INFLUENCE OF FALSE CLOCK SIGNALS ON IMAGE RECOVERY FROM COMPROMISING ELECTROMAGNETIC EMANATIONS OF VIDEO PATH OF COMPUTER SYSTEMS

Foziljonov Khojiakbar Ismoil o'gli

Tashkent University of Information Technologies named after Muhammad al-Khwarizmi
Foziljonov.x.i@gmail.com

KEYWORDS

compromising electromagnetic emanations, video path of computer systems, information security, false clock signal, time synchronization; image restoration, TEMPEST, SDR, image similarity metrics

ABSTRACT

This paper presents an approach to ensuring the protection of computer system video signals from leakage via compromising electromagnetic emanations channels. This approach is based on the generation and emission of false clock signals. The influence of the false clock signal's temporal shift on the synchronization and reconstruction of visual information is considered. Experimental verification was performed using software-defined radio tools and the GNU Radio and TempestSDR software packages. The restoration quality was assessed using the SSIM metrics, Pearson's correlation coefficient, LPIPS, and PSNR. The obtained results demonstrate that increasing the temporal shift leads to deterioration of the structural and perceptual characteristics of the restored images, including the loss of the information component. The practical significance of this work lies in the possibility of increasing the level of protection of computer systems from technical information leakage channels.

INTRODUCTION

In modern conditions, virtually all information about objects and processes, regardless of the field of human activity, is represented digitally and processed using computer systems. Information displayed on a monitor screen is transmitted from the system unit via digital interfaces (DVI, HDMI, DisplayPort) to the display device (monitor). These components together form the computer system's video path. During the processing and display of information, this process is accompanied by the generation of compromising electromagnetic emanations (CEME) hereinafter referred to as CEME, also known as TEMPEST emissions [1-5].

Computer system video paths are among the most vulnerable elements, since the signals generated during image transmission have a repeating temporal structure, which facilitates their interception and subsequent analysis using temporal and spectral processing methods [2, 5-6].

Existing methods of protecting against information leaks through stray electromagnetic radiation channels are typically based on the creation of noise or masking effects with predetermined parameters [7-10]. However, when using adaptive filtering and synchronization methods, such approaches demonstrate limited effectiveness, since informative components of the video signal can be distinguished from the background noise through correlation analysis, signal accumulation, and restoration of its temporal structure [6, 11-14]. In this regard, there is growing interest in active protection methods aimed not only at reducing the level of interference, but also at specifically influencing the timing processes used in restoring the structure of the video signal.

LITERATURE REVIEW

In [15-16], it was shown that the CEME emissions from DVI and HDMI interfaces (cables) are in the form of amplitude-shift keyed signals.

© *Foziljonov Khojiakbar Ismoil o'gli*

In [17], a step-by-step analysis of the image reconstruction process based on CEME from computer system video paths was presented, establishing that correct clock signal reconstruction is a prerequisite for subsequent image structure reconstruction.

In [18], the authors postulate that the CEME from the clock signal can be represented as binary amplitude-shift keyed signals and conduct a theoretical study showing that increasing the time shift τ of the false clock signal leads to an increase in the probability of a P_{error} in a coherent receiver. This, in turn, makes interception and recovery of information impossible. Thus, based on the analysis and generalization of the results presented in [15-18], the key element of the information recovery process from CEME of computer system video paths is the correct recovery of the clock frequency and its temporal position. Considering the amplitude-shift keyed nature of the CEME of DVI/HDMI interfaces and the sensitivity of coherent reception to timing shifts in the synchronization signal, this paper proposes a new information protection method based on the formation and emission of a false clock signal. The proposed approach is disrupting synchronization procedures at the receiver side, which leads to a disruption in the recovery of the video signal structure and a decrease in the probability of successful interception of information via CEME channels.

METHODOLOGY

The experimental methodology is aimed at studying the impact of a false clock signal on the process of intercepting and recovering information via CEME from video paths of computer systems, as well as quantitative image quality assessment under false clock signal injection.

The experimental setup is designed to ensure comparability of the results obtained in the basic mode and in the active protection mode, under constant video signal generation and display conditions. This allows us to isolate the impact of a false clock signal on the stability of the recovery of the temporal structure and visual representation of intercepted information.

The experiment is conducted in two modes:

1. Basic mode – receiving and recovering CEME from a video path without emitting a false clock signal.

2. Protection mode – receiving and recovering CEME when emitting a generated in the GNU Radio environment.

Two computers and two SDR transceivers were used in the experiment. A block diagram of the experiment is presented below (Fig. 1).

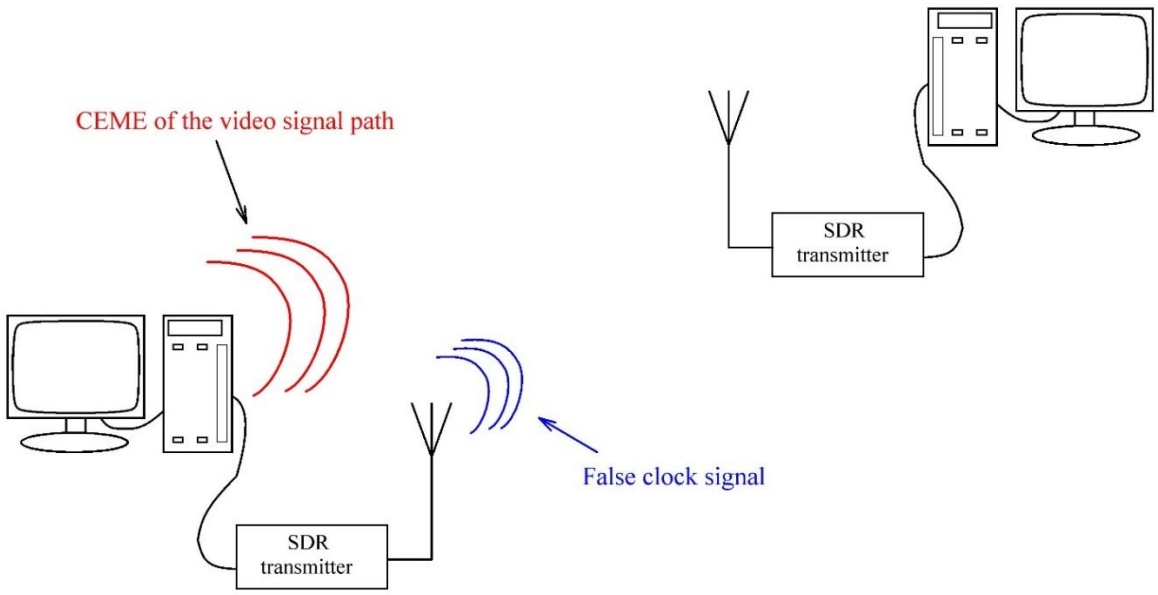


Fig. 1. Structural diagram of the experiment

© Foziljonov Khojiakbar Ismoil o'gli

The first computer is used as the test object. It generates and displays a test image (Fig. 2), the CEME signals of which are to be intercepted and analyzed. The test image includes symbolic, geometric, and color elements with distinct spatial boundaries, ensuring the sensitivity of the similarity metrics to distortions that occur during the interception and reconstruction of the video signal via the CEME channels.



Fig. 2. The original test image used in the experiment to generate and display a video signal on the research object

This computer runs the GNU Radio software environment, which generates a false clock signal and transmits the generated false clock signal over the air using an SDR transceiver.

The second computer serves as a receiving and analysis station. Connected to an SDR transceiver, it receives CEME from the video path of the object being studied. This computer runs TempestSDR software, which is designed to reconstruct the displayed information based on the intercepted CEME signals.

The parameters of the false clock signal are varied during the experiment to assess their impact on the reconstruction of the displayed information on the receiving side.

The CEME are received using an SDR transceiver connected to the second computer. The digitized radio signal is transmitted to the TempestSDR software, where filtering, detection, synchronization, and reconstruction of the displayed information are performed. To quantitatively evaluate the results of image restoration, the indicators discussed in [19] are used as informative metrics of image similarity obtained from CEME. These metrics were chosen due to their ability to reflect both structural and perceptual differences between the original and intercepted images. The following numerical metrics were used in the experiment:

SSIM (Structural Similarity Index Measure) – a quantitative assessment of the structural similarity between the original and intercepted images. Lower SSIM values correspond to a more pronounced violation of structural correspondence and indicate a reduced ability to visually restore the image.

Pearson's correlation coefficient (PCC) – an indicator of the linear relationship between images. Values close to zero indicate a weak correlation and, accordingly, a low degree of similarity between the original and reconstructed images.

LPIPS (Learned Perceptual Image Patch Similarity) – a metric that evaluates perceptual

(cc) BY © Foziljonov Khojiakbar Ismoil o'gli

differences taking into account the characteristics of human visual perception. Higher LPIPS values indicate increased visual differences between images.

PSNR (Peak Signal-to-Noise Ratio) is the ratio of the maximum signal power to the distortion power, expressed in decibels (dB). Higher PSNR values correspond to a greater degree of similarity between the original and reconstructed images.

RESULTS

This section presents the results of an experimental study of the impact of a false clock signal on the interception and restoration of displayed information via CEME from computer system video paths. The results, obtained in two modes (basic and protection mode), are presented as reconstructed images.

Experimental results in the basic mode. Figure 4 shows an image reconstructed from intercepted CEME from a video path at a frequency of 472.5 MHz in the absence of a false clock signal. The frequency of 472.5 MHz was selected as the region of maximum spectral energy concentration of the CEME for the given experimental configuration. Despite the presence of a significant noise component and contour distortions, the spatial and structural organization of the main symbolic and geometric elements is preserved. However, color information is significantly degraded and is represented primarily as shades of gray.



Fig. 4. Reconstructed image obtained

from CEME of the video path in the basic mode (without using a false clock signal)

The results of the quantitative assessment of the similarity of the original and reconstructed images using the PSNR, SSIM, PCC and LPIPS metrics are given in Table 1.

Table 1.

Results of quantitative image similarity assessment

Metrics	PSNR, db	SSIM	PCC	LPIPS
Numerical value	10,61	0,0442	0,3996	0,7751

Experimental results in protection mode. Figures 5–7 show images reconstructed from the CEME video path during the emission of a false clock signal at different values of the time shift τ. The introduction of a protective effect disrupts the receiver's synchronization procedures with the temporal structure of the video signal, resulting in a consistent degradation of the spatial organization and readability of symbolic and geometric elements.

© Foziljonov Khojiakbar Ismoil o'gli

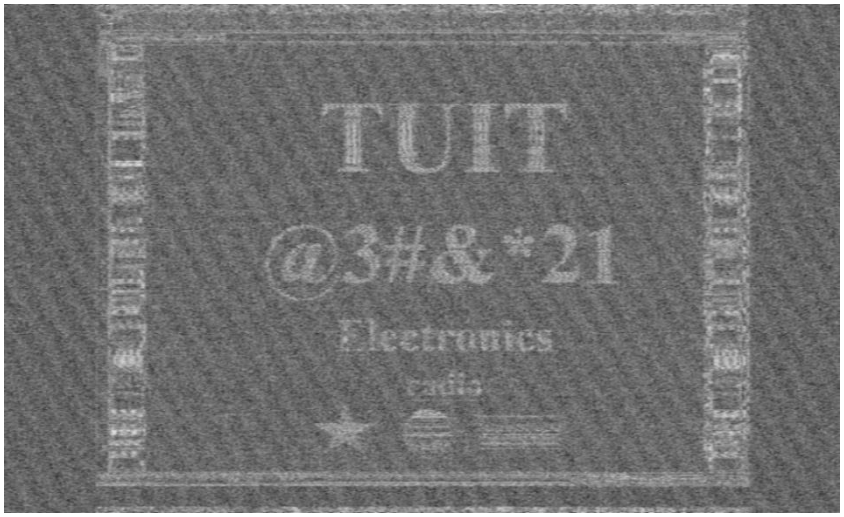


Fig. 5. Reconstructed image, with τ=0%

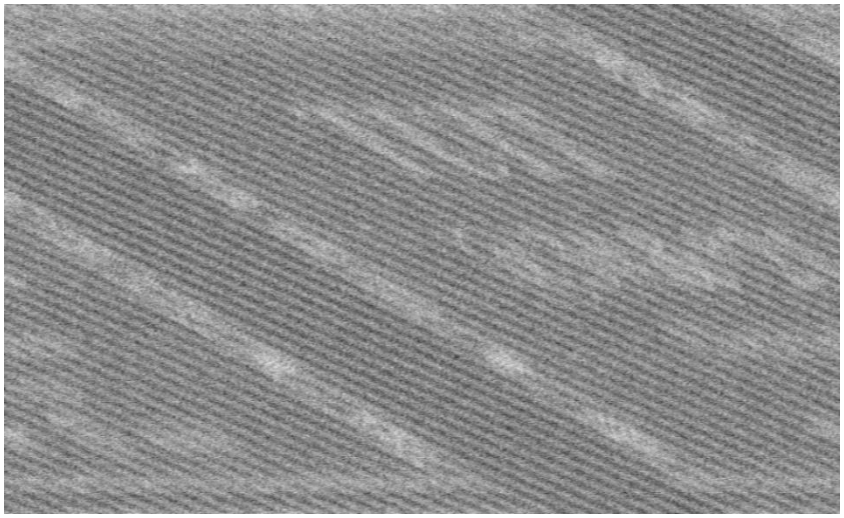


Fig. 6. Reconstructed image, with τ=5%

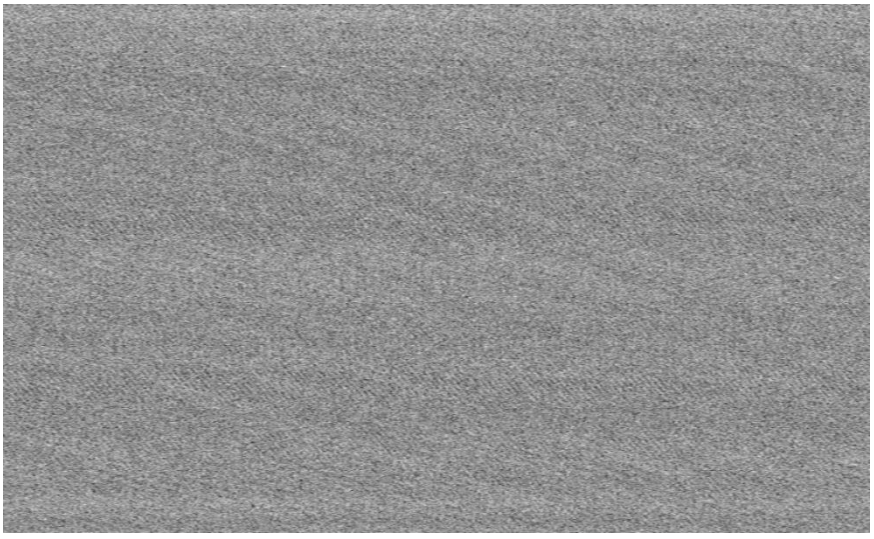


Fig. 7. Reconstructed image, with τ=20%

The obtained results show that the quality of image reconstruction from CEME significantly depends on the value of the temporal shift τ. As the parameter value increases, a consistent degradation of contour and symbolic elements is observed, and when a critical value is reached, reconstruction of the information component

© Foziljonov Khojiakbar Ismoil o‘gli

becomes impossible, and the image becomes predominantly noise-based.

For a clear quantitative assessment, the reconstructed image obtained in the base mode is used as a reference image, against which the reconstructed images generated in the protection mode with different temporal shift values are compared. The results of the quantitative similarity assessment using the PSNR, SSIM, PCC, and LPIPS metrics are presented in Table 2.

Table 2.

Results of quantitative image similarity assessment

Metrics				
τ, %	PSNR, db	SSIM	PCC	LPIPS
0	27,7203	0,0795	0,3215	0,1964
5	27,712	0,0558	0,01819	0,2906
20	27,708	0,0512	0,018025	0,2998

In general, the obtained results show that an increase in the value of the time shift τ leads to a decrease in the structural and perceptual similarity of the reconstructed images with the reference one, which quantitatively confirms the effectiveness of using a false clock signal to disrupt the processes of synchronization and restoration of information through the channels of the CEME video path of computer systems.

DISCUSSION

The obtained experimental results confirm the key role of temporal synchronization in the process of reconstructing information from CEME by computer video systems. Quantitative evaluation using the SSIM, PCC, LPIPS, and PSNR metrics demonstrates that the introduction of a false clock signal leads to a consistent degradation of the structural and perceptual characteristics of the reconstructed visual information.

It is noted that at small temporal misalignment values, partial synchronization is maintained, ensuring limited reproducibility of the image's spatial structure. As the temporal misalignment increases, a breakdown in the temporal referencing procedures and a loss of the linear relationship between the reference and reconstructed images are observed, which is quantitatively confirmed by a decrease in the SSIM and Pearson correlation coefficient values with a simultaneous increase in the LPIPS metric.

Unlike amplitude metrics such as PSNR, which are weakly sensitive to temporal structure disruptions, structural and perceptual metrics demonstrate greater information content in assessing the effectiveness of masking. This indicates the feasibility of using them as the primary criteria in analyzing the stability of CEME recovery.

The obtained results are consistent with the findings of [15-18], which emphasize the need for accurate clock frequency and timing recovery for successful video signal reconstruction, and expand on these findings by experimentally confirming the possibility of controlled disruption of these procedures using a false clock signal.

CONCLUSION

This paper proposes and experimentally investigates an approach to ensuring protection of video signals from leakage via CEME channels, based on the emission of false clock signals with a controlled time shift. It is shown that correct restoration of the temporal structure and clock synchronization is a key condition for reconstructing visual information from the CEME of computer system video paths.

The experimental results demonstrate that increasing the temporal mismatch between the false and informative clock signals leads to deterioration of the structural and perceptual characteristics of the reconstructed images. Quantitative evaluation using the SSIM metrics, Pearson correlation coefficient, LPIPS, and PSNR confirms a decrease in the similarity of the reconstructed images to the reference image with increasing time shift.

References:

1. Liu, T., & Li, Y. (2019). Electromagnetic Information Leakage and Countermeasure Technique: Translated by Liu Jinming, Liu Ying, Zhang Zidong, Liu Tao. Springer.
2. Хорев, А. А. (2010). Технические каналы утечки информации, обрабатываемой

© Foziljonov Khojiakbar Ismoil o'gli

средствами вычислительной техники. Специальная техника, (2), 39-57.
3. Ogli, F. K. I. (2021, November). Study of the spectrum of side electromagnetic radiations of video interface DVI. In 2021 International Conference on Information Science and Communications Technologies (ICISCT) (pp. 1-3). IEEE.
4. Kuhn, M. G. (2003).Compromising emanations: eavesdropping risks of computer displays(No. UCAM-CL-TR-577). University of Cambridge, Computer Laboratory.
5. Kubiak, I., & Przybysz, A. (2019, September). DVI (HDMI) and DisplayPort digital video interfaces in electromagnetic eavesdropping process. In 2019 International Symposium on Electromagnetic Compatibility-EMC EUROPE (pp. 388-393). IEEE.
6. de Meulemeester, P., Scheers, B., & Vandenbosch, G. A. (2020, July). Eavesdropping a (ultra-) high-definition video display from an 80 meter distance under realistic circumstances. In 2020 IEEE International Symposium on Electromagnetic Compatibility & Signal/Power Integrity (EMCSI) (pp. 517-522). IEEE.
7. Lavaud C. et al. Whispering devices: A survey on how side-channels lead to compromised information //Journal of Hardware and Systems Security. –2021. – Т. 5. –С. 143-168.
8. Guri M., Elovici Y. Bridgeware: The air-gap malware //Communications of the ACM. – 2018. – Т. 61. – №. 4. – С. 74-82.
9. Foziljonov, K., & Faziljanov, I. (2023). Active methods and means of information protection against leakage through channels of side electromagnetic radiation and interference. Science and innovation, 2(A4), 46-52.
10. Foziljonov, K. (2025). Analysis of new methods of information protection from the leakage of side electromagnetic radiation from video tract of computer equipment. In Proceedings of the 10th International Scientific and Practical Conference "Scientific Community: Interdisciplinary Research" (pp. 276–279). Hamburg, Germany.
11. Proakis, J. G., & Salehi, M. (2001). *Digital communications* (Vol. 4, pp. 593-620). New York: McGraw-hill.
12. Haykin, S. S. (2002). *Adaptive filter theory*. Pearson Education India.
13. Sklar, B. (2021). *Digital communications: fundamentals and applications*. Pearson.
14. Kubiak, I. (2014). Digital processing methods of images and signals in electromagnetic infiltration process. Image Processing and Communications, 18(1), 5-14.
15. De Meulemeester, P., Scheers, B., & Vandenbosch, G. A. (2020). Differential signaling compromises video information security through AM and FM leakage emissions. *IEEE Transactions on Electromagnetic Compatibility*, *62*(6), 2376-2385.
16. De Meulemeester, P., Scheers, B., & Vandenbosch, G. A. (2019). A quantitative approach to eavesdrop video display systems exploiting multiple electromagnetic leakage channels. *IEEE Transactions on Electromagnetic Compatibility*, *62*(3), 663-672.
17. Foziljonov, K. (2026). Key stages of recovery of visual information from side electromagnetic radiation video paths of computing systems. *Yangi davr ilm-fani: inson uchun innovatsion g 'oya va yechimlar*, *2*(1), 5-9.
18. Фазилжанов, И. Р., & Фозилжонов, Х. И. (2023). Исследование зависимости вероятности ошибки оптимального когерентного разведовательного приемника при перехвате пэми видеотракта компьютеров от ложной тактовой синхронизации. *Science and innovation*, *2*(Special Issue 3), 411-414.
19. Foziljonov, K. (2026). Analysis of quantitative metrics for assessing similarity of images recovered from electromagnetic emanations. In Proceedings of the V International Scientific Conference "Innovative Scientific Forum" (pp. 155–157). Helsinki, Finland.

© *Foziljonov Khojiakbar Ismoil o'gli*