Power line Compromising Emanations Analysis

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Abstract - **The paper presents an innovative method used to analyze the video-compromising signals that computer equipment generates during normal operation. It presents the measurement results achieved for conducted emissions for a commercial laptop using a shielded power source and a commercial transformer as well as conducted emissions generated by a display unit which is connected to a laptop and is alternatively powered by a commercial and a shielded cable. In order to perform these tests, there were selected several graphical images consisting of horizontal bars of various widths to facilitate the detection and evaluation of the compromising video signal level.**

Cuvinte cheie: *emisii compromiţătoare, refacerea semnalului video, emisii conduse, sursă alimentare, cablu alimentare, imagine de test.*

Keywords: *compromising emanations, video signal recovery, conducted emissions, power supply, power cable, test image.*

I. Introduction

This paper is meant to continue the research conducted in [1] with a new approach and using a different measurement equipment.

Most of the electronic, electromechanical or electro-optical devices unintentionally emit electromagnetic signals and sometimes, these radiations might be strong enough to interfere with the operation of nearby radio or TV devices.

Undesired emissions of electronic equipment are generally being handled from the design stage, but, in general, these emissions cannot be completely eliminated, just reduced under given acceptance limits imposed by Electromagnetic Compatibility (EMC) standards [2, 3, 4]. Each time such an electronic device handles information, it can be leaked by unwanted emissions. Those unwanted emissions, from which information can be extracted, are considered compromising emanations (CE) as they might be a threat to the confidentiality of the information processed by the equipment. The TEMPEST domain involves the investigation of these undesired radiations and sets the procedures and methods for protecting the confidentiality of information despite of CE [5, 6].

All computer cables, telephone lines and inappropriate electronic connection systems can act as a transmitter for the unwanted electromagnetic radiation (EMR). Computer displays, processors and other electronic devices, such as keyboard, mouse, printers, etc., radiate EMR in space or in any conductive environment, such as wires, power lines, or even water pipes. These EMRs contain information that the device displays, processes, creates, stores, or transmits, and may be captured by an intruder with a relatively unsophisticated device that includes an active directional antenna, processed and evaluated using specialized software systems.

The risks to the confidentiality leak of information due to the CE from the PCs peripherals is known from couple of decades, and it has been first reported by Markus Kuhn in early1985 [7], who analyzed both CE from cathode ray tube (CRT) [8] and liquid crystal display (LCD) [9, 10, 11]. In [12], Sekiguchi and Seto developed a measurement system for conducted CE on power leads, in the 100-1000 MHz range. More recent research analyzed CE for image transmission. In [13], Przesmycki, studied the propagation channels of electromagnetic permeability and presented a number of results of CE derived from a laser printer, while in [14] Kubiak presented a number of research regarding the CE level that can be intercepted when image is transmitted in accordance with both the analogue VGA and the digital DVI standards, as well as the possibility of manipulating the level of video signal and its influence on the quality of displayed images. In [15], Prvulovic, A. Zajić et al. develop an algorithm to identify unintentional amplitude (AM) and frequency (FM) modulation carriers radiated by a PCs by using a set of alternative actions that will be executed periodically in a process loop. In [16], Rubab, Manzoor, et al. proved that the image from a display unit can be recovered up to a distance of 29.5 m based on the reception of CE transmitted through the network cable. In a previous paper [17] some of the authors have demonstrated for the first time that it is possible to recover CE signals generated by small size displays, such as a 4.3-inch LCD display of a multi-function laser printer device.

II. Detection of video signals

A. Video signal timing specifications

The VGA protocol is composed of 5 active signals, namely the *horizontal sync*, that is a digital signal used to synchronize the video frame; the *vertical sync*, that is a digital signal used to synchronize the line frequency; the *red colour level* (R), that is an analogical signal between 0 and 0.7 V, used to control the level of the red colour for each pixel; the *green colour level* (G), that is an analogical signal between 0 and 0.7 V, used to control the level of the green colour for each pixel and the *blue colour level* (B), that is an analogic signal between 0 and 0.7 V, used to control the level of the blue colour for each pixel.

In order to generate an image on the screen, the electron beam is projected onto the screen respecting the digital syncs mentioned above. The information about the RGB colour from the video frame is used to control the electron beam density. The screen refresh process begins from the upper left corner of the screen and traces one by one pixel from left to right, each time period corresponding to the pixel frequency. After scrolling through the first row of pixels, the line index is incremented and the column address is reset to the first position. After scrolling the whole screen, the refresh process resumes. The video signal is refreshed 60 times per second to ensure the image dynamics and to avoid blinking which leads to human eye tiredness.

Usually, the time span required for the electron beam to project each pixel by the rule mentioned above is 16,6 ms which conducts to a screen refresh rate of 60 Hz. The standard VGA resolution is 640x480 pixels and a screen refresh rate is 60 Hz. One pixel requires 40 ns to be projected on the screen which means the pixel refresh rate is 25 MHz.

Using the 1920 x 1080 resolution and the 60 Hz refresh screen rate, the frequency of each pixel is 148.5 MHz (6.73 ns). The structure of this type of video signal is shown in Figure 1 and was inspired by [18, 19].

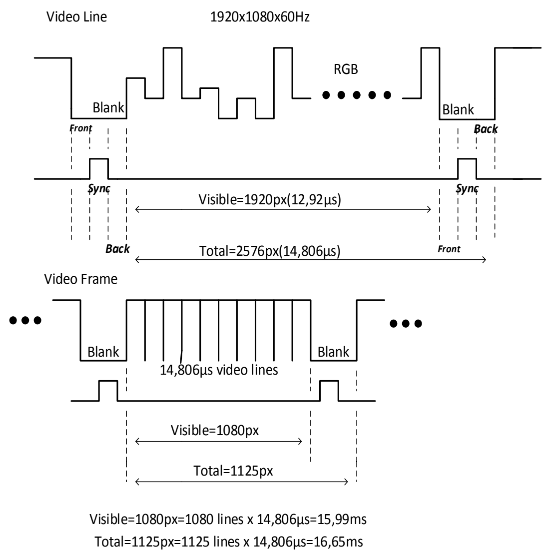

Fig. 1. The structure of a analogical video signal for the 1920 x 1080 resolution at 60 (Hz) refresh rate

During the projection of a single line from the video frame, the video signal contains 1920 pixels, but in addition with a horizontal transition pause time, it leads to a number of 2576 pixels which means a duration of 14.806 µs. During the transition time, a horizontal sync signal is transmitted to emphasize the fact that a new 2576 pixels line from the video frame is ready to be displayed on the screen.

The video projecting process is repeated for 1125 times, from which 1080 is the number of the lines embedded into the video frame, and the rest of 45 lines is represented by the vertical porch time. After the 1125 lines are synchronized with 1125 horizontal sync signals, a vertical sync signal is emitted to mark the fact that the next video frame is ready to be displayed. The electron beam is reset from the top left corner of the screen, and the whole video displaying process mentioned above is resumed. While the transition to the next video frame projection is in process, all the pixels from the screen should be black (the voltage of each RGB analogic signal channel is zero).

B. *Description of the analyzed video signals*

During this research, several types of image patterns displayed on the screen of a laptop with 1920 x 1080 resolution and a screen refresh rate of 60 Hz have been studied. The image patterns consist of black and white stripes, alternatively displayed. The choice of these colours is due to the fact that the RGB voltage level of the black colour is 0 V and the RGB voltage level of the white colour is 0.7 V. In Fig. 2 there is detailed one of the studied image patterns, composed of 6 white stripes and 6 black stripes alternatively disposed.

Each horizontal stripe is composed of 90 lines from the video frame with a 90 pixel thickness. In the bottom part of Fig. 2, is described the timing for the considered video frame. Thus, the first line from the video frame, including the horizontal time sequence has a duration of 14.806 µs and a voltage level of 0.7 V.

The duration necessary to display the first white stripe is 1.33 ms. The black stripe, with the same thickness of 90 pixels, requires the same time to be displayed. The duration necessary to display all the 12 stripes as a visible signal is 15.99 ms. Adding also the duration of the vertical transition, a total duration of 16.65 ms has been obtained for the overall video frame, corresponding to the screen refresh rate of 60 Hz.

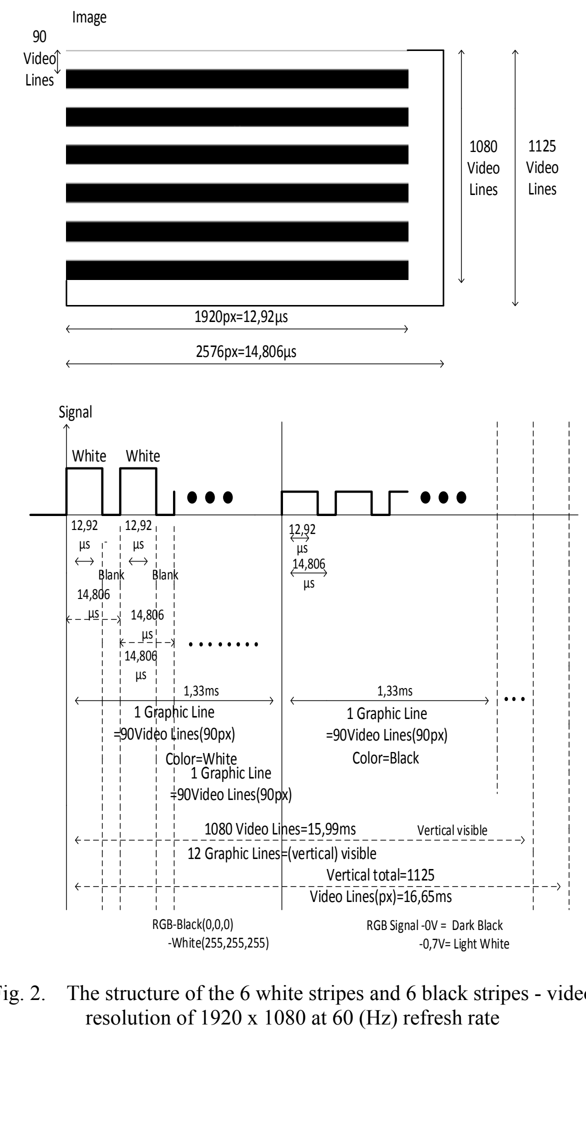

Fig. 2. The structure of the 6 white stripes and 6 black stripes - video resolution of 1920 x 1080 at 60 (Hz) refresh rate

III. MEASUREMENT SETUP AND EQUIPMENT

In order to detect the video compromising emanations of a system of electronic devices the configuration setup as illustrated in Fig. 3 and 4 has been used.

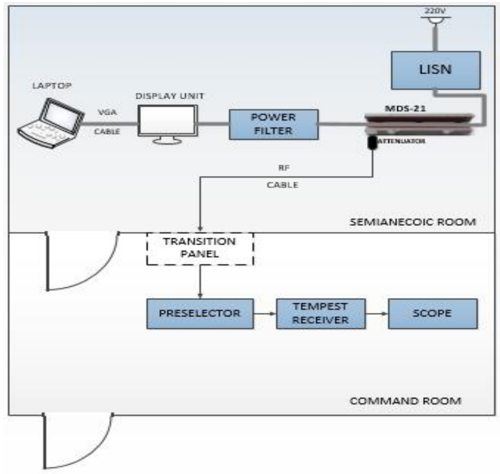

Fig. 3. Test configuration setup – MDS21 measurements

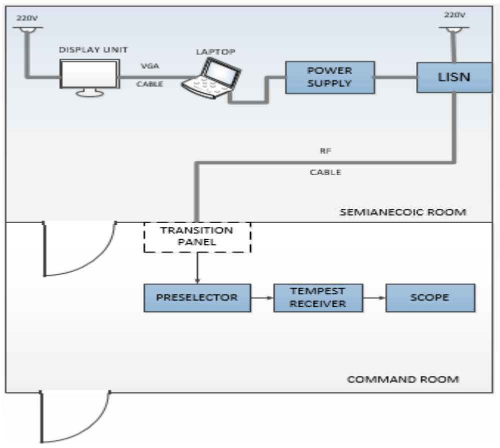

Fig. 4. Test configuration setup – LISN measurements

The research was performed in a TEMPEST measurement laboratory belonging to the Special Telecommunications Service and the Equipment Under Test (EUT) was the power filter of a video display unit connected to a laptop in the first stage of the research and the laptop power supply unit respectively in the second one.

The TEMPEST laboratory consists of two adjacent rooms: a semi-anechoic and a shielded chamber. The two rooms communicate through a transition panel and a door with finger strips electromagnetic gaskets.

The Line Impedance Stabilization Network (LISN) device fulfils four basic functions:

– providing a constant impedance to the input power of the EUT to obtain repeatable measurements;
– low-pass filter function that prevents the high-frequency noise of the power supply network from coupling to EUT;
– provides a measuring port with a stabilized output impedance of 50 Ω;
– DC components rejection to the LISN measuring port for receiver input protection.

All these functions of a LISN device facilitate the coupling of the high frequency noise signal to the input of the measuring receiver and determine the repeatability degree of the performed measurements.

LISN devices are RF transducers that were first mentioned in the EMC domain [2] and typically had a range of operation from 9 KHz to 30 MHz as required by the EMC field. Instead, the TEMPEST domain specifies that conducted CE measurements should be performed also above 30 MHz, in opposition to the EMC standards. The limits are specified in [5, 6] and they represent classified information.

For this reason, the measuring equipment manufacturers have tried to keep up with the new technical requirements imposed by the TEMPEST field. Therefore, LISN equipment was launched on the market that works up to 1GHz, and was called Power Line Impedance Stabilization Network (PLISN). TEMP 8400 and EMCO 3925/2 are examples of PLISN equipment that are produced by two well-known companies in this field, such as Schwarzbeck and ETS-Lindgren, operating in the 9KHz÷1GHz and 5KHz÷1GHz range respectively [18, 19].

The LISN or PLISN devices are able to capture the CE signals from phase or null conductor relative to ground connection.

In the following sections we will present a number of results, as follows. In section IV, the LISN device was only used to power the EUT, while in section V it was also used to capture the CE occurred via the power supply network in two situations: using a commercial power supply and a shielded non-commercial power supply, especially designed for TEMPEST equipment.

In section IV a Rohde & Schwarz MDS-21 was used as radio frequency (RF) transducer, with an absorbing clamp which was positioned around the power cable of the monitor to receive the electromagnetic signals transmitted on the power line. The monitor's shielded power cord contains a low pass filter that should achieve an insertion loss of approximately 40 dB for frequencies above 14 kHz. The filter is disposed in a metal housing that has a base flange to ensure the grounding.

MDS-21 absorbing clamp contains a series of chained ferrite rings that form the secondary part of a current transformer which provides the radiated power generated by the CE current running through the power cord, representing the primary part of the current transformer. Through its characteristics, the absorbing clamp captures the common mode CE signals whilst the LISN or PLISN devices capture the differential mode CE signals.

During the experiments, the clamp is moved along the power cord until a maximum level of electromagnetic radiation is received. The MDS-21 clamp is provided with a 6 dB attenuator (for adjusting the output impedance); the subsystem MDS-21 and the 6 dB attenuator is connected to a TEMPEST receiver via a RF cable. The RF signal transmission from the attenuator to the control room is made through the transition panel.

All the operations dealing with the measurements and the equipment control are realized from the room that encapsulates the semi-anechoic chamber and for this reason we will call it the "control room". The control room includes: a RF pre-selector, a TEMPEST receiver, an oscilloscope, and a control and command specialized system.

The pre-selector is a band-pass filter that connects the electromagnetic transducer to the receiver input, improving the performance of the receiver. The pre-selector is usually tuned to have a narrow bandwidth, centred on the receiving frequency in order to reduce the unwanted interferences as much as possible. However, the pre-selector unit does not remove all interferences from its input, but it possesses the capability to amplify the signals that pass the filters through its built-in preamplifier unit. The TEMPEST receiver has an input bandwidth capability up to 500 MHz. The TEMPEST receiver output, represented by the intermediate frequency of 21.4 MHz, is transferred to the oscilloscope input.

IV. Measurement Results Using The MDS-21 Clamp

The EUT receives video signal from a portable PC. The laptop does not require a power connection because it is using its standalone battery. Thus, the leaking device is the cable that ensures the alimentation of the DUT. The monitor is connected via an electrical cable to a LISN.

The compromising signals generated by displaying graphic images were compared in two situations: powering the display unit with a shielded cable versus a commercial one. In order to facilitate the detection of the video CE, suggestive image test patterns have been used, consisting of white stripes on black background. Fig. 5 shows the reception of the compromising signal displayed on the oscilloscope, with the filtered signal obtained from the shielded cable configuration.

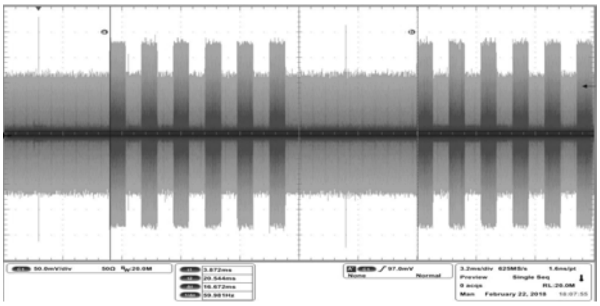

Fig. 5. Video signal - 6 horizontal lines, using MDS-21 clamp and a shielded power cable

The receiver was tuned on the central frequency of 81 MHz where the CE had the maximum amplitude. The constant of the scope's time base is 3.2 ms/div, enabling us to see two video frames on the oscilloscope screen. Due to the signal to noise ratio (S/N) of about 100 mV, a stable view of video frames is obtained by using a Trigger level.

It is interesting to notice that the waveform displayed on the scope illustrates that the compromising signal amplitude is opposite to the test signal amplitude. The white colour records the maximum amplitude while the black colour records the minimum amplitude.

Fig. 6 illustrates the image displayed on the scope, recovered based on the CE, when the EUT is powered by a commercial power cord.

It can be noticed that a peak to peak amplitude of 600 mV results for the signal received, when using the shielded power cable configuration and 750 mV, respectively, when using the unfiltered signal obtained from the commercial power cord configuration. Also, the S/N ratio measured is 110 mV in the first case and 150 mV, respectively, in the second case.

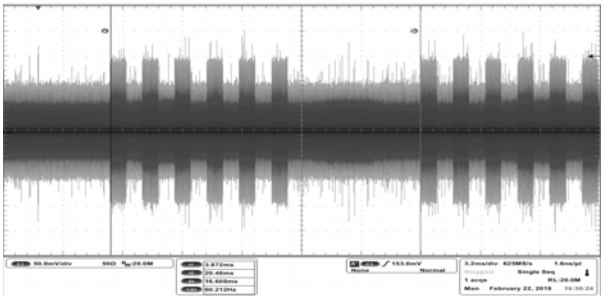

Fig. 6. Video signal - 6 horizontal lines, using MDS-21 clamp and a commercial power cable

During the test, the same receiver reference level was used, so the compromising signal amplitude that was viewed on the oscilloscope is not influenced by the receiver measurement parameters. By applying 2 vertical markers, a signal period of approximately 16.7 ms was measured, corresponding to a video refresh rate of 60 Hz of the video display signal.

A power filter designed specifically for this type of signal applied to the power line should have considerably reduced the level of the compromising signal. However, in this case, the filter has reduced only the noise level, highlighting the level of compromising signal.

V. Measurement Results Using The LISN

In this section we will alternatively analyse the induction phenomenon of compromising signals conducted on the power line of both commercial and shielded power supplies of a laptop which has connected to its VGA port a display unit, using a LISN device, type Rohde & Schwarz ESH3-Z5, operating in the 9KHz÷30 MHz range.

In the CE detection phase, an image consisting of two thick bars and a thin one was selected as a test message. The measurements were performed using the same parameters set for the receiver that was tuned on the central frequency of 8 MHz where the CE had the maximum amplitude. Fig. 7 represents the compromising signal with peak to peak amplitude of 150 mV and an S/N ratio of 80 mV, thus being able to clearly distinguish the test message used, and the VGA standard frame timing corresponding to a 60 Hz refresh rate.

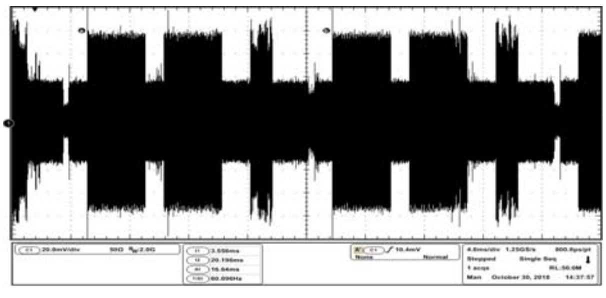

Fig. 7. Video signal - two thick horizontal bars and a thin one, using a LISN and a commercial power supply

In comparison, replacing the commercial power supply with a shielded one results a signal with the same amplitude, but with a significantly lower S/N ratio, of just 20 mV, as shown in Fig. 8. In this case the original signal cannot be identified easily.

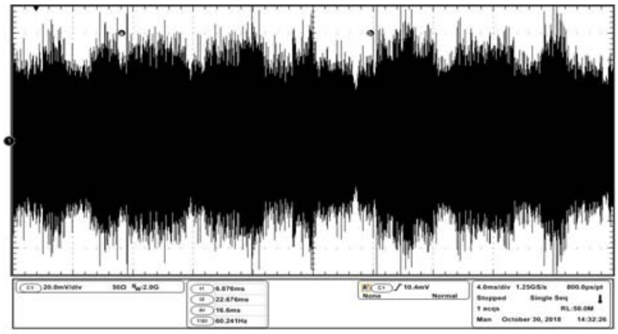

Fig. 8. Video signal - two thick horizontal bars and a thin one, using a LISN and a shielded power supply

In the next phase of the experiment we displayed a text message on the EUT in order to check the possibility of video signal recovery. A text message, written in black colour with 24 size ”Arial” font was used. We managed to recover the text message, illustrated in Fig. 9 and 10, on the same reception frequency mentioned above. In Fig. 9 we can see the image recovered from the commercial power supply while in Fig. 10 we have the image recovered from the compromising signal received from the shielded power supply.

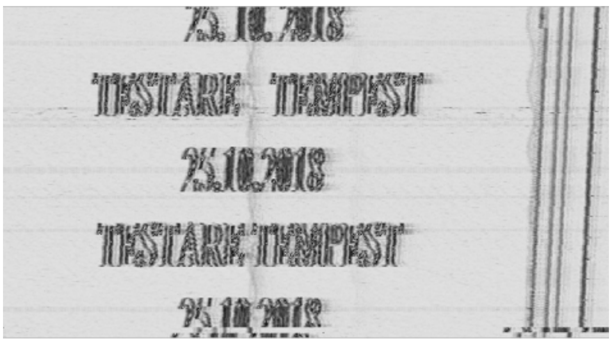

Fig. 9. Video image recovery - 24 font text, commercial power supply

The image recovery process confirms our previous results based on S/N ratio measurements, the image from Fig. 9 being intelligible while the one from Fig. 10 shows a significantly noisier and blurred image.

In order to emphasize in a better way the difference between the two power sources, we decided to use a larger font to counter effect the lower degree of intelligibility caused by the lower S/N ratio using the shielded power supply, thus achieving the same degree of comparison. However, using the commercial power source, we were able to recover texts written with smaller fonts, the smallest one being ten.

During the image recovery process, it is possible to observe the video signal synchronization, corresponding to its line transitions, mentioned in Fig. 1, fact which is visible both in Figs. 9 and 10 by the vague vertical stripes from the right side of both images.

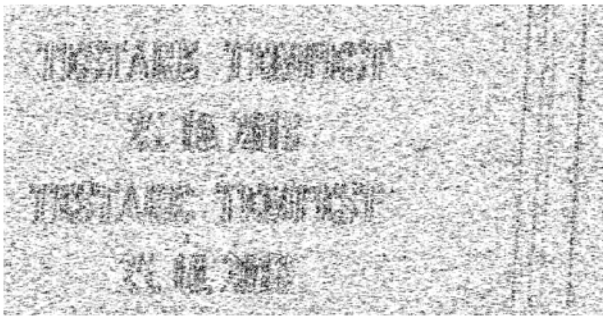

Fig. 10. Video image recovery - 24 font text, shielded power supply

In opposition to the tests performed in section IV, here we can observe that the shielding applied to the power source is very effective, reducing the S/N ratio in such manner that the compromising signal cannot be distinguished from the noise in some circumstances.

VI. UNINTENDED ELECTROMAGNETIC INDUCTION

In the following, more experiments were performed, emphasizing the importance of the measurement configuration setup for different type of images displayed on the screen of the device under test.

We should notice that positioning the VGA cable that interconnects the laptop with the display unit in the vicinity of the power cables can lead to the induction of CE radiation through it. In this sense we connected an electric extension cord to the LISN device and we did not supply any equipment with it. We positioned the VGA cable near the power extension cable at a distance of less than 10 cm.

The CE radiation, emitted through the electric cable that is induced by the VGA cable, is captured, and the recovered image is illustrated in Fig. 11.

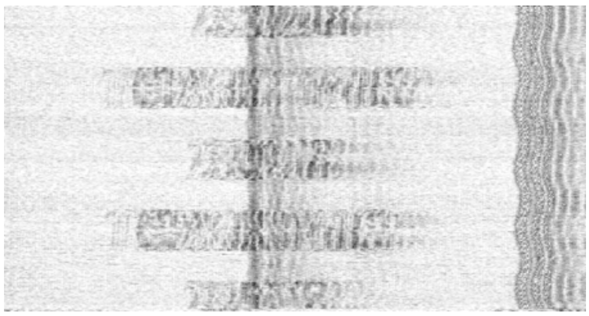

Fig. 11. Video signal recovery – no EUT, VGA cable in proximity of power line cable

Although the recovered image is not readable, it contains information leaked from the EUT, and potential attackers could take advantage from this by using various signal processing tools to exploit those spurious emissions.

The positioning of the interconnection cables is an important aspect to be considered both in the equipment testing stage and in the installation procedure. These issues are covered by the TEMPEST regulations and are detailed in [18].

VII. CONCLUSIONS

This paper presents a detailed analysis of time parameters for the video signal corresponding to the image displayed both on a laptop screen and a display unit, with the same resolution of 1920 x 1080 x 60 Hz.

The study was focused on the experimental research of video display signals using two different power supplies for the laptop and two different power cables for the display unit: commercial (COTS) and shielded.

The attenuation efficacy (insertion loss) of a power filter connected with the power cable of a display unit, and a shielded power supply of a laptop, both manufactured by a company specialized in the production of shielded equipment was analysed.

The results of the study highlight the ineffectiveness of the filter for the analysed test frequencies, as illustrated in the measurement results presented in section IV. In comparison, the shielded power supply leaded to positive results proven by both the measurements and the video image recovery, thus fulfilling the expectations as a protective measure. This paper is a starting point for analysing the effectiveness of power filters for other types of compromising emanations that are considered in the equipment TEMPEST evaluation. In order to improve the TEMPEST efficacy of electronic equipment, we strongly recommend a preliminary evaluation of the EUT from the spurious emissions perspective, preceded by designing customized power supplies and power cables to reduce the CE conducted through the power supply network. The TEMPEST evaluation should be followed by a proper equipment installation and positioning for EUT, data lines, power cables and peripheral devices.

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