INFORMATION EXTRACTION FROM THE RADIATION OF VDUs BY PATTERN RECOGNITION METHODS

N. E. Köksaldı [(1),(2)] S.S. Şeker [(1),(2)] B. Sankur [(2)]

(1) TUBITAK UEKAE 41470 Gebze-Kocaeli/TÜRKİYE , e-mail: koksaldi@mam.gov.tr
(2) Boğaziçi University, Department of E.E. 80815 Bebek-İstanbul/TÜRKİYE

Abstract - In this work, the information which is captured from the radiated and conducted emissions from the computers' video display units (VDU) is analyzed and recognized. The results are compared with the available literature. As a new approach, storage of the emanation data in the digital environment and reconstruction of the display contents by converting this data into the image format with a software are introduced and analyzed.

1. INTRODUCTION

The need to protect both equipment and humans from the electromagnetic radiation was the starting point for electromagnetic compatibility (EMC) studies. A second related problem is electronic intelligence, whereby unauthorized information can be seized from the radiated/conducted emissions. Radiation arising from data processing equipment or Information Technology Equipment (ITE) may contain classified information which may be intercepted and analyzed.

Due to the increasing speed of digital equipment, the radiated emissions are broadband [1]. They reach up to very high frequencies like the emissions from the computers' VDUs. For periodic signals, the probability of detection increases. If the structure of the signal is also known, correlation and averaging techniques can be used for further analysis. For computers, the character generation process, the structure of different font types and operating systems are known.

The starting point of the studies about the eavesdropping risk of the VDUs was a research program carried out by the Dr. Neher Laboratories of the Netherlands PTT [2] [3]. They report that they picked up information displayed on a remote video screen placed in a building from a large distances by using a small van equipped with a very high frequency (VHF) band III antenna, a receiver system, and a television screen. However, they only reconstructed the information on the video screen by using the television receiver system principles. They did not analyzed the information hidden in the time-domain data and enhance the picture for a better view in digital domain.

All of these studies proved that information displayed on a computer monitor can be easily reconstructed from the radiated emissions by using low cost equipment. However the time-domain data also contains all the screen map data such that considering the scanning method each character can be recognized in a computer [4]. The basic idea behind that is to capture one frame at a time in the computer and monitoring the frame and line pulses. After having synchronized with the source screen, one can analyze the pattern of 1's and 0's, each corresponding to a pixel value. Since characters are displayed on a video display unit in matrix blocks (generally 9x14), the picture can be divided into its subblocks. By using appropriate pattern recognition methods, each character can be identified.

In this work, the information which is captured from the radiated and conducted emissions from the computers' VDU is analyzed and recognized. Samples are taken from the MS-DOS and windows operating systems. Hence, the studies are collected under three steps: Electromagnetic interference measurements of personal computers (PCs) and frequency spectrum analysis, reconstruction of display contents on an external monitor, and character recognition.

First, frequency and time domain characteristics of several computers were analyzed by extensive measurements of their different operating modes including MS-DOS graphics, MS-DOS text and Windows 95 modes. In frequency domain measurements, radiated emissions from the computer's monitor and cables were observed and the spectral contents were analyzed. Radiated emission measurements were carried out in the Compact Diagnostic Chamber (CDC). In the reconstruction measurements, with the help of the a prior information about emission levels, the display contents of the tested personal computer was reconstructed on an external monitor. For this purpose, synchronization rates were also observed by direct signal measurements. Finally, the time domain data was analyzed. The feasibility of the information extraction from this continuos serial data were discussed.

All instruments were fully automated. and software controlled via an IEEE-488 standard bus. This allows a personal computer - resident program to adjust the device settings, take measurements with the correct parameters in minimum time consistent with gap-free coverage. Software was written in LabWindows/CVI.

2. PERSONAL COMPUTER VIDEO SYSTEM

Electromagnetic interference (EMI) or EMC analysis of digital computers is very complicated since there are a lot of parameters such as several resolution types, synchronization rates, and operating modes. According to the operating mode, properties of the characters and as a result the radiated emission levels change.

The VDU screen is consists of pixels and these pixels are arranged in horizontal line. Electron beams from cathode ray tube (CRT) scan these lines. Each character is built up from M×N matrix. It is called as a character cell. According to the electron beam in the CRT (on-off modulated) some of the pixels will be highlighted (white spot) while some of them not. Each combination results with a new character. To produce an 80-column text screen with characters 8 pixel wide, a minimum of 640 horizontal pixels is required.

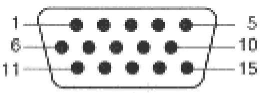
Another important parameter is scanning rates. Horizontal scan rate is a measure of how many scanlines of pixel data the monitor can display in one second. It is controlled by the horizontal sync signal which is generated by the video card, but is limited by the monitor. Vertical scan rate measures the maximum number of frames that can be displayed on the monitor per second at a given resolution. It is controlled by the vertical sync signal coming from the video card. Multisynchronous monitors capable of synching to video signals within a range of frequencies. A computer does not support all the video modes. The supported video modes are determined by the video controller. This information is supplied by the computer's manufacturer.

Most video adapters can run in either text (character) mode or graphics mode. In text mode, a monitor can display only ASCII characters. In graphics mode, a monitor can display any bit-mapped image. Text mode is also called character mode. All video standards for the PC, support a text mode that divides the screen into 25 rows and 80 columns. Programs that run in graphics mode can display an unlimited variety of shapes and fonts, whereas programs running in character mode are severely limited.

When a computer is operating in windows mode, it becomes more complicated to analyze the contents of the video signal the text style is not standard, i.e. it changes from one application to another. On the other hand, in MS-DOS operating system, the distance between the pixels and the size of the characters (ASCII) are standard. Each character is represented by a M×N matrix. In MS-DOS mode, it is also possible to switch to the graphics mode.

CRT device is attached to the display adapter through a standard 15-pin high-density D shell connector. The image or text message is transferred to the monitor as analog signal with this connector interface. Figure 1 defines the connector's pins and some of the signals on the interface.

The signal characteristics and the exact synchronization rates were determined by directly observing and recording the transmitted signals through each pin. From these observations, the pixel waveform frequency and character cell size were determined and the actual total line number were calculated from the vertical and horizontal synchronization rates. It is simply the ratio of these two values. These measurements can be named as "direct pin measurements". The signals are noise free except the cable losses. Therefore, this is a very useful method to establish the a database for radiated emission analysis.



PIN NO.	FUNCTION
1	Red Video
2	Green Video
3	Blue Video
5	ground
6	Red return (ground)
7	Green return (ground)
8	Blue return (ground)
10	Sync return (ground)
13	Horizontal Sync
14	Vertical Sync

Figure 1 - 15-pin D Connector and Corresponding Signals.

3. MEASUREMENTS

3.1. Frequency Domain Measurements

Before starting the time-domain measurements, frequency-domain characteristics, i.e. radiated emission properties, of the environment and the effect of the PC was observed [5]. These pre-measurements are very useful to get an idea about the tuning frequency that will be used in the time-domain measurements. By comparing the ambient level and the emissions from the PC, an initial information about the frequencies at which these emissions are dominant. The affects of different resolutions, color schemes, fonts, and character patterns on spectral characteristics were observed. Test setup for frequency domain measurements is given in Figure 2. GPIB refers to General Purpose Interface Bus. All measurements were done in CDC to get rid of the undesired environmental affects.

The frequency range was divided into two bands: 5 - 30 MHz and 30 MHz - 1 GHz. Monopole antenna and bilog antenna was used at each band, respectively. The peak detector was used in all measurements. The selected bandwidths, step sizes, and measurement times for each frequency band is given in Table 1. Radiated emission levels were recorded by EMI receiver in "dBµV/m" after adding appropriate correction and gain factors.

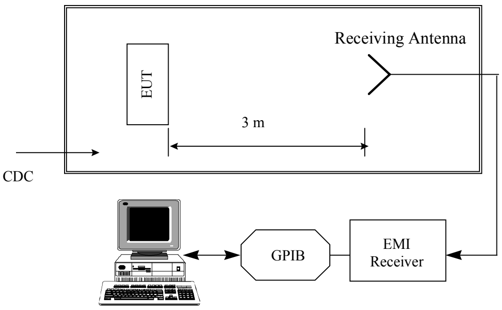


Figure 2 - Frequency Domain Test Set-up

The measurement results were recorded graphically with the ambient level. To obtain reliable and repeatable results, the ambient of the CDC was measured and set as a reference noise level.

Table 1 - Resolution Bandwidths and Step Sizes.

	5 - 30 MHz	30 MHz-1 GHz
Resolution Bandwidth	100 kHz	120 kHz
Step Size	50 kHz	60 kHz
Measurement Time	20 ms	20 ms

The radiated emissions were recorded for blank screen (cursor only), full with character 'H' in MS-DOS mode, and for windows mode.

3.2. Reconstruction Of The Display Contents
A current probe or a broadband antenna was used to pick up emissions. Test set-up is given in Figure 3. Instead of a TV receiver, an analog oscilloscope or another computer monitor was used as an external monitor to view the reconstructed picture. The EUT was an industrial computer with LCD monitor.
The radiated emissions collected by the bilog antenna was fed into the super heterodyne receiver. Detected emissions were demodulated and amplified. This demodulated time data was given to the external monitor's video (z-axis) input. To obtain the picture, vertical and horizontal synchronization signals were supplied from two signal generators. If these synchronization frequencies is not adjusted correctly, the video screen will scroll up and down or the information will not be seen correctly (distorted). Hence, in advance, the synchronization rates for each EUT was determined from their corresponding pin outputs.

The receiver must be tuned to a suitable frequency with a wide bandwidth to obtain best image quality on the external monitor. At this point, the results obtained from the first part was used as a reference. The frequencies where the highest emission levels occurred were chosen. Also, the receiver's bandwidth must be at least 10 MHz since video signal bandwidth is very high. Lower resolutions blurred the image, caused distortions, and hence decrease the signal to noise ratio.

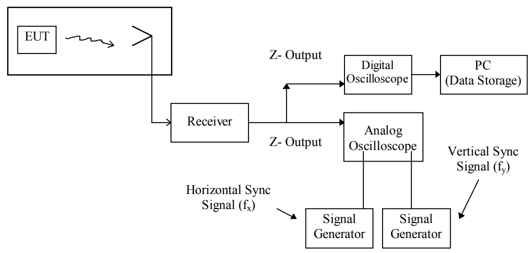


Figure 3 - Reconstruction Test Setup.

The video signal samples obtained from the receivers' z-axis output was also stored on a personal computer for analysis part.

3.3. Character Recognition
Although, the display contents of a remote computer can be reconstructed on an external one from a couple of meters, the understanding of this captured data is not an easy job. The information is hidden inside the emission data which also contains environmental noise, emissions from the other electronic devices and internal noise. This noisy data received from the antenna can be enhanced by using several devices such as filters, lock-in amplifiers, etc. Also software based enhancement tools can be applied this data. Emission data can be stored in a serial format or can be converted to the still picture.

One of the video signal pin outputs or z-signal output of the measuring receiver is used as an input to the digitizing oscilloscope. Oscilloscope settings (time scale, delay, voltage division, etc.) are adjusted such that the desired portion of the video signal is displayed on the oscilloscope screen. I set the scale such that the first line of the character stream on the video screen is the starting line. Digitizing oscilloscope is controlled via IEEE 488.2 bus by a LabWindows/CVI program. The user enters the line scanning rate in kHz, the total number of lines - N - that will be stored, and also the output data filename.

When the measurements are started by pressing the "Start" button, real time data is stored on the computers' memory. This is done recursively for each line. Moreover, each line is measured for 16 times and the final data is obtained from the average of these 16 measurements. This is a very useful method to get rid of noise for periodic signals.

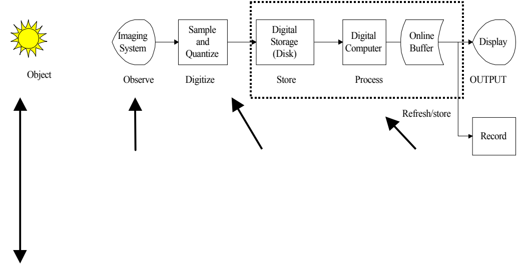
To store complete frame data at the same time, a high rate data acquisition system is needed with approximately 1 MB memory module on it. In other words, 640x480 resolution with 60 Hz refresh rate means that 640x480x60= 18.43 MB information in a second. However due to the hardware limitations, it was impossible to record time domain information for whole screen at a single shot. Digitizing oscilloscope can only transfer 1000 samples/measurement. Hence, lines were store separately by inserting a delay. Whole data are stored in a N×1000 matrix as a text file. Then, this data can be converted to image format to obtain the picture of the EUT screen or directly time domain signal can be analyzed. It is quantized to desired levels and negative values are corrected. A software toolbox was established for both enhancement and recognition. All of these modifications were done by MATLAB programs.

3.4. Digital Image Processing System

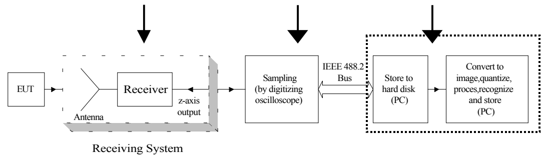
A typical digital image processing system is shown in Figure 4 (a) [6]. When this system is adapted to reconstruction test setup (Figure 3), corresponding components are given in Figure 3 (b).

The emission data picked by the antenna or current probe and is fed into the receiver. The receiver's output is connected to the digitizing oscilloscope which samples this data. This voltage amplitude data is transferred to the computer with its time information. The negative voltage values are quantized to zero.

Then, each amplitude value is assigned to a gray scale color directly and it is converted to a M×N matrix. M represents the number of lines where N is the desired resolution (or number of samples). Finally, a gray-scale image representation of the original analog data is obtained.



(a) A typical digital image processing system.



(b) Corresponding Building Blocks in Reconstruction Test Setup.

Figure 4 - Comparison Of Typical Digital Image Processing System and Reconstruction Test Setup.

4. RESULTS

4.1. Frequency Domain Measurements

In Figure 5, recorded emissions when the screen is empty and filled with the same character ('H' or '|') are given. Pixel clock harmonics are exist in both graphs, but the field strengths differ. The number of harmonics and amplitude levels are directly related with the character cell size. When the screen was full with characters, a lot of additional harmonics were detected comparing with the empty screen. Moreover, the broadband emission levels are increased. Hence, it is related with the number of characters.

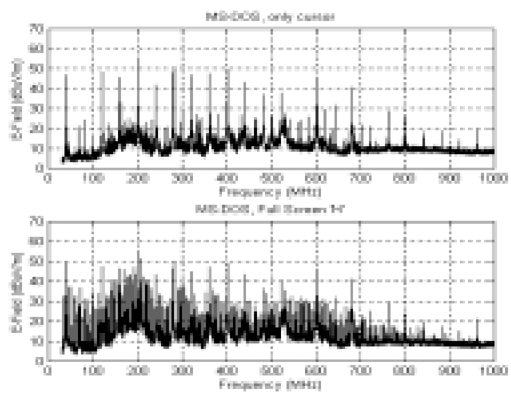


Figure 5 - The Effect of Character Pattern on Electric Field Strengths: 'H' versus empty screen (vertical polarization)

Higher emission levels were obtained with vertically polarized antenna. Both narrowband and broadband components detected. Harmonics (narrowband components) are related with pixel clock frequency and character cell size while broadband emission levels are related with number of characters operating mode affects the level of emissions.

Two operating systems, Windows 95 (desktop) and MS-DOS, were compared. The results are given in Figure 6. The broadband emission levels were higher in Windows 95 while the number of harmonics increased in MS-DOS system. However, this observation is not enough to discriminate these two operating systems by looking at their spectral contents. Because spectral components are directly related with the character pattern, its size, and the number of characters.

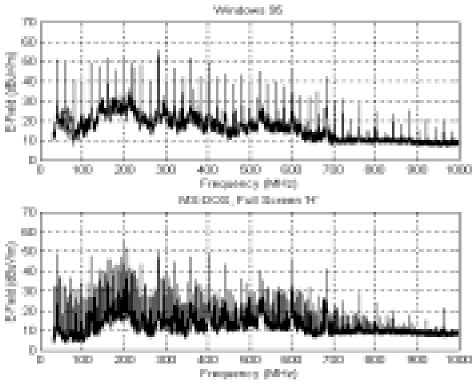


Figure 6 - Comparison of Electric Field Strengths of Windows 95 and MS-DOS (‘H’) Operating Systems (vertical polarization)

4.2. Reconstruction Of The Display Contents

The reconstruction was generally possible up the 20 meters with decreasing picture quality. Frequency measurement results given in section 4.1. were used and tuning frequency of the receiver was selected according to these results. Antenna polarization was set to vertical direction. Receiver bandwidth was adjusted to 10 MHz (at least).

Then, EUT was placed into the CDC. For that time, data obtained from the z-axis output of the receiver was in a personal computer. The scanning rates, resolution, etc. were adjusted by using a program written in MATLAB. The results are given in Figure 7, and 8. These characters written in MS-DOS graphics mode.

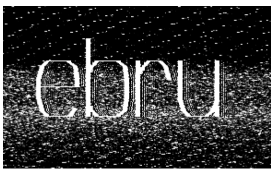


Figure 7 - Reconstructed “ebru”

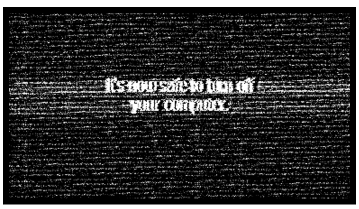


Figure 8 - Reconstructed “It’s now safe to turn off your computer”

4.3. Character Recognition

The emission data stored in the reconstruction part was analyzed and converted to two-dimensional picture. Then images were binarized, and suitable spatial filters (if desired) were applied. After this pre-processing , they were dilated, and the possible objects were labeled with different colors. Several features were extracted from the original character set.

In this application, all lower case letters were written on the screen in MS-DOS mode. An image database for small case letters was established by converting the original video signal data to 64×64 gray scale image. Binary (area, center of gravity, etc.) and histogram (mean, variance, entropy, average energy, skewness, etc.) image features were calculated.

There is not an important difference between the binary image features. Area can be used as a discriminator. ‘l’ and ‘r’ are smaller. But area is related with the size of the image. Hence, it can be misleading in most of the situations. As an example, the original ‘a’, its thresholded, dilated, and labeled images are given in Figure 9.

Original Image | Thresholded (method 2) and Dilated Image | Labeled Image

Figure 9 - Enhancement and Labeling of character ‘a’.

After collecting these information, noisy data was subjected to the same procedure. A word was written on the black screen with white color. Although the data was not very noisy, the objects (in this case letters) were labeled correctly. The results are shown in Figure 10.

Noisy Image

Thresholded Image (with 114)

Dilated Image

Labeled Image (‘i’ was detected as two different objects)

Figure 10 - Analysis of Noisy Image

5. CONCLUSIONS

In this work, the collected data from the radiated and conducted emissions of VDUs was analyzed. These measurements were taken from different environments and working conditions.

There were three parameters that affect the performance of frequency spectrum measurements. The first one is the height and the direction of the receiving antenna. It was observed that when antenna was vertically polarized, higher emission levels were detected for all tested personal computers. Polarization did not effect the position and number of the harmonics. Theoretically, it is very hard to say that in which Cartesian direction emissions are more dominant.

The second parameter was the narrowband and broadband components of the emissions. The source of the harmonics is the pixel clock which is generated by a crystal oscillator located on the video card. The number of harmonics and the amplitude levels are directly related with the character cell size. When the full screen and empty screen (only a blanking cursor) results are compared, it is determined that the broadband emission levels are related with the number of characters. A lot of additional harmonics were detected in full screen text mode.

The third parameter was the effects of the operating systems. Windows 95 desktop view and MS-DOS is compared. The broadband emission levels were higher in Windows 95 mode while the number of harmonics increased in MS-DOS system. However, this is not enough to discriminate these two operating systems. A further analysis of the spectral contents has to be made.

The second part of the measurements consist of the reconstruction of the display contents. PC was subjected to these tests and its screen was captured from 20 meters.
Finally, the feasibility of using the image processing algorithms for detailed analysis and character recognition was examined. For MS-DOS environment, the characters were recognized successfully. Also the image samples obtained for Windows 95 operating system were subjected to the OCR program. Due to low resolution, it was hard to discriminate the characters and we did not get the desired performance.

In the later stages of my work, I have started to use a sophisticated data acquisition system with very high data transfer rates and storage capacity. The image quality was increased due to the high sampling rates. Considering all of these studies, we have preferred to process the serial data instead of enhancing the image. We currently study on de-noising algorithms and noise reduction techniques.

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