Rev. Roum. Sci. Techn.– Électrotechn. et Énerg.
Vol. **65**, *1-2*, pp. 15–20, Bucarest, 2020

Dedicated to the memory of Academician Gleb Drăgan

STUDY OF COMPROMISING EMISSIONS OF PS/2 KEYBOARDS BY CORRELATIVE METHODS

XELINA-IOANA ROGNEAN[1], GEORGIANA ROSU[1], ALEXANDRU BOITAN[2], BOGDAN TRIP[2], VLAD BUTNARIU[2],
CHAOUKI KASMI[3], LARS OLE FICHTE[4], OCTAVIAN BALTAG[5]

Key words: Correlation, Electromagnetic interference, Information security, Information systems, Keyboards.

Information is a valuable asset nowadays and there is a strong interest in ensuring the security of information transmitted within information systems. This paper focuses on the electromagnetic information leakage from PS/2 keyboards, in order to prove the possibility of capturing and disseminating signals containing useful information by employing common laboratory equipment. Although the PS/2 protocol is not new, it is still very common in many computer systems that are still in use, such as SCADA (Supervisory Control and Data Acquisition) systems in the industrial domain. The experimental results were obtained with equipment accessible to the general public - thus proving that access to such sensitive information can be attained with minimal and low cost resources, but also with TEMPEST equipment. There is presented a novel method of capturing and reconstructing the signal transmitted by a keyboard using PS/2 communication, with classical signal processing techniques.

1. INTRODUCTION

Electrical and electronic equipment generates electromagnetic radiation during their normal operation and these electromagnetic signals propagate through free space (radiated emissions) or across power lines (conducted emissions) [1]. The signal can be extracted if these electromagnetic emissions are intercepted, analyzed and the information contained in that signal can be decoded [2]. Security features of electronic systems are used to ensure confidentiality integrity and availability, but are not widely deployed for peripherals such as keyboards and computer screens. TEMPEST is the technical field that studies unintended emissions of electronic equipment from which sensitive information can be extracted [3,4]. Depending on the level of classification of the information processed by the electronic equipment, different TEMPEST protection measures can be applied [5,6]. These are generally more restrictive than those provided by electromagnetic compatibility (EMC) domain [7].

In the case of information technology (IT) systems, there are several categories of sources of unintended emissions, identified in [8] as: electromagnetic emissions, optical emissions and acoustic emissions. Exploitation of optical emissions is done by way of a shoulder surfing method or by image recovery from the projection of the image or its reflection [9–11]. The acoustic emissions targeted by TEMPEST attacks are generated by the keypads of telephones, ATMs and computers [12–14]. In this case, real-time automated detection of keypad inputs is feasible, based on statistical analysis enriched with grammatical correctors in order to increase the amount of data recovered.

In the case of information systems, electromagnetic emissions are an important source of unintended emissions due to the existence of multiple possible sources: monitors, connection cables, keyboards. Video display units (VDUs) are vulnerable to interception because of the video frame structure that is almost periodic at the video frame level and the video signal can be recovered if the synchronization pulse parameters are known. This is true both if the electromagnetic radiation is emitted by the VDU [15,16] as well as the video interface [17,18]. Keyboard electromagnetic radiation has low amplitude and is more difficult to process because keyboard-specific communications do not have the repeatability properties of the video signal but still represent a high risk of bit-level information recovery [19,20].

We propose in this study to focus on the electromagnetic information leakage from PS/2 keyboards. The paper is organized as follows: Section 2 describes the PS/2 keyboard structure and communication protocol, Section 3 presents the correlative methods that were used in the process of extraction and identification of the signals, Section 4 describes the experimental methods used in the two stages of the research, and Section 5 discusses the results obtained through the employed correlative methods.

2. PS/2 KEYBOARD

The personal computer (PC) keyboards and interfaces used today are part of the Advanced Technology PC (PC/AT) generation, launched by IBM in 1984. There are complex devices that have a proprietary microprocessor which identifies the keystrokes through a scan-matrix technique consisting of *X* and *Y* addressing lines and columns. Each key is identified by the intersection of line *X* and column *Y* corresponding to its position.

The software implemented in the keyboard's microprocessor detects the command of a key press and/or release, being able to distinguish the double-tapping of a key by the user. The keyboard microprocessor checks the state of the scanning array and determines the closed or open states of the key switches located by the *X* and *Y* coordinates.

The keyboard control integrated circuit (IC) identifies the pressed key and writes its corresponding code into the internal keyboard buffer. This code is transmitted to the PC via a serial cable connected to the keyboard interface. The PS/2 port is the data interface used by older generation computers to connect input/output (I/O) devices like keyboard and mouse and it has six pins and approximately

---

[1] "Ferdinand I" Military Technical Academy, Bucharest, Romania, E-mail: georgianamarin01@gmail.com
[2] Special Telecommunications Service, Bucharest, Romania, E-mail: boitanalexandru@yahoo.com
[3] Technology Innovation Institute, Abu Dhabi, United Arab Emirates, E-mail: chaouki.kasmi@tii.ae
[4] "Helmut Schmidt" University, Hamburg, Germany, E-mail: lo.fichte@hsu-hh.de
[5] Terraflux Control, Iasi, Romania, E-mail: octavian.baltag@terrafluxcontrol.ro

circular shape [21]. Each PS/2 personal computer interface is designed to accept a specific peripheral equipment.

The keyboard connected to a PS/2 interface communicates with the host computer via two signals [22]:

- a clock signal that has a constant value of "1" when the keyboard does not send data, and passes to "0" when a valid bit is transmitted to the data port (which implies that the circuit will be sensitive to the falling edge of this signal);
- a data signal consisting of eleven bits that carries serial data transmitted from the keyboard which is read on the falling edge of the clock signal.

The clock line transfers the clock data from the motherboard used to synchronize with the keyboard interface. Thus, the transfer is performed synchronously. Activating the keyboard reset signal leads to its initialization via the PS/2 interface. Information is transferred between the keyboard and the PC interface through the data line.

The frequency of the clock signal is between 10 kHz and 16.7 kHz and is generated by the keyboard, but only when data transmission takes place. Thus, for each transmitted byte of data, the clock signal has the indicated frequency for 11 clock cycles. When a key is pressed, the keyboard will send 11 bits packets as follows:

- 1 start bit, which is always "0";
- 8 bits (1 byte), starting with the least significant bit (LSB), representing a unique code associated with the key press scan code;
- 1 parity bit (for detecting errors), which is 1 if the number of bits of "1" is even and "0" otherwise;
- 1 stop bit, which is always "1".

The values for each pressed key are coded according to a scan code. For example, the "L" key corresponds to the "0x4B" (hexadecimal form) scans code, and rewritten in binary form, the 8 bits corresponding to this key are 01001011.

From this code, the last bit represents the most significant bit (MSB), which means that the bit transmission will be in reverse order: 11010010. By adding start, parity, and stop bits, the frame will be 01101001011. Fig. 1 illustrates the clock and data signals transmitted by the PS/2 keyboard by pressing the "L" key, acquired with a DPO70804B Tektronix oscilloscope.

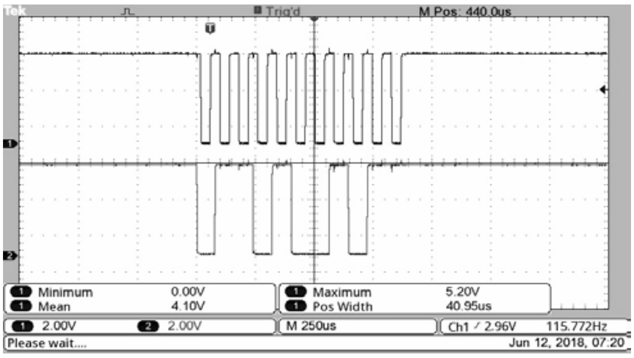

Fig. 1 – Clock and data signals while pressing the "L" key ("0x4B" code).

3. **CORRELATIVE METHODS**

The concepts of autocorrelation and correlation play an important role when it comes to the signal analysis domain [23–27]. The autocorrelation function of a random signal describes the general dependence of the sample values at one time and the sample values at another moment of time. In other words, this function indicates the similarities between the original signal and its delayed version.

The correlation function measures the dependence of the values of a signal against another signal. Having $x(t)$ and $y(t)$ two real time domain signals, the correlation function between those signals is described by:

$$R_{xy}(\tau)=\int_{-\infty}^{\infty} x(t)\,y(t-\tau)\,\mathrm{d}t, \tag{1}$$

where τ represents the time delay between the two signals. For the sampled signals, the correlation function is defined as:

$$R_{xy}[m]=\sum_{n=-\infty}^{\infty} x[n]\,y[n-m], \tag{2}$$

for $m = 1, 2, 3, \ldots, N+1$, where N represents the number of samples. For an analog signal $x(t)$, the autocorrelation function is defined by:

$$R_{xx}(\tau)=\int_{-\infty}^{\infty} x(t)\,x(t-\tau)\,\mathrm{d}t \tag{3}$$

The notation τ represents the delay between the signal and itself. $R_{xx}(\tau)$ always has real values and is a function with the maximum in $\tau = 0$. For sampled signals, the function is defined by:

$$R_{xy}[m]=\sum_{n=-\infty}^{\infty} x[n]\cdot x[n-m], \tag{4}$$

for $m = 1, 2, 3, \ldots, M+1$, where M represents the number of samples.

An important role in identifying a correlation and its shape is played by the so-called correlation coefficient.

The most commonly used is Pearson's correlation coefficient r (linear correlation coefficient), which measures the degree of similarity between two variables. It is defined as the ratio between the covariance of the series and the ratio of their standard deviations:

$$r=\frac{\sum_{i=1}^{n}\left(x_i-\bar{X}\right)\cdot\left(y_i-\bar{Y}\right)}{\sqrt{\sum_{i=1}^{n}\left(x_i-\bar{X}\right)^2}\cdot\sqrt{\sum_{i=1}^{n}\left(y_i-\bar{Y}\right)^2}}, \tag{5}$$

where $X = \{x_1, x_2, \ldots, x_n\}$ and $Y = \{y_1, y_2, \ldots, y_n\}$ are the measured values and $\bar{X}$, $\bar{Y}$ are the mean values of the corresponding time series.

The correlation coefficient r values are between –1 and 1. The "+" or "–" sign shows the relationship type (direction) and the numerical value shows the intensity of the relationship.

4. MATERIALS AND EXPERIMENTAL METHOD

The paper describes a series of methods used for the detection and identification of the compromising signals emitted by PS/2 keyboards, using both TEMPEST equipment and the usual laboratory equipment for the academic environment. The first step is to demonstrate the possibility of detecting and identifying data signals transmitted by the keyboard to the PC. The test bed is illustrated in Fig. 2.

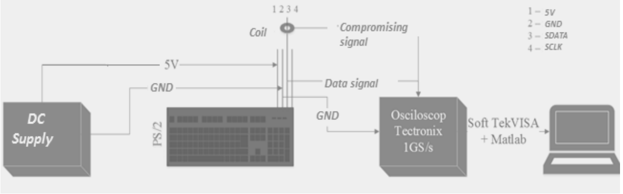

Fig. 2 – The test bed used to detect the compromising emissions in laboratory environment.

The PS/2 keyboard has been separated from the PC and powered directly from a dc source. The data line was connected directly to the Tektronix oscilloscope to view the key strokes in real-time and the correspondence between the electrical signal and its code value from the scan code matrix. On the second channel of the oscilloscope there will be shown the signal detected by a coil mounted on the same line – a wire attached to the keyboard microprocessor data pin. Finally, in order to export the raw data to be processed, the oscilloscope was connected to a computer with the MATLAB development environment and the TekVISA software tool.

At this stage, the objectives of the research were to find the correspondence between the signal acquired directly on the data line and the signal detected by the coil and to highlight the required parameters of the detection circuit to ensure a correct signal identification. For the second objective, the coil illustrated in Fig. 3 was used.

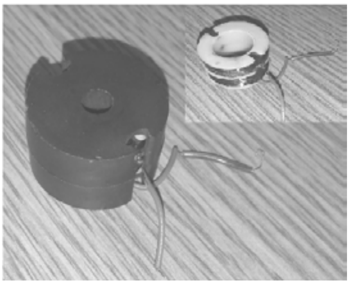

Fig. 3 – The coil with ferrite core pot used in measurements (top right–coil in detail after core removal).

It contains a ferrite pot-shaped magnetic core to focus the magnetic field lines generated by the electrical current passing through the data wire when the signals corresponding to keystrokes are transmitted. Although a proper solution would have been the use of a Rogowski coil, the coil's magnetic core closes the dispersive magnetic flux lines generated by the data wire, thus facilitating the detection of PS/2 keyboard emissions.

The coil's electrical parameters in both cases (with and without the ferrite core) were measured with an Instek LCR meter and are presented in Table 1.

Table 1

The coil's electrical parameters

Parameter	Coil without core	Coil with ferrite core
Dc Resistance [Ω]	18	18.7
Ac Resistance [Ω] at f=10 kHz	18.7	20.2
Inductance [mH]	4.72	63.6

It is noted that the ferrite core coil has a much higher inductance, which justified the choice of its use in the next stage of the experiment. To adjust the attenuation of the coil's transient signal, a variable resistor was connected in series with the coil.

Since the compromising electromagnetic emissions generated by the PS/2 keyboards have a low intensity, their detection was performed in a semi-anechoic chamber by using a Rohde & Schwartz TEMPEST receiver. The test bed is shown in Fig. 4.

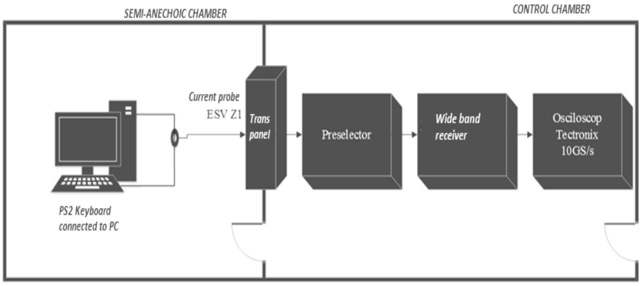

Fig. 4 – The test bed used to detect the compromising emissions with TEMPEST equipment.

The device under test was a PS/2 keyboard connected to a PC, in contrast to the previous stage, when the keyboard was directly powered by a 5V dc power supply. A Rohde & Schwartz ESV-Z1 current probe was mounted on the PS/2 keyboard cable. The current probe operates in the frequency band from 9 kHz to 600 MHz and has a measuring range from –33 dB μA to + 117 dB μA. The signal detected by the probe was transmitted via an RF panel to the measuring equipment – preselector, TEMPEST receiver and oscilloscope which are all placed in a shielded room adjacent to the semi-anechoic chamber.

The RF panel allows the passage of RF cables connecting the electromagnetic transducers used in the test and located in the semi-anechoic chamber with the measuring equipment located in the adjacent room without influencing the experiments. The preselector is installed in front of the receiver in order to improve the signal-to-noise ratio (SNR). The preselector enhances the sensitivity of the detection system as it amplifies by a fixed amount only the signal received within the passband filter limits and rejects the noise outside this band.

The purpose of the receiver is to detect the useful signal from the multitude of signals and disturbances that are present at its input. The receiver was used to select the desired signals and to reject the unwanted ones, thus performing a selection of the compromising frequencies for the PS/2 keyboard. An amplification of the received signal is also performed and both signal level and SNR are therefore improved, thus increasing the quality of the raw data sent to the oscilloscope. The Tektronix DPO70804B oscilloscope used in the setup has a 10 GS/s sampling frequency.

5. EXPERIMENTAL RESULTS

The results presented in the first stage were performed with the test bed illustrated in Fig. 4. The data signal transmitted by the keyboard and the signal detected by the coil were acquired on the two channels of the oscilloscope. The second channel represents the voltage induced in the coil by the variable magnetic field produced by the electrical conductor which is crossed by an electrical current proportional to the data signal.

The signals received by pressing the "L" key are shown in Fig. 5. In the upper side, the data signal transmitted by the keyboard is shown. In the lower side, the signal detected by the coil connected in series with a resistor is shown. The purpose of such connection is to reduce the time constant of the coil, so that it detects only the spikes of amplitude at moments of time equivalent to the transitions in the data signal. It is noted that the higher spikes are corresponding to the falling edge of the original signal and are determined by the shorter transition duration.

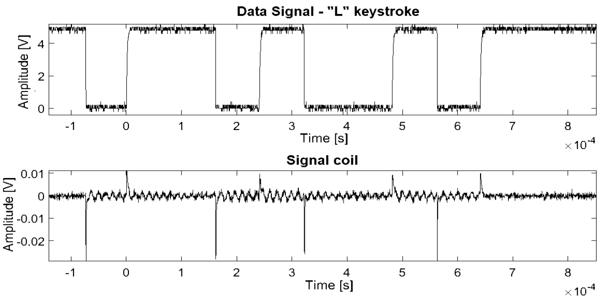

Fig. 5 – The data signal (up) and the signal detected by the coil with series resistor *R* (bottom).

Starting with two types of signals, the next objective was to develop a correlative method of decoding the signals detected by the coil. The proposed method consists in calculating the correlation coefficient between the two signals. A relevant correlation coefficient between the two types of signals can only be achieved if they have similar shapes [25–27]. Since the coil derives the detected signal, the output signal should be integrated to bring it to its original form. This cannot be successfully done, because the data is lost when the signal is derived and it cannot be completely recovered, because the integration is performed on an "incomplete" signal. For this reason, it has been chosen to develop an algorithm that simulates the behavior of the coil by deriving the data signal and performing the correlation with the signal detected by the coil.

Due to the shorter duration of a keystroke signal and the low sampling frequency of the oscilloscope used (Tektronix TBS 1072B-EDU), it was not possible to acquire a multi-key signal and so the algorithm tracked the identification of a single keystroke. In order to create the key identification algorithm, the following steps have been followed:

- A database of galvanically acquired data signals has been created for various keys of a PS/2 keyboard - including time and amplitude signal information.
- For the galvanic signal corresponding to each key, the derived signal was determined.
- The derived signal is truncated through peaks detection in order to extract that part of the signal representing the transmission of the frame.
- For keystroke identification, the signal detected by the coil was acquired using the oscilloscope connected to the computer.
- The Pearson's correlation coefficient between the signal detected by the coil and each of the derived truncated signals from the database is calculated. Coefficients are stored in a matrix.
- The keystroke is identified by determining the highest correlation coefficient obtained from the matrix coefficient.

Figure 6 illustrates the comparison for the correlation signals corresponding to the "L" keystroke. At the top of the figure the signal from the database is shown and the bottom part of the figure presents the signal detected by the coil. We can see that the waveforms contain large variations in amplitude at the instant times.

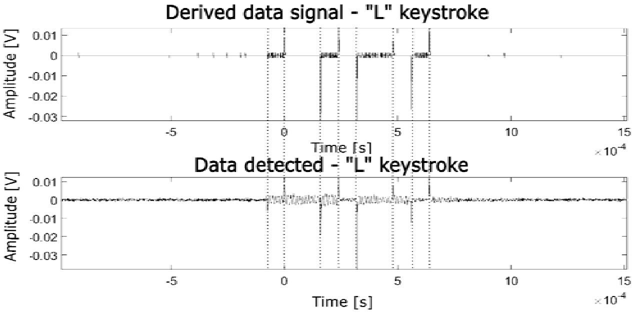

Fig. 6 – The derived database signal (up) and the signal detected by the coil for "L" keystroke (bottom).

When the acquisition is performed at a favorable time and channel noise does not significantly deform the detected signal, a maximum value of 0.7378 is obtained by applying this algorithm for the Pearson's coefficient between the detected signal and the keystroke signal at the time of detection - in this case, the "L" keystroke.

In the second stage, the results obtained with equipment in the TEMPEST domain are presented, using the test bed illustrated in Fig. 4. In order to find the most suggestive form of time variation of the compromising signals, one key was pressed continuously for data acquisition. An electromagnetic frequency sweep was performed and the frequency of interest was selected with the help of the TEMPEST receiver. Due to the large sampling frequency of the oscilloscope used in this measurement configuration, it was possible to record several keys. The image displayed on the oscilloscope and the data saved for each capture was stored for later processing using correlative methods.

Figure 7 illustrates the received signal using the current probe when the "L" key is pressed continuously. It can be

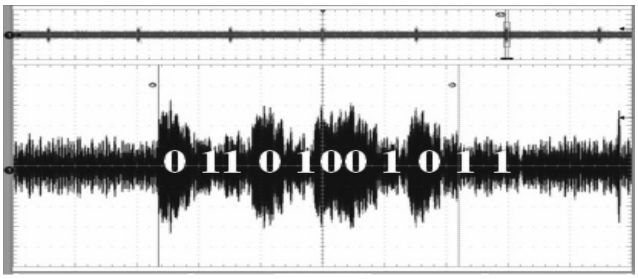

Fig. 7 – The signal corresponding to "L" keystroke.

seen that the signal consists of pulse sequences with sharp amplitude variations that are transmitted with a period of about 30 ms. These sequences represent the compromising signals that the tested keyboard generates for each keystroke and each of these signals has a different shape depending on the pressed key. It is noted that the probe detects the signal opposite to the corresponding waveform.

The data was saved using the oscilloscope and then imported to the computer for further processing. Thus, Figs. 8 and 9 represent the signals acquired by the oscilloscope corresponding to a sequence of 4 successive "L" keys, respectively one single "L" key. In order to correctly identify the pressed keys, the correlation function was applied (eq. (2)), operating on the principle of the sliding window and providing maximum points for a high degree of similarity between the compared signals. The main objective of the method is to identify the time instant when a key of interest appears in a set of analyzed keys.

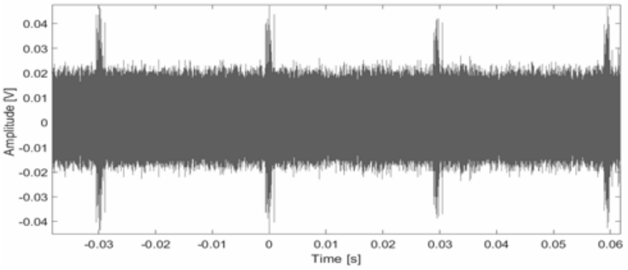

Fig. 8 — Detected signal when the "L" key is pressed continuously, four successive keys.

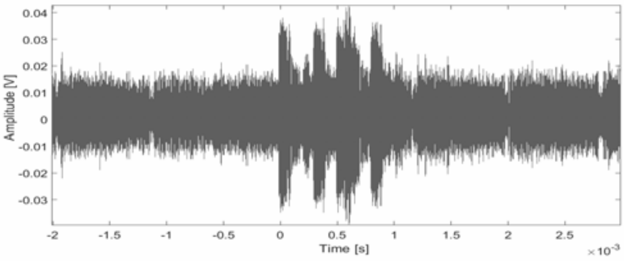

Fig. 9 – Detected signal when a single "L" key is pressed.

Therefore, the peaks of the correlation function are determined and the maximum values of the correlation function (which provide the corresponding amplitude and the sample/ time information) are stored. Thus, the correlation applied between a key and other four keys was performed using the correlation function for data sets saved from experimental measurements. The correlation function was applied between a single-key sequence and a four-key sequence, both of the same type and of different types from the singular key, in order to highlight the difference between the correlation levels resulting from different situations. To facilitate the correlation process, the reference key was extracted from the entire frame in order to eliminate the background noise that appears when no data transmission takes place.

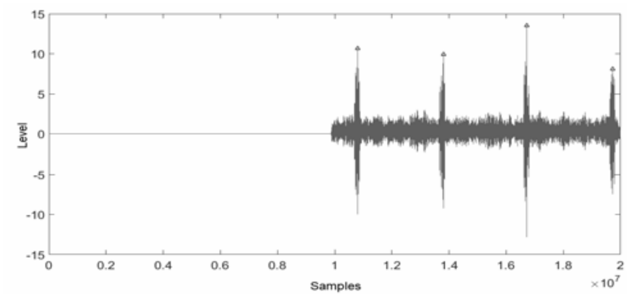

Fig. 10 – The result of the correlation between a single "L" key and four successive "L" keys.

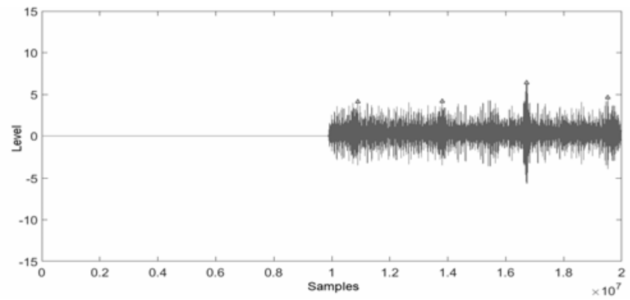

Fig. 11 – The result of the correlation between a single "T" key and four successive "L" keys.

Figures 10 and 11 show the results of the correlation function between the "L" key signal and the signal corresponding to a sequence of four "L" keys, respectively between the "T" key signal and the signal corresponding to the same L-key sequence. In Fig. 11 it can be seen that the correlation function provides local peak values when the similarity between the compared signals is high. In Fig. 10 there are 4 peaks with significantly high values, meaning that there are 4 "L" keys in the analyzed signal.

Figure 11 shows significantly lower values for the correlation function than Fig. 10, which suggests that the analyzed signal does not contain the key we are looking for.

The data was acquired with a sampling rate of 100MS/s. Therefore, in a 10 ms division there are saved 1,000,000 samples. For the analyzed signals, time windows of 5 ms and 100 ms, respectively were used, resulting in a number of 500,000 and 10,000,000 samples, respectively.

6. CONCLUSIONS

In this paper, methods for detecting and identifying electromagnetic emissions generated by a PS/2 keyboards have been developed. The methods were appropriate to the experimental configuration and signal acquisition mode.

In the first phase of the experiments, university laboratory equipment and a ferrite core coil were used to detect the data signals. The signal received at the coil terminals contains only the galvanic signal transition edges according to the scancode of the pressed key. In this case, the correlation method was based on the Pearson correlation coefficient that was calculated for two sets of data: the signal acquired by the coil and the derived galvanic signal.

In the second phase, we used a test bed based on TEMPEST equipment, and the acquired signals had a similar shape to that of the galvanic signal. A correlative method based on the correlation function was used, but the recorded data was very large, making it difficult to process.

The research has demonstrated the facility of detecting and identifying electromagnetic emissions generated by PS/2 keyboards, even with regular laboratory equipment, requiring the adoption of protective measures for equipment that delivers sensitive information. Further ongoing research is focused on the analysis of compromising emissions of USB keyboards [20,28,29].

Received on May 20, 2020

REFERENCES

1. M. Miloudi, A. Bendaoud, H. Miloudi, *Common and differential modes of conducted electromagnetic interference in switching power converters*, Rev. Roum. Sci. Techn. – Électrotechn. Et Énerg., **62**, *3*, pp. 246–251 (2017).
2. M.G. Kuhn, *Security limits for compromising emanations*, in J.R. Rao, B. Sunar (Edit.), *Cryptographic Hardware and Embedded Systems* – CHES 2005. Lecture Notes in Computer Science, **3659**, pp. 265-279, Springer, Berlin, 2005.
3. NATO Standard, SDIP-27/1*, NATO TEMPEST Requirements and Evaluation Procedures*, NATO Military Committee Communication and Information Systems Security and Evaluation Agency (SECAN), 2009.
4. EU Standard, IASG 07-03*, Information assurance security guidelines on EU TEMPEST requirements and evaluation procedures*, General Secretariat of the Council of the European Union (GSC), 2013.
5. NATO Standard, SDIP-29*, Facility Design Criteria and Installation of Electrical Equipment for Processing Classified Information*, NATO Military Committee Communication and Information Systems Security and Evaluation Agency (SECAN), 2009.
6. EU Standard, IASG 7-01*, Information Assurance Security Guidelines on Selection and Installation of. TEMPEST equipment*, General Secretariat of the Council of the European Union (GSC), 2013.
7. US Military Standard MIL-STD-461G, *Electromagnetic Interference Characteristics Requirements for Equipment*, 2015.
8. R. Frankland, *Side Channels, Compromising Emanations and Surveillance: Current and future technologies*, Royal Holloway, University of London, London, RHUL–MA–2011–07 (2011).
9. J. Loughry, D. A. Umphress, *Information leakage from optical emanations*, ACM Transactions on Information and System Security (TISSEC), **5**, *3*, pp. 262-289 (2002)
10. M. Backes, M. Dürmuth, D. Unruh, *Compromising reflections-or-how to read LCD monitors around the corner*, IEEE Symposium on Security and Privacy, Oakland, USA, pp. 158-169 (2008).
11. M. G. Kuhn. *Optical time-domain eavesdropping risks of CRT displays*, in Proc. of IEEE Symposium on Security and Privacy, Berkley, California, USA, pp. 3-18 (2002).
12. D. Asonov, R. Agrawal, *Keyboard acoustic emanations*, IEEE Symposium on Security and Privacy, Proceedings, 2004.
13. Y. Berger, A. Wool, A. Yeredor, *Dictionary attacks using keyboard acoustic emanations*, Proc. of 13th ACM Conference on Computer and Communications Security, pp. 245-254 (2006).
14. T. Zhu, Q. Ma, S. Zhang, Y. Liu, *Context-free attacks using keyboard acoustic emanations*, Proc. of 2014 ACM SIGSAC Conference on Computer and Communications Security, pp. 453-464 (2014).
15. M.G. Kuhn, *Electromagnetic eavesdropping risks of flat-panel displays*. In D. Martin, A. Serjantov (Edit.), *Privacy Enhancing Technologies* – PET 2004. Lecture Notes in Computer Science, Springer, Berlin, **3424**, pp. 88-107 (2004).
16. H. S. Lee, J. Yook, K. Sim, *Measurement and analysis of the electromagnetic emanations from video display interface*, 2015 IEEE Electrical Design of Advanced Packaging and Systems Symposium, Seoul, pp. 71-73 (2015).
17. R. Przesmycki, M. Bugaj, L. Nowosielski, M. Wnuk, *Implementation a database of hardware interfaces for information devices in the identifying process based on radiated emissions*, 2016 International Symposium on Electromagnetic Compatibility – EMC EUROPE, Wroclaw, pp. 701-706 (2016).
18. L. Nowosielski, R. Przesmycki, M. Nowosielski, *Compromising emanations from VGA and DVI interface*, 2016 Progress in Electromagnetic Research Symposium (PIERS), Shanghai, pp. 1024-1028 (2016).
19. M. Vuagnoux, S. Pasini, *An improved technique to discover compromising electromagnetic emanations*, 2010 IEEE International Symposium on Electromagnetic Compatibility, Fort Lauderdale, FL, pp. 121-126 (2010).
20. A. Boitan, R. Bartusica, S. Halunga, M. Popescu, I. Ionuta, *Compromising electromagnetic emanations of wired USB keyboards*, International Conference on Future Access Enablers of Ubiquitous and Intelligent Infrastructures 2017, Bucharest, pp. 39-44 (2017).
21. L. Wang, C. Zhou, B. Yu, *Laboratory test and mechanism analysis on electromagnetic compromising emanations of PS/2 keyboard*, 2012 Eighth International Conference on Computational Intelligence and Security, Guangzhou, pp. 657-660 (2012).
22. M. Kinugawa, Y. Hayashi, T. Mizuki, H. Sone, *The effects of PS/2 keyboard setup on a conductive table on electromagnetic information leakages*, 2012 Proceedings of SICE Annual Conference (SICE), Akita, pp. 60-63 (2012).
23. R. Johansson, M. Verhaegen, B. R. J. Haverkamp, C. T. Chou, *Correlation methods of continuous-time state-space model identification*, 1999 European Control Conference (ECC), Karlsruhe, pp. 3310-3315 (1999).
24. Z. Jiangwei, X. Yulin, X. Shiyou, C. Zengping, *Research on correlation description and processing method of multi-sensor fusion*, IEEE 10th International Conference on Signal Processing Proceedings, Beijing, pp. 2439-2442 (2010).
25. H. Fei, G. Daheng, *Two kinds of correlation analysis method attack on implementations of Advanced Encryption Standard software running inside STC89C52 microprocessor*, 2016 2nd IEEE International Conference on Computer and Communications (ICCC), Chengdu, pp. 1265-1269 (2016).
26. A. Serbanescu, C. Ioana, A. Digulescu, *Overview of our recent results in signal analysis using recurrence plots*, Rev. Roum. Sci. Techn. – Électrotechn. et Énerg., **63**, *2*, pp. 172–177 (2018).
27. A. Digulescu, T. Petrut, C. Bernard, I. Candel, C. Ioana, A. Serbanescu, *Advanced signal processing techniques for detection and localization of electrical arcs*, 2014 10th International Conference on Communications (COMM), Bucharest, pp. 1-4 (2014).
28. D.-J. Sim, H.S. Lee, J.-G. Yook, Kyuhong Sim, *Measurement and analysis of the compromising electromagnetic emanations from USB keyboard*, 2016 Asia-Pacific International Symposium on Electromagnetic Compatibility (APEMC), Shenzhen, pp. 518-520 (2016).
29. R. I. Sokolov, R. R. Abdullin, D. A. Dolmatov, *Development of synchronization system for signal reception and recovery from USB-keyboard compromising emanations*, 2016 2nd International Conference on Industrial Engineering, Applications and Manufacturing (ICIEAM), Chelyabinsk, pp. 1-4 (2016).