Real Time Digital Signal Processing and Measurement Method for Electromagnetic Compatibility Verification into the Ships

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Abstract— In this paper, we present a new Electromagnetic Compatibility (EMC) measurement and verification system for ships, based on real time digital signal processing techniques, in combination with a VLF-UHF receiver. We programmed all the algorithms for the systems, in order to have reliable software, known, expandable and intuitive. The basis of our strategy is first described, then, our implemented computing algorithms are explained. Recommendations and examples about the significant parameters for dealing with the measurement process are given, and finally several measurements are performed to validate the proposed method.

Keyword: Electromagnetic Compatibility (EMC), Electromagnetic Interference (EMI), Digital Signal Processing (DSP), Sound Card, Maritime Radiocommunications.

I. INTRODUCTION

Any metallic vessel behaves like a Faraday cage from which the radiation generated on board will probably remain on the ship and this situation will increase the possibility of EMC problems [1, 2]. On board the vessel there are a lot of radio-communication and radio-navigation equipment [3, 4] including VHF, HF, UHF communication transmitters, X-band, S-band Radar, satellite communications transmitters, Automatic Identification system (AIS), among others. This equipment emits electromagnetic radiation during their normal operation; in this case we are talking about on-board intentional electromagnetic radiation i.e. emissions. Moreover, inside the ship we can find many devices and apparatus like the air conditioning equipment, machinery being powered by motors, generators to operate tools, inverters, computers, printers, vacuum cleaners, washing machine, etc. These devices can emit non-intentional electromagnetic radiation during their normal function. Each device installed on the ship must comply with the current regulations, but when numerous electrical and electronic apparatus and equipment on board are working together in the vicinity, this leads to the creation of a hostile electromagnetic environment [2].

In a medium or large size warship, at least a spectrum analyzer is used for monitoring the radio-link quality for HF, VHF or UHF, even apart from the sensitive equipment Electronic Warfare (EW) or SIGnals INTelligence (SIGINT), which cannot be displaced by the ship given its size and weight

characteristics. However, on civilian vessels, the only tool for detecting a malfunction or interference is the LF-HF receiver. Assuming that on-board the ship there is, a Radio official who knows what to do, a portable receiver, and a portable antenna, which is highly improbable since it came into full force on the 1999 "Global Maritime Distress and Safety System" GMDSS [5], when such officers were landed, and just until 1 February 1999 were part of the cadres of minimum crew of the ship since the radio was invented, becoming now a maintenance staff at ground stations or companies of the ports.

Thus, and particularly when on-board there is no calibrated equipment for spectrum analysis, it is necessary to resort to the ingenuity and symbiosis between electronic and computer sciences, to detect, locate and if possible identify the sources of noise and interference that cause malfunctions in the rest of the ship's equipment. The availability of a reliable software, known, expandable and intuitive, with VLF-UHF receiver, weighing less than one kilogram and that can be powered with batteries will be one of the best tools available for the electro-technical officer of the ship, department staff of machinery with Radio-electronic training, as provide the Manila Amendments (2010) for the on training, certification, and watch-keeping for the seafarers signed by hundred of International Maritime Organization (IMO) members [6]. For this purpose, we developed various autonomous algorithms running in a parallel way, and making up, in the whole, a new low cost electromagnetic compatibility (EMC) measurement and identification system for ships (Figure 1). First, we design algorithms for controlling the IC-PCR1000 [7] receiver for the task of receiving signals in the band above 10 kHz. It is a wide band receiver that covers the frequency from 10 kHz to 1300 MHz, with different reception modes (AM, FM, FM-W, CW, LSB, and USB) (Table I). The IC-PCR1000 is connected to the PC sound card, leading to a powerful low cost system for signals analysis and measurement [8]. Second, we compute the low-level programming for the PC sound card in order to capture the signal received by the IC-PCR1000 for their further processing. The sound card has been used in several applications in the last years [15-21]. In most of the cases, sound card was used at the high-level programming, using some pre-existing tools and library available in software like Labview and Matlab. The sound card has a very good

capability, but it is necessary to compute the low-level programming, in order to control the parameters which affect the capturing process. To our knowledge, this task has not been explored previously. Third, we program various algorithms; for the calculation of the signal spectrum [9], for the signal analysis [10], for the Digital Signal Processing [11], for measuring the signal detected [12, 13, 14]. Fourth, we build a visual interface for the control and data displays of the system measurement. Last, we create a strategy to save data into a data base containing the relevant information.

The task of measuring signals and detecting Electromagnetic interferences (EMI) require understanding of several factors [22, 23]. From one side, it is necessary to know the nature of the interference we are looking for, the frequency range of these interferences, the adequate antenna [24], cables and connectors to be used. From the other side, we must recognize which bandwidth (BW) filter must be applied, when it is necessary to use the averaging techniques and what type is appropriate, how many data samples must be captured, what sampling frequency should be selected, how many FFT points must be calculated, what is the optimal buffer size, and other important parameters. Changing one of these parameters will affect the whole measurement process. Each of these factors requires special consideration.

II. SYSTEM DESCRIPTION

The basic scheme for the system measurement is represented in Fig. 1. Next we describe each stage of the system.

Figure 1. The basic scheme for the system measurement developed

A. Radio Control

The IC-PCR-1000 (Fig. 2) is a wideband radio receiver that is controlled via the PC serial port. It has wideband coverage from 10 kHz to 1.3 GHz and can operate at CW, LSB, USB, AM, FM and WFM mode (Table I). This receiver will be our primary interface with radio-frequencies. We will use the audio output to have an intermediate frequency on which will perform the spectral analysis by the next stages. So, we will have a maximum bandwidth of 20 kHz.

Figure 2. IC-PCR1000 receiver

TABLE I
IC-PCR1000 RECEPTION MODE

RX mode	Description	Compatible Emission class
AM	Amplitude Modulation Double Sideband	6K00A3EJN
USB	Superior Single Side Band (SSB) with suppressed carrier (Analog Phony)	2K70J3EJN
LSB	Inferior Single Side Band (SSB) with suppressed carrier (Analog Phony)	2K70J3EJN
CW	Carrier interruption Telegraphy	1K00A1AAN or 1K00J2AAN
FM	Frequency Modulation, commercial quality	15K0F3EJN or 15K0G3EJN
WFM	Frequency Modulation, Broadcasting stereo quality.	150KF3EGN or 150HG3EGN

For example, we have implemented a monitoring system algorithm for scanning some important maritime frequencies and when detecting emission at these specific bands, the system triggers an alarm, saves the detected events in a data base with information of the time, level of the signal, frequency, etc. In addition we store the image of the spectrum for further analysis. This algorithm is described in Figure 3.

B. Signal Capturing

The signal received by the IC-PCR1000 is a continuous signal $x(t)$. This signal will be sampled into a sequence of a discrete data $x[n]$ (EQ1). This periodic sampling is achieved by using the PC-sound card. For this purpose, we compute a low-level programming algorithm in order to control the tasks of capturing signal, and buffers management to store data in the optimal way without losing information.

$$X_N = \sum_{n=0}^{N-1} x[n] \quad (1)$$

Several implementations can be used to capture the signal using the sound card. Nowadays, advanced techniques known as —simultaneous multi-buffer acquisition and readout (SAR) mode [22] are used to improve the precision of the capturing method with no information loss, especially used in the case of measuring pulse that can appear in a very short time. In our application we use the double buffering technique. It consists of using two buffers in order to achieve the processes of continuous capturing without loss of data.

While one buffer is capturing data, the other is making the processing task. This process is described in Fig. 4.

Figure 4. Capturing process protocol used

The algorithm implementation for computing the buffers management is shown in the Fig. 5.

C. Spectrum estimation & Digital signal processing

The discrete-time signal X_N (1) is then converted from the time domain to the frequency domain though the calculation of the Discrete Fourier Transform DFT (2) [10-12]. We compute the DFT by the Fast Fourier Transform (FFT) algorithm [26-29].

$$X(m) = \sum_{n=0}^{N-1} x(n)e^{-2\pi m n / N} \quad (2)$$

Where:

$X(m)$: discrete Fourier Transform of $x(n)$
 m : index DFT output at the frequency domain,
 $m=0,1,2,\dots,N-1$
 $x(n)$: samples of time input waveform $x(0), x(1), x(2), \dots, x(n)$
 n : index sample of the signal of time input
 N : total number of the input samples.

Figure 3. Monitoring system algorithm flowchart for IC-PCR1000 scanning

Figure 5. The buffers management algorithm flowchart

In order to reduce the leakage effect we use the windowing technique. The input sequence X_N (1) is multiplied by a function window $w(n)$ (4-9) before the DFT is performed.

$$X_w(m) = \sum_{n=0}^{N-1} w(n).x(n)e^{-j2\pi mn/N} \quad (3)$$

The windows implemented in our measurement system are presented bellow.

Rectangular window:

$$w(n) = 1 \text{ for } n = 0, 1, 2, \dots, N-1 \quad (4)$$

Triangular window:

$$w(n) = \begin{cases} \frac{n}{N/2} & \text{for } n = 0, 1, 2, \dots, N/2 \\ 2 - \frac{n}{N/2} & \text{for } n = N/2 + 1, N/2 + 2, \dots, N-1 \end{cases} \quad (5)$$

Hanning window:

$$w(n) = 0.5 - 0.5 \cos\left(\frac{2\pi n}{N}\right) \text{ for } n = 0, 1, 2, \dots, N-1 \quad (6)$$

Hamming window:

$$w(n) = 0.54 - 0.46 \cos\left(\frac{2\pi n}{N}\right) \text{ for } n = 0, 1, 2, \dots, N-1 \quad (7)$$

Blackman window:

$$w(n) = 0.42 - 0.5 \cos\left(\frac{2\pi n}{N}\right) + 0.08 \cos\left(\frac{4\pi n}{N}\right) \text{ for } n = 0, 1, 2, \dots, N-1 \quad (8)$$

Blackman-Harris window:

$$w(n) = 0.36 - 0.49 \cos\left(\frac{2\pi n}{N}\right) + 0.14 \cos\left(\frac{4\pi n}{N}\right) - 0.01 \cos\left(\frac{6\pi n}{N}\right) \text{ for } n = 0, 1, 2, \dots, N-1 \quad (9)$$

Applying a window reduces the leakage effect, but at the same time reduces the magnitude of the output, for this reason, it is necessary to multiply the output magnitude DFT value by a scaling factor [30, 31]. Table II shows the different scaling factor values for the different windows used in our measurement system.

TABLE II
DIFFERENT SCALING FACTOR
FOR THE DIFFERENT WINDOW

Window	Scaling Factor
Rectangular	1
Hamming	0.54
Blackman	0.42
Blackman-Harris	0.42
Hanning	0.50

III. EXPERIMENTAL RESULT

A. Reducing the effect of noise

When the level of the signal to be detected is nearly equal to the noise level, it is difficult to extract this signal from noise. Especially when using the receiver. In order to improve the accuracy and repeatability of measurements we give some recommendations for this purpose.

A.1. Measurement in narrow band

Doing measurement in narrow band (NB) mode is one way of reducing the quantity of the background noise mixed with the signal (Fig. 6), so we can identify the signal of interest better when we choose a narrower filter.

Figure 6. Quantity of noise included in (a) NB measurement (b) WB measurement

A.2. Increasing the size of the number of points FFT

Increasing the size of the number of points FFT to be computed has the advantage of increasing the processing gain [11], which allows for the possibility of extracting signal that is inserted into noise.

The output signal-to-noise ratio (SNR) of the DFT increases when the number of points FFT computed increase. In [8] several examples were presented to show this effect. The FFT act like a digital filter, the higher the FFT size is, the lower is the background noise included; the narrower is the main lobe of the signal to be detected.

A.3. Averaging

We give example of implementation of the technique of Exponentially Weighted Moving Average (EWMA) [32, 33] which is a statistical method to monitor the data averaging process, giving more weight to the latest data, but at the same time take into account the effect of the older data.

The EWMA is expressed in terms of the averaging calculated in the previous period using the following equation:

$$Y_N = \alpha \cdot SPCTRM_FFT + (1 - \alpha) Y_{N-1} \quad (10)$$

$$Y_1 = SPCTRM_FFT(1)$$

$$\text{For } N = 1, 2, \dots, N_FFT$$

Where:

Y_N : AVG computed

Y_{N-1} : old AVG computed

$SPCTRM_FFT$: Actual spectrum signal computed.

α : Constant, $0 < \alpha < 1$

Each calculation of the exponential moving average adds the effect of the latest data without ignoring the old one.

The equation (10) can be written in a different way (11) to emphasis that the exponential moving average tends to retain its previous values and only update by a fraction of its difference from the most recent data.

$$Y_N = Y_{N-1} + \alpha \cdot (SPCTRM_FFT - Y_{N-1}) \quad (11)$$

$$Y_1 = SPCTRM_FFT(1)$$

$$\text{For } N = 1, 2, \dots, N_FFT$$

The EWMA initialization value can be $Y_1 = \text{Spectrum_FFT}(1)$. It is possible also to choose other value like the $\text{Spectrum_FFT}(2)$ or $\text{Spectrum_FFT}(3)$, etc. The effect of Y_1 initialization in EWMA calculation will also depend on the constant α . The more α increases, the lower is the impact of the oldest capture.

B. Method performance evaluation

Obtained specifications with the method described in this work are shown in Table III-VI.

As we can see in Table IV and Table V which represent the sensitivity of the IC-PCR1000 and the sound card respectively, with the sound card IEEE-32 bits configuration, and the IC-PCR1000 in SSB mode we obtain impressive sensitivity, which is one of the advantages of our method. Another advantage presented by our method is the possibility to measure narrow band signals (Table. III) This kind of measurement is very important in case of having signals very close and could be detected as a unique signal if the selectivity of the measurement instrument is not narrow enough (Fig. 7).

A Comparison between the minimum specifications for a precompliance spectrum analyzer [13] and the characteristics of our method is shown in Table VI. As we can see, the total specification for our system, present an excellent capabilities.

Figure 7. Narrow band measurement signals

TABLE III
IC-PCR1000 FILTER BANDWIDTH

Modes of reception	Bandwidth
AM	15/6 kHz
SSB	2.8 kHz
CW	2.8 kHz
FM-Narrow	15/6 kHz
FM-Wide	230 kHz

TABLE IV
IC-PCR1000 SENSITIVITY

Frequency (MHz)	SSB/CW 2.8kHz filter (10 dB S/N) dBμV	AM 6kHz filter (10 dB S/N) dBμV	FM 15kHz filter (12 dB SINAD) dBμV	WFM 230kHz filter (12 dB SINAD) dBμV
0.5 - 1.8	-5.04	7.96	--	--
1.8 - 28	-11.1	2.92	--	--
28 - 30	-11.1	2.92	-6.02	--
30 - 50	-9.12	5.11	-6.02	--
50 - 700	-14.0	0.00	-9.90	-2.05
700 - 1300	-12.0	2.28	-7.96	0.00

TABLE V
SOUND CARD SENSITIVITY

Bit Number	Sensitivity	Sensitivity (dBμV)
8 bits	3.9215 mV	71.9 dBμV
16 bits	12,207μV	21.6 dBμV
24 bits	0.0596 μV	-24.5 dBμV
IEEE-32 bits	0,00023 μV	-72,65 dBμV

TABLE VI
COMPARISON BETWEEN THE MINIMUM SPECIFICATIONS FOR A
PRECOMPLIANCE SPECTRUM ANALYZER AND THE
CHARACTERISTICS OF OUR METHOD

Parameter	Precompliance Specification	IC-PCR1000 Specification	Sound Card Specification	System Total Specification
Frequency range	100kHz - 1GHz	10 kHz to 1300 MHz	50 Hz to 20kHz	50 Hz to 1300 MHz
Resolution IF bandwidth	9 or 10kHz and 100 or 120kHz	2.8/6/15/50/230 kHz	1 Hz - 374 Hz	2.8/6/15/50/230 kHz by Hw 1 Hz - 374 Hz by Sw
Detector functions	Peak and average	-	-	Peak and average AVG EXP
Sensitivity	<20dBμV at 100kHz Bandwidth	<0dBμV at 230kHz Bandwidth <-5.04 dBμV at 2.8 kHz Bandwidth	-72,65 dBμV	-72,65 dBμV for frequency <20kHz
				<0dBμV at 230kHz Bandwidth
				<-5.04 dBμV at 2.8 kHz Bandwidth
Display	Free run and max-hold modes	Free run and max-hold modes	Free run and max-hold modes	Free run and max-hold modes
Input impedance	50 Ω	50 Ω	-	50 Ω

We have tested the Analog to Digital Converter (ADC) errors of the sound card, and have found a good linearity (Fig.8), an offset error which is corrected by software through an initial calibration before starting the measurement process.

Figure 8. Linearity testing of the sound card

For the frequency and amplitude calibration we used the Agilent 33250A waveform generator.

Figure 9. Frequency Calibration process

We give an example of signal detection and measurement by our method. We use a radio-telephone BAOFENG VHF/UHF in order to emit a VHF signal with frequency 144,010 MHz in FM-Narrow mode, with a low power. We tune the IC-PCR1000 receiver to the frequency 144,007 MHz; we use the LSB reception mode, with a filter BW 15 kHz. The parameters of the analysis used are: Sampling Frequency $F_s=44,1\text{kHz}$. $N_{\text{FFT}}=8192$, Window: Hanning. The Fig.10 shows the spectrum of the frequency 144,007MHz when no emission was made from the BAOFENG VHF/UHF radio-telephone.

Figure 10. Spectrum of the frequency 144,007MHz when no emission from the BAOFENG VHF/UHF radio-telephone

The Fig.11 depicts the spectrum detected by our method measurement when an emission is sent from the BAOFENG VHF/UHF radio-telephone.

Figure 11. Spectrum detected when an emission is sent from the BAOFENG VHF/UHF radio-telephone

The next example (Fig.12) shows the measurement of a radiated known AM signal sent from the PCE-SDG1010 waveform generator. We use the AN200 E1-124819 Eton (520 kHz-1710 kHz) antenna for the emission of the signal 550 kHz modulated with 5 kHz.

To detect this signal we use the following parameters: Frequency reception 550 kHz, mode AM, BW 15 kHz,

Window Black-Harris, Sampling frequency 44100 Hz, N FFT= 2024.

Figure 12. Measurement of a radiated AM signal

IV. CONCLUSION

In this paper, the design of simple low cost electromagnetic compatibility (EMC) measurement and verification system for ships was presented. We programmed all the algorithms for the systems, in order to have reliable software, known, expandable and intuitive, in combination with a VLF-UHF receiver. The method has a remarkable performance which is summarized in TABLE VI. Some measurements were conducted to illustrate method capabilities.

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