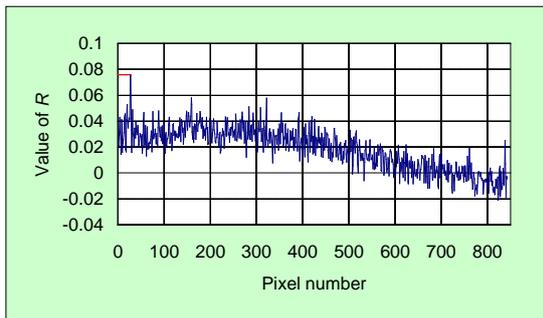
The factors of two-dimensional correlation  $R$  for the SNR ranging from about -7.0 to -9.0 dB are really low and never exceed the value of 0.1 as shown in Table 3. It means that for images with considerable noise level it proves impossible to find out locations where the desired graphic signs are present in the primary image (the  $R < 0.1$  clearly indicates that no correlation exists between the images). The visual analysis is also incapable of providing results that would justify any decision whether the desired graphic signs are present or not in the specific image.

For such cases it is mandatory to analyse variability of the correlation factors  $R$  or amplitudes of pixels for individual lines (rows) of the correlation image. Such an analysis enables clear identification of coordinates for the image pixel that corresponds to the location where the sought graphic sign occurs. It is possible by tracking the  $R$  waveform for a sudden peak of amplitude, substantially exceeding the amplitude at preceding and subsequent points of the waveform. It is the point that shall be identified as the location where the desired data occur.

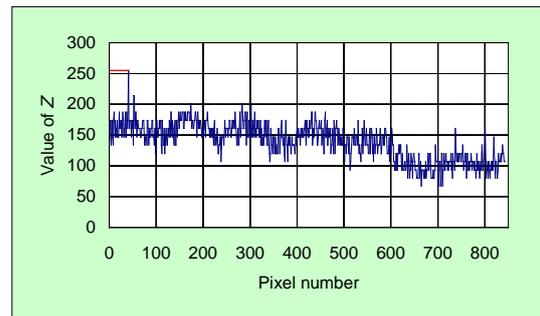
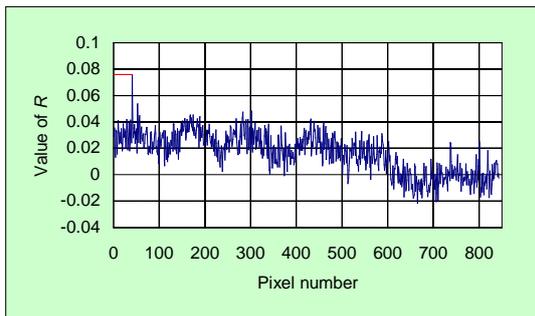
The Fig. 8 below presents waveforms for correlation factors  $R$  and pixel amplitudes  $Z$  for specific lines (rows) of images.

a)  $f_o = 525\text{MHz}$

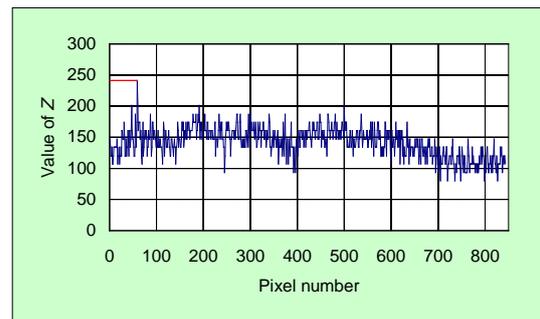
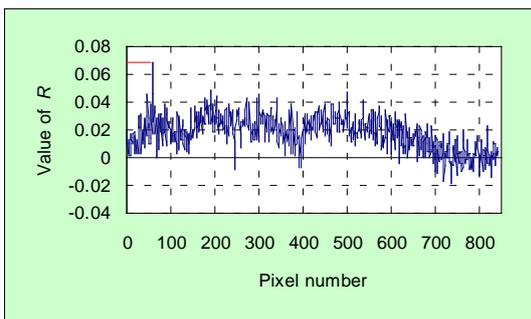
line number 6



line number 193

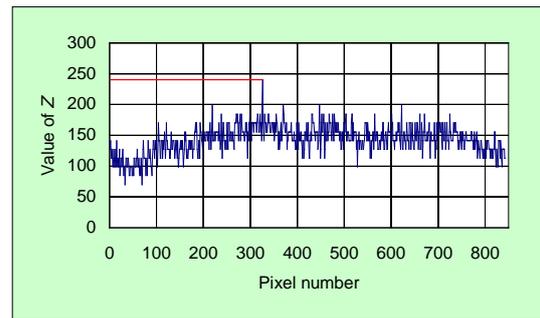
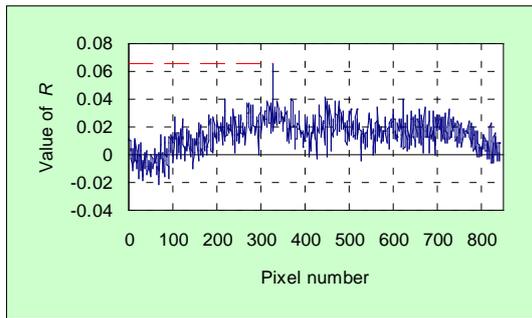


line number 445

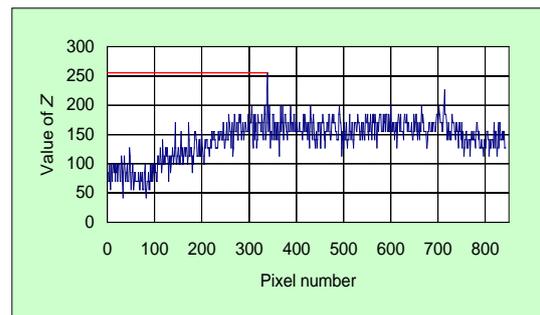
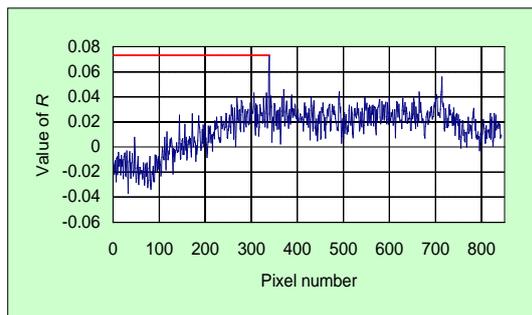


b)  $f_o = 850\text{MHz}$ 

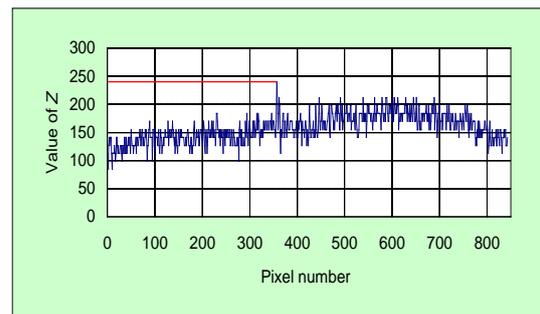
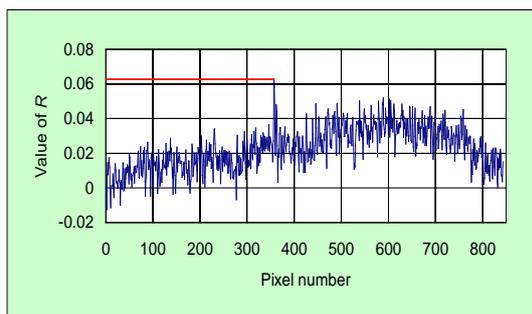
line number 43



line number 231



line number 482

Fig. 8 Waveforms for correlation factors  $R$  and pixel amplitudes  $Z$  for selected lines (rows) of correlation images

The analysis of waveforms for amplitudes of pixels that make up the correlation images or the correlation factors themselves makes it possible to find out that the values for the  $R$  parameter are really low when the SNR is less than 0. Nevertheless, jumps of numerical values of  $R$  as so significant as compared to the adjacent vicinity that detection of the desired sign is really probable. However, the decision is still partly associated with the visual analysis. To facilitate the decision-making process it is necessary to adopt a criterion that shall support that process.

#### IV. CRITERION FOR CORRECT EVALUATION

To find out whether it is possible to state that a fragment of the image under analysis is similar to a certain pattern one has to adopt a relevant measure of probability. For the cases covered by this study such a measure is assumed as the factor of two-dimensional correlation. The two-dimensional feature is associated with possible displacement of the pattern on the image under analysis down both rows and columns of that image. However, former studies demonstrated that adoption of a single threshold value for the correlation factor  $R$  is impossible due to various qualities of reproduced images subjected to the analysis. For some images the value  $R > 0.08$  is sufficient, for other ones such a value indicates that the desired pattern occurs on the entire area of the primary image.

Therefore the first classification criterion is the correlation image  $Z$  that is drawn up on the basis of correlation factors  $R$  calculated for the pattern. Then one has to find out points with the brightness that substantially exceeds the adjacent background. Such points appear when for specific fragments of the image under analysis the correlation factor reaches the considerably higher value than for other fragments. If such points are detected, the second phase commences that consists in checking the  $D$  criterion that is based on the *Zeroing Filter* ( $ZF$ ).

The idea of the  $ZF$  consists in calculation of averages  $G$  for amplitudes of pixels within a defined vicinity of the central pixel under analysis and determination of the differential between the amplitude of the central pixel and the calculated average  $G$ . The pixel vicinity is assumed as a window with the dimensions  $[b \times b]$ . Such a calculation is carried out for each point of the primary image according to the relationship below, however the amplitude for the central pixel is excluded from calculations.

a) *without duplication of boundary columns and rows*

$$G'_{j+\frac{b-1}{2}, i+\frac{b-1}{2}} = \frac{Z_N^{-b} \sum_{j=0}^{Z_N-b} Z_M^{-b} \sum_{i=0}^{Z_M-b} \left( \left( \sum_{n=j}^{b+j-1} \sum_{m=i}^{b+i-1} z_{n,m} \right)^{-z_{j+\frac{b-1}{2}, i+\frac{b-1}{2}}} \right)}{b^2 - 1} \quad (11a)$$

b) *for duplicated boundary columns and rows*

$$G''_{j+\frac{b-1}{2}, i+\frac{b-1}{2}} = \frac{Z_N^{-\frac{b+3}{2}} \sum_{j=0}^{Z_N-\frac{b+3}{2}} Z_M^{-\frac{b+3}{2}} \sum_{i=0}^{Z_M-\frac{b+3}{2}} \left( \left( \sum_{n=j}^{b+j-1} \sum_{m=i}^{b+i-1} z_{n,m} \right)^{-z_{\frac{b-1}{2}+j, \frac{b-1}{2}+i}} \right)}{b^2 - 1} \quad (11b)$$

where:

$G'$ ,  $G''$  – average for amplitudes of pixels that make up the correlation image, calculated for the window of zeroing filter except for the amplitude of the central pixel;

$Z_N$  – number of rows within the correlation image  $Z$ ;

$Z_M$  – number of columns within the correlation image  $Z$ ;

$Z$  – amplitude of a single pixel within the correlation image;

$B$  – window dimensions for the zeroing filter.

When the calculated differential is less than the assumed threshold  $D$  the amplitude of the central pixel is zeroed ((12a) or (12b)). Otherwise, it remains unaltered. Such a filtering process unambiguously indicates locations of the primary image where the desired graphic sign (pattern) may occur.

$$ZF_{j,i} = \begin{cases} z_{j,i} - G'_{j,i} & \text{dla } (z_{j,i} - G'_{j,i}) \geq D \\ 0 & \text{dla } (z_{j,i} - G'_{j,i}) < D \end{cases}, \quad (12a)$$

or

$$FZ_{j,i} = \begin{cases} z_{j,i} - G''_{j,i} & \text{dla } (z_{j,i} - G''_{j,i}) \geq D \\ 0 & \text{dla } (z_{j,i} - G''_{j,i}) < D \end{cases}, \quad (12b)$$

where

$FZ$  – amplitude of a pixel within the correlation image  $Z$  after processing by means of the zeroing filter.

However, the problem remains how to find out the appropriate threshold of  $D$  and the window size of  $b$  for the vicinity of the pixel in question. The  $b$  dimension unambiguously defines the number of pixels that shall be taken into account for calculation of the average amplitude (without the central pixel). In turn, the  $D$  threshold shall determine the corresponding classification of the central pixel. On one hand too high value of  $D$  may lead to the situation that the point with indication for occurrence of the desired graphic component shall be omitted. On the other hand, insufficient threshold of  $D$  entails the possibility of false decision with regard to occurrence of the desired pattern within the image under analysis.

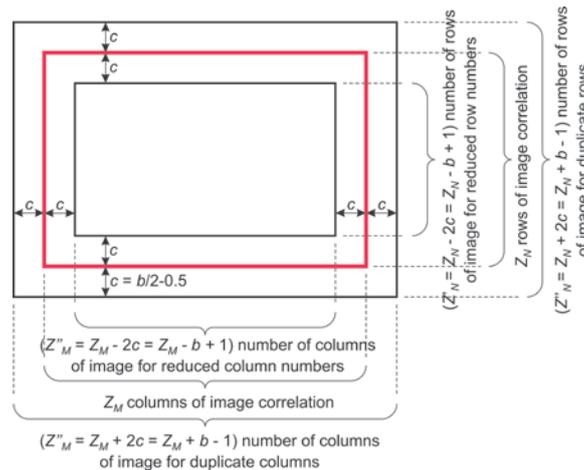


Fig. 9 Dimensions of the correlation image for the correct analysis with use of the zeroing filter

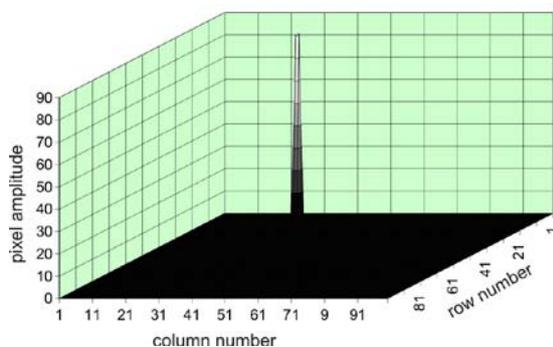
Let the window size for the zeroing filter (ZF) is  $b \times b$  and let  $b$  is a natural odd number and  $b > 1$ . The assumption that  $b$  is odd guarantees that the central pixel is located exactly in the centre of the assumed square window. But let us pay attention to the fact that the need to perform the analysis for all pixels of the correlation image  $Z$  entails the problem with the analysis of boundary pixels. If so, the correct analysis is possible when any of the following two solutions is adopted as shown in Fig. 9:

- boundary rows and columns of the correlation image must be expanded by the number  $(\frac{b}{2} - 0.5)$  at each side, which increases the size of the correlation image by  $(b - 1)$  rows and columns;
- leave the size of the correlation image unaltered but carry out the algorithm for  $(Z_N - b + 1)$  rows and  $(Z_M - b + 1)$  columns, i.e. the calculations for the central pixel shall start from the row (column) with the index  $(\frac{b}{2} - 0.5)$  and end (for the central pixel) at the row (column) with the index  $(Z_N - \frac{b}{2} - 0.5)$  provided that the first row and the first column of the correlation image are indexed from '0'.

The optimum values for  $D$  and  $b$  were found out on after a series of analysis carried out a many images acquired from compromising emanation. The results of analyses have demonstrated that correct detection of patterns hidden in investigated images is possible when the values  $D = 73$  and  $b = 9$  are adopted. Improper alteration of the  $D$  and  $b$  parameters may lead to wrong decisions. For instance, expansion of the window size by 2, i.e. to  $b = 11$ , with unaltered threshold of  $D$  leads to detection of false points in the correlation image upon application of the zeroing filter, which misinforms that the desired data are found. The similar situation is when the threshold limit  $D$  is decreased by 1. On the contrary, when the  $D$  parameter is increased some information essential for the electromagnetic infiltration process can be omitted or ignored. The same happens when the size of the window for the analysis is squeezed.

Examples of calculation results for the  $D$  and  $b$  parameters assumed as above are depicted in the Figs. 10 and 11 below.

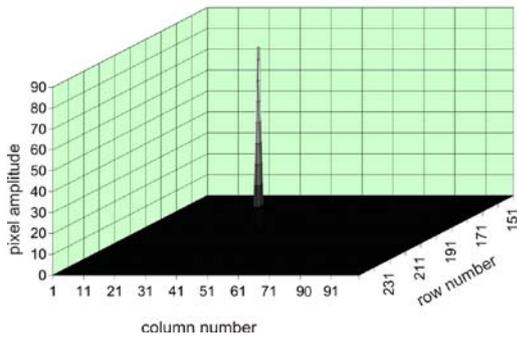
a)



pixel parameters:

number of the row that corresponds to the row number for the investigated image: 6  
 number of the column that corresponds to the column number for the investigated image: 28  
 differential of  $G'$ : 81.0125

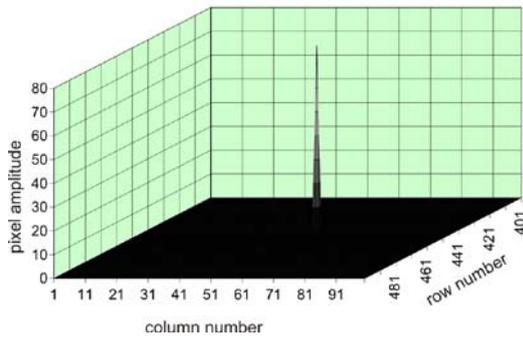
b)



pixel parameters:

number of the row that corresponds to the row number for the investigated image: 193  
 number of the column that corresponds to the column number for the investigated image: 41  
 differential of  $G'$ : 86.3250

c)

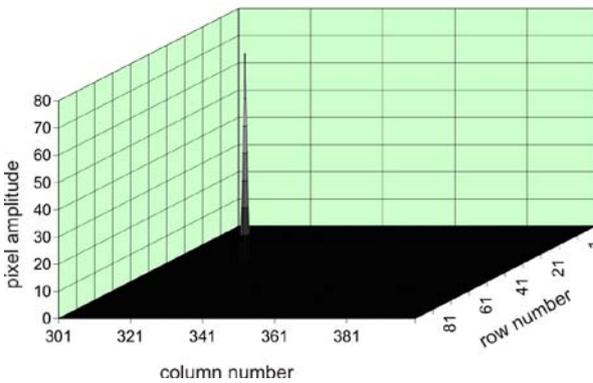


pixel parameters:

number of the row that corresponds to the row number for the investigated image: 445  
 number of the column that corresponds to the column number for the investigated image: 59  
 differential of  $G'$ : 77.8375

Fig. 10 Image for correlation from Fig. 7a upon application of the zeroing filter with the parameters:  $[9 \times 9]$  and  $D = 73$

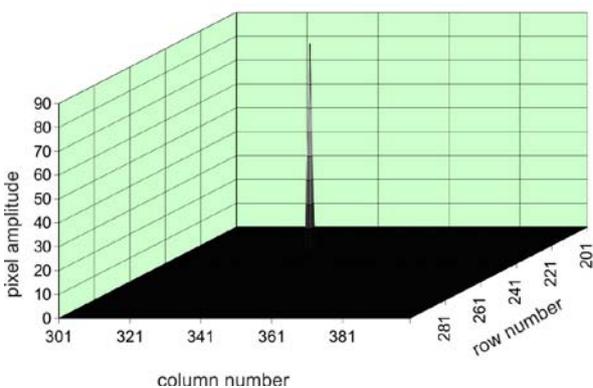
a)



pixel parametrs:

number of the row that corresponds to the row number for the investigated image: 43  
 number of the column that corresponds to the column number for the investigated image: 326  
 differential of  $G'$ : 76.6125

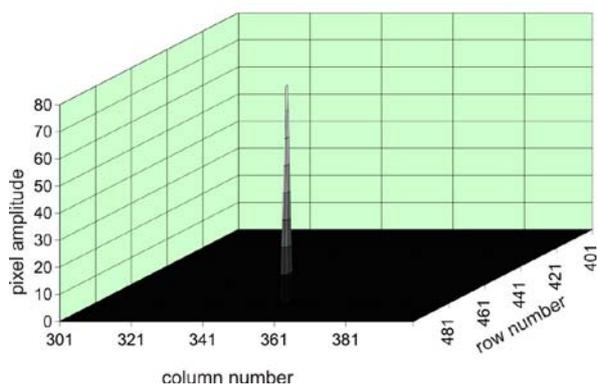
b)



pixel parametrs:

number of the row that corresponds to the row number for the investigated image: 231  
 number of the column that corresponds to the column number for the investigated image: 339  
 differential of  $G'$ : 87.0375

c)

pixel parameters:

number of the row that corresponds to the row number for the investigated image:	482
number of the column that corresponds to the column number for the investigated image:	357
differential of $G'$ :	79.3625

Fig. 11 Image for correlation from Fig. 7b upon application of the zeroing filter with the parameters:  $[9,9]$  and  $D=73$

## V. CONCLUSION

The process of electromagnetic infiltration concerns very weak signals of compromising emanation released by equipment dedicated to process confidential information. Such a process may result in identification or even reproduction of the displayed information and is carried out with use of methods for digital processing of information and analysis of images obtained from these signals by means of half-tone screening. However, due to high content of noise in these signals the methods for digital processing of images, even modified for needs of that process, become insufficiently efficient. It imposes the need to search for such a method for analysis that enable identification and reproduction of data in spite of accompanying noise and interferences that considerably conceal the desired information. One of the suggested methods assume two-dimensional correlation between the pattern image and a fragment of the image under analysis that is reproduced from already recorded signal of compromising emanation. It is commonly accepted that correlation factors above 0.2 serve as the proof of a relationship between the two images (signals) and for less values the correlation is no existent. For the process of electromagnetic infiltration the correlation factors are several times less than 0.2. Thus, should we say that reproduction of information on the basis of signals from compromising emanation is infeasible? The analysis carried out in this study provides evidences that such opportunities really exist and can be used in practice. Identification of images and information conveyed by them is possible by means of two-dimensional correlations that serve as the proof that taking a decision about detection of pattern images not only can be taken on the basis of the absolute magnitude of the correlation factor. Even such low value of it as about 0.06 is not the reason to classify the investigate image as uncorrelated with the information processed on the 'eavesdropped' computer.

The method of two-dimensional correlation and the suggested criterion of Zeroing Filter successfully identify locations where specific signs occur in acquired images and, when the pattern images are already known, these patterns can be even reproduced. The method consists in calculation of the factor for two-dimensional correlation for each point of the investigated image. These correlation factors enable drawing up of the correlation image that is subsequently subjected to operation of the Zeroing Filter that carries out the conversion within the adopted analytic window comprising the predefined number of pixels. The central pixel of that window is referred to as the analysed one whilst all the remaining pixels make up the adjacent vicinity for which the average amplitude is computed. To correctly identify the desired signs it is mandatory to maintain the required threshold distance between the calculated average amplitude and the amplitude of the investigated pixel. When the distance is less than the presumed threshold  $D$  the investigated image is unambiguously discarded and occurrence of the standard pattern within the image is definitely excluded. For the differences of amplitudes (the average and of the current pixel) the process identifies occurrence of the pattern image at the specific point of the investigated image.

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