Low-Cost EMI Analysis in the Low-Frequency Band

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***Abstract* — This paper will present the development of a low-cost tool for the analysis of radiated Electro-Magnetic Interference (EMI) in the Low-Frequency band. Real-Time, accurate and effective EMI analysis is vital in the debugging stage of RF system installation. When information such as the frequency and amplitude of the EMI are readily available, the source of the EMI can often be quickly found and eliminated. If the EMI analysis tool can be designed as a portable device it can have the added advantage of being able to locate the EMI source by observing the magnitude of the EMI relative to the location and orientation of the system antenna.**

Several devices used for low-frequency spectrum analysis were evaluated along with a suitable antenna system for the reception of radiated electro-magnetic signal in laboratory conditions. Based on this evaluation an antenna and spectrum analysis tool were selected and evaluated 'on-site' in an industrial setting.

***Keywords* — Electro-Magnetic Interference, EM-Noise Low-Frequency, Signal Analysis.**

I. Introduction

This project aims at the development of a low cost system to intelligently analyse radiated Electro-Magnetic Interference (EMI) in the Low-Frequency (LF) band within an industrial environment. The project concentrated on the investigation of EMI occurring in the LF spectrum which greatly affects the operation of LF Radio-Frequency Identification (RFID) systems in particular. These systems operate in the LF unlicensed band, often between the frequencies of 125 kHz and 135 kHz. The goal was to provide a technician/engineer with a basic system to identify EMI and demonstrate this in an industrial environment. Based on initial testing with a Texas Instruments® (TI®) LF RFID system, it was found that EMI occurring within the band 120kHz to 160kHz had a severe effect on the operation of the system.

The TI® system uses a voltage level taken directly from the LF RFID system as measure the amount of EMI present at an installation site. This voltage level represents the EMI detected by the LF RFID system antenna. At the point where this voltage is taken, the EMI has been received, filtered and amplified by the input stage of the RFID system and is about to be presented to the RFID systems signal demodulation stage. While this method proves effective in identifying the presence of EMI, it gives almost no information about the frequency, magnitude or composition of the EMI.

To aid the elimination of EMI in an industrial setting it is vital to be able to make a detailed analysis of the EMI present. Such an analysis should yield information including the frequency components and corresponding amplitudes of the EMI. From this it is often easy to quickly identify the EMI source and deal with the issue. A detailed knowledge of the composition of the EMI present in an industrial setting is also needed if future devices are to be designed which can automatically account for these interference signals and operate as designed.

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II. Electro-Magnetic Interference

Electro-Magnetic Interference (EMI), often referred to as "noise", is any unwanted externally generated signal which enters the signal path of a device [1]. Such unwanted signals can often be separated into two distinct groups based on the method by which they enter the signal path of interest; 'conducted' and 'radiated'. Conducted EMI will enter the system through some physical electrical connection, while radiated EMI is coupled into the circuit through capacitive or inductive coupling between the device components and the EMI source. Such noise sources include electric motors, power invertors, RF communication transmissions and lighting systems. [2]

This paper will deal specifically with the analysis of radiated EMI which greatly affect the operation of wireless RF systems. While conducted EMI can often be accounted for through effective filtering methods on the power stage, radiated EMI is received through antenna stage of an RF receiver. If this EMI is occurring at or near the frequency at which the RF system is operating it becomes extremely difficult to filter from the system.

III. System Requirements

The analysis of EMI in the low-frequency band in an industrial environment requires a portable system for the reception, storage and analysis of the EM signals present. Such a system should include a LF antenna system for the reception of EMI signal, a storage and display unit and a data acquisition system to digitize and interface the signals received signals with the storage and display unit. The storage and display unit should also have adequate processing power to enable it to present the received EMI signals as a spectrum covering the LF band. This project identified a number of devices which were suitable for the purpose.

IV. SYSTEM DEVELOPMENT

A. EMI Analyser

Specialised EMI receivers are designed for the reception and analysis of EMI signals. Initial investigations showed that specialised EMI receivers used for the analysis of EMI were outside the budgetary constraints put on this project. Many of these receivers operate in much the same way as lower-cost and more commonly available spectrum analysers. [3] Therefore it was decided to focus on the spectrum analyser method of EMI analysis. Consultation was sought with a number of company representatives specializing in the analysis of real-world EMI signals. These representatives recommended the use of a portable spectrum analyzer in conjunction with an antenna system tuned to the LF band.

A spectrum analyzer is a device used to examine the spectral composition of a signal presented to it. These devices operate by decomposing the signal into its frequency components and measuring the amplitude associate with each component. This is often performed by applying a Fourier transform (or an equivalent operation) to the input signal. This has the effect of transforming the signal from the time-domain to the frequency domain. The results are then displayed on an amplitude versus frequency graph. With the increased computing power available to modern digital oscilloscopes, many are now able to perform the Fourier transform on a presented signal, hence making them a low-cost alternative to the spectrum analyzer.

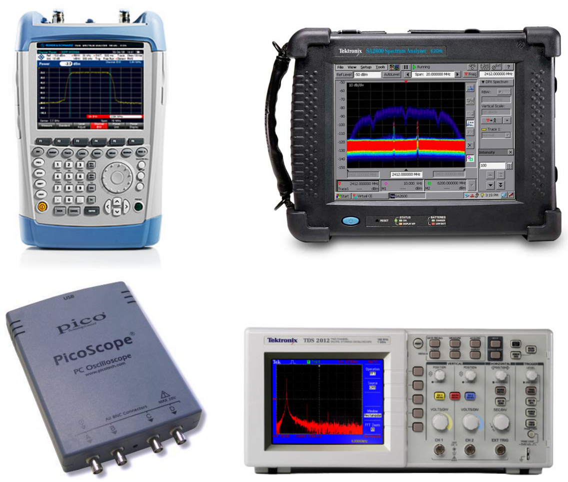

Fig. 1. Clockwise from top-left: R&S® FSH4/8, Tektronics® SA2600, PicoScope® 3424 and Tektronics TDS2002

In order to evaluate the use of a spectrum analyzer for this purpose, two different units, the Rhode&Schwarz® FSH4/8 Handheld Spectrum Analyzer [4] and the Tektronix® SA2600 Portable Spectrum Analyzer [5], were acquired for a short period from their respective distributers in Ireland. The Rohde&Schwarz® device was also supplied with a low-frequency antenna system, the R&S® HE300 Active Directional Antenna System [6].

Two other 'lower-end' devices with the ability to perform the Fourier transform on a received signal were also tested; the PicoScope® 3424 and the Tektronix® TDS2002. The PicoTechnology® PicoScope® 3424 [7] is a USB powered PC-based oscilloscope. This device is comprised of a Data-Acquisition USB device and a software program to process and display the captured data on a PC. This software, PicoScope6®, has a spectrum function which computes and displays the Fourier transform of the signal received. The Tektronix TDS2002 [8] is a standard digital desktop oscilloscope with an option of displaying the Fourier Transform of a signal through the use of its Math function.

B. Antenna System

As this project is interested in analyzing the EMI which may affect the operation of LF RFID systems, an investigation was conducted into how such an RFID system receives both RFID tag signals and EMI signals. It was found that LF RFID systems use a resonant Inductive-Capacitive (LC) antenna circuit for the reception of electromagnetic signals. This circuit takes the form of a loop antenna (inductor) and a tuning capacitor. The components of the antenna circuit are chosen to allow the antenna circuit to be resonant close to the operating frequency of the RFID system (130kHz) according to equation (1).

$$f_R = \frac{1}{2\pi\sqrt{LC}} \qquad (1)$$

A similar antenna circuit was designed for the purpose of receiving EMI signals using the Texas Instruments Series 2000 RI-ANT-G01E loop antenna [9]. This antenna consists of a loop of wire creating an inductance of 27µH. Applying equation 1, a capacitance of approximately 53nF, placed in parallel with the antenna loop, is required to tune this antenna circuit to resonate at 130kHz. A resistor is also placed in parallel with the loop and capacitor to act as a resonance damper, resulting in a flatter, broader frequency response to the antenna circuit This allows the antenna circuit to accurately receive EMI occurring over the range 120kHz to 160kHz, but giving a slightly greater emphasis to those signals occurring closer to the operating frequency of the RFID system. A diagram of the antenna circuit is shown in Figure 2.

The Rohde&Schwarz® distributor in Ireland also supplied this study with the HE300 Active Directional Antenna System. This antenna system is described as a "Portable directional antenna for tracing signal transmitters and interference sources" [6]. It also contains an active pre-amplification stage and claims that the direction of the signal source can be found by pointing the antenna towards the direction of maximum signal voltage. To allow this antenna system to operate in the LF band the optional HE300HF antenna was also provided. This fitting has a frequency range spanning form 9 kHz to 20MHz.

Fig. 2. R&S® HE300HF

V. Antenna System evaluation

Both antenna systems described in Section 3.B were tested with the Rhode &Schwarz®FSH4/8 Handheld Spectrum Analyzer. It was found that, due to the HE300s built in pre-amplification stage, that the EMI signal received by this antenna was of much greater amplitude than that received by the loop antenna. This unfortunately did not increase the clarity of the EMI of interest as all base-band EMI was also amplified by the pre-amplifier.

It was also found that while the HE300HF had a much greater bandwidth (9 kHz to 20 MHz) the resonant antenna circuit performed equally well in the frequency band of interest (120 – 160 kHz).

Testing also showed the direction finding capability of the HE300 antenna system proved to be largely based on a 'trial and error' based method during which the EMI signal amplitude will vary with respect to various antenna locations and orientations. It was found that the direction finding capabilities of the resonant antenna circuit compared very favorably with that of the HE300 antenna system.

Having found that both antenna systems performed the required task to a very similar level, the decision of which antenna system to use for this EMI analysis system was based upon the financial cost associated with each antenna system. The HE300 Active Directional Antenna System is prices at $8130 (€5,500.24), $6430 (€4,350.13) for antenna set plus $1700 (€1,150.11) for LF antenna option [12] while the purpose-built LC resonant antenna circuit cost a total of €154.43 (Antenna Loop €154.28 [10], Capacitors: €0.10 Resistor €0.05 [11]). This makes the purpose built LCR resonant antenna circuit the obvious choice for use in this system.

The cost of the this antenna circuit can be further reduced by producing a loop antenna 'in-house' to replace the Texas Instruments Series 2000 RI-ANT-G01E loop antenna, which is composed of a 27uH loop of high-quality wire.

VI. Spectrum analyser Evaluation

Initial evaluation took place in a laboratory setting, with various EMI sources, such as waveform generators and unfiltered power invertors, present. Each spectrum analyser tool (together with an LF antenna) was tested to determine if it could successfully detect the correct frequency of the EMI source in use and also if the source could be located by observing the change in the signal amplitude as the location of the antenna changed.

Upon testing of each of the spectrum analysis systems mentioned in Section 3.A, it was found that all four had the ability to detect strong EMI signals in real-time. The spectral composition of these signals could be viewed immediately on the display and by moving and rotating the low-frequency antenna a good estimation of the location of the EMI source could be determined.

In the presence of weaker EMI signals it was found that the Tektronics TDS2002 Oscilloscope performed poorly. This was mainly attributed to the fact that the display on the unit is quite small and the magnification function available did little to enable accurate frequency and magnitude analysis. The TDS2002B is priced at €1160 representing a very economic option to industry [8].

Both the Tektronix® H600/SA2600 Spectrum Analyzer and the Rhode &Schwarz®FSH4/8 Handheld Spectrum Analyzer performed well, detecting the EMI present in the LF band with a high degree of accuracy and easily magnified displays. Both had the ability to identify the frequency of EMI with great accuracy and by moving the antenna the EMI source could be located by 'trial and error', based on the EMI signal amplitude with respect to various antenna locations and orientations. Both of these options prove highly expensive, with the Tektronics® SA2600 priced at €21000 [5] and the Rohde&Schwarz® spectrum analyser priced at $9220 [12].

Table 1: Spectrum Analysis Tool Price Comparison

Spectrum Analysis Tool	***Cost***
R&S® FSH4	€6244.43
Tektronics® SA2600	€21000.00
PicoScope® 3424	€873.75
Tektronics TDS2002	€1160.00

(Currency conversion [13])

The PicoTechnology® PicoScope® 3424 proved to be the device most suited to the application. While the PicoScope® hardware device has a degree of on-board processing power, its ability to access the processing and data storage capabilities of a PC or laptop allows it to perform to a level similar to that of much higher-end devices. The supplied PicoScope6® software which operates on the PC or laptop has a very accurate 'Spectrum' function which produces a very high resolution Fourier transform of the received signal with a resolution similar to that of the Rohde&Schwarz® and Tektronics® purpose-built spectrum analysers. It also proved far more user friendly than the other devices tested. The user-interface of this device is based on a Windows® operating system, allowing technicians with moderate PC skills to be quickly trained to operate the device. This device also represents a very economical solution, at a cost of €873.75 [7], when compared to the other devices tested, see Table 1. In addition to this low cost, the device also operates as a standard desktop PC-oscilloscope, making it highly useful commodity for industry.

The final system to be used for the analysis of LF EMI in an industrial setting is shown in Figure 3.

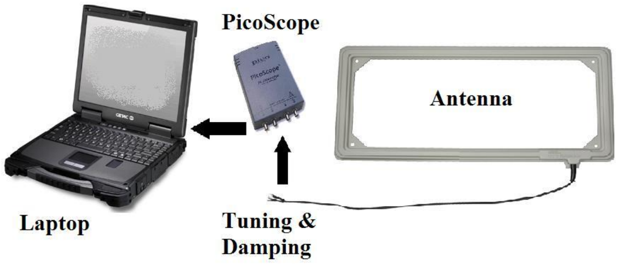

Fig. 3. Final System Assembly

VII. 'ON-SITE' SYSTEM EVALUATION

To evaluate the effectiveness of the system developed, comprising of the PicoScope® 3424, a laptop computer and a LF resonant antenna circuit, it was tested in number of industrial settings. These locations were chosen as due to their radiated EMI characteristics.

Firstly the device was taken to a facility know for excellent RF system operation. The EMI levels were analysed at this facility and found to be extremely low (lower than those observed in the laboratory) with a base-band level of approximately -120dBu. This low-level EMI reception can be used as a base-band to which all other EMI analysis' can be compared to. A screen grab taken from the EMI analysis system is shown in Figure 4.

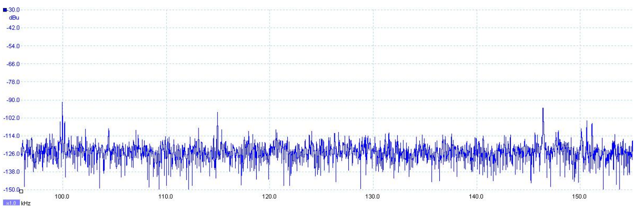

Fig. 4. LF EMI Spectrum

The second facility visited was chosen as it has an ongoing serious EMI issue which has been affecting the installed LF RF systems. Engineers have already tracked the source of the EMI to a high-frequency fluorescent lighting installation approximately 150meters from the RFID antenna system. The lighting system was identified by process of elimination involving the successive deactivating of any potential noise source until the RFID system functioned correctly.

Again, a screen grab taken from the EMI analysis system is shown in Figure 5.

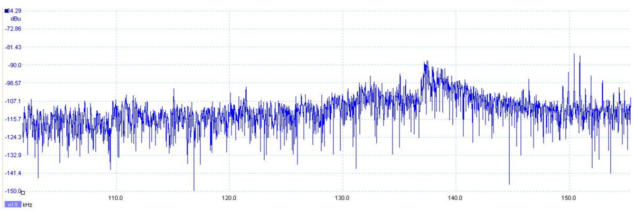

Fig. 5. LF EMI Spectrum

Comparing the spectrums shown in Figures 4 and 5, it is clear that an EMI issue is present in the second facility. The form of the EMI is clearly a wide-band of EMI ranging in frequency form 135kHz to 145kHz with a peak level of -87dBu.

VIII. CONCLUSION

This paper has presented the development of a low-cost EMI analysis tool suitable for use in industrial settings. The system has been tested and evaluated 'on-site' and performs as described. The final system has already been used by an industrial partner of I.T.Tralee in the EMI analysis of current problem facilities.

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