MEASURING THE IMPACT OF IN-VEHICLE-GENERATED EMI ON VHF RADIO RECEPTION IN AN UNSHIELDED ENVIRONMENT

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Abstract: Radiation generated by electronic equipment inside a vehicle can interfere with radio reception even though that equipment is in compliance with FCC standards. The result of that interference is an undesired reduction in radio coverage at frequencies where the interference exists.

The objective of this paper is to present an approach for measuring electromagnetic interference (EMI) generated by in-vehicle electronic equipment without requiring the measurements to be made inside a shielded anechoic chamber. Such measurements are straightforward in a shielded chamber since interfering signals from external radiation sources does not confound the measurement process. The contribution of the work presented here is to define a method for measuring EMI when external radiation is present. The basic approach is to identify regions in the spectrum where externally-generated signals exist and then to bypass those regions when measuring interference from in-vehicle-equipment. Because external interference can come from unlicensed as well as licensed sources, using the FCC database of licensed radiation sources to identify the regions to bypass will not achieve the desired goal. Rather, an analysis of the received spectrum is used to assess the presence of signals. Details regarding measurement equipment, procedures, accuracy and repeatability are given.

Key words: EMI measurements, in-vehicle, radio coverage, FCC-compliant, external EMI.

1. Introduction

The motivation for the work presented in this paper stems from an effort to install networked computer equipment in police cruisers. That effort, named Project 54 [1], seeks to increase the efficiency and safety of police operations by networking equipment such as digital radios, computers, GPS units, radars, lights, sirens and other equipment. Networking equipment in this manner enables that equipment to be controlled by central computer, which affords the use of voice-recognition and touch-screen displays that are far more user-friendly than the original equipment.

The equipment used in these installations is off-the-shelf with the exception of the network itself, which was designed specifically for this application. Although the off-the-shelf equipment used is FCC compliant, it was observed that some of the equipment had to be turned off in order to maintain VHF radio reception in fringe-coverage areas because EMI from that equipment masked the desired signal.

To better understand EMI generation mechanisms, measurements of radiation were performed to determine explicitly the effect of in-vehicle EMI on VHF radio reception. Some of the initial measurements were performed in a shielded (not anechoic) enclosure to determine the spectral signature of EMI for specific equipment, while other measurements were made using the roof-mounted, VHF radio antenna for a completed installation. These latter measurements were performed in an unshielded environment, and hence radiation from external sources complicated the measurement process, making it difficult to quantitatively assess the EMI impact of a particular piece of equipment.

The significant and not surprising conclusions reached as a result of these initial measurements were that the EMI radiated was dependent upon installation practices, and that each vehicle installation would have to be measured to ensure that EMI was at acceptable levels.

One of the overall objectives of the project is to identify a system configuration that can be installed by the personnel who currently convert stock vehicles into police vehicles. These installers have experience with electronic equipment, although few if any have access to anechoic chambers or spectrum analyzers that would be needed for high-accuracy measurements of EMI. Consequently, one of the challenges for the project was to develop a method for measuring EMI that does not require expensive, specialized equipment or extensive expertise on the part of the user. The method developed is the topic of this paper.

To meet cost and ease-of-use objectives for the measurement procedure, a computer-controlled radio

[2] is used. Once that radio is calibrated, the only equipment needed to perform the EMI measurements is a PC and the computer-controlled radio, as pictured in Figure 1. The cost for the equipment pictured is approximately $3500 US, and a calibrated signal source can be obtained for under $500 US.

Figure 1 Computer-Controlled Radio And Laptop Computer Used To Perform EMI Measurements.

When performing measurements, the radio's input is connected to the vehicle's antenna in place of the vehicle's VHF radio. Under computer-control, the radio scans across a predetermined range of frequencies and returns the signal level at those frequencies. The user is instructed to turn on or off the equipment under test (EUT) through a graphical user interface. After analysis, the software provides both tabular and graphical EMI data regarding interference generated by the EUT. These measurements typically require under 10 minutes for each device tested, and do not require in-depth knowledge about EMC on the part of the user. Further, the measurements show accuracy and repeatability within the requirements of this application, as is discussed in greater detail below.

2. Strategy for Bypassing External Radiation Sources When Measuring In-Vehicle EMI

If the measurements described above were to be performed in a shielded anechoic chamber, the analysis of spectral data to determine EMI impact would be straightforward. However, performing these measurements without shielding necessitates bypassing frequencies where external radiation is present so that those sources do not contaminate the measurement process. Because the environment in which these measurements are to be performed can contain unlicensed radiation sources, such as radiation from nearby vehicles and equipment, the bypassing of local licensed radiation source frequencies determined from the FCC Frequency Assignment Database [3] would not be effective. The approach that has proven effective here is to scan through the band of interest to identify, and subsequently bypass, frequencies where signals are present when the EUT is turned off. The intermittent nature of radio transmissions in the police band poses a challenge in this process, although a judicious selection of measurement parameters (i.e., scan range, frequency step size, resolution bandwidth, and signal and noise thresholds) enable the measurements to be performed accurately and in a reasonable amount of time.

The most crucial parameters in the frequency bypassing scheme are the ambient noise threshold and the threshold level for determining whether a signal is present. As the receiver sweeps over the predefined scan range, frequencies where the signal exceeds the signal threshold are added to the bypass list. The sweeping process is repeated over the scan range, bypassing the previously identified signals, and the signal strength for all un-bypassed frequencies is averaged. Sweeping is repeated until both no new signals are identified and the averaged level in the un-bypassed frequency range goes below the ambient noise threshold. In the event that the background interference is so high that the averaged level does not go below that threshold, it indicates that the measurements cannot be made in that environment, and the user is so notified. The range of un-bypassed frequencies is also checked to ensure that there is adequate bandwidth in which to analyze the interference. However, experience has shown that this check is unnecessary, as an excessive ambient noise background will prevent the averaged noise threshold from being reached.

Ambient background noise in areas that are electromagnetically quiet was measured to be around -115 dBm in 17kHz bandwidth, and this value is in reasonable agreement with publish values [4, 5]. However, because the environments in which these measurements are to be performed tend to be somewhat noisy, a default ambient noise threshold of -110 dBm is used in this application. This value is decreased in quieter environments in order to obtain greater detail about EMI. The signal threshold was determined by a statistical analysis of measured data to be between 2 and 3 dB above the ambient noise.

The effect of bypassing frequencies is shown in the Figure 2, which plots the average signal level after each sweep. As expected, the averaged signal level decreases with each sweep as new signals are detected and then eliminated from the sweeping process. As seen in the figure, the averaged level asymptotes to just under -110 dBm; in the actual measurement process, the sweeping is stopped when the ambient noise threshold is reached. For most of the measurements performed in this study, that threshold is reached in less than 10 minutes, although that time can vary depending upon the nature of external radiation sources.

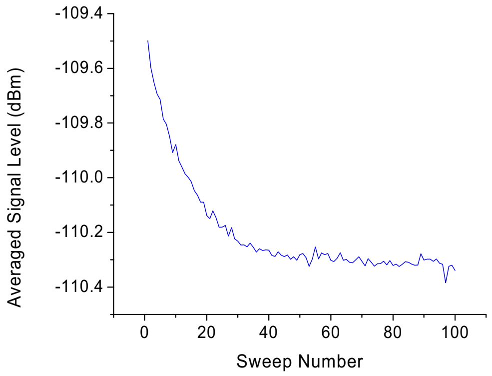

Figure 2. Averaged Signal Over Scan Range as a Function of Scan Number

Figure 3 plots the remaining bandwidth as a function of the number of sweeps, and it corresponds to the averaged signal level plot of Figure 2. It is worth noting that for all cases where the ambient noise threshold was reached, the remaining bandwidth was in excess of 90%, which is generally more than adequate to analyze the EMI characteristics.

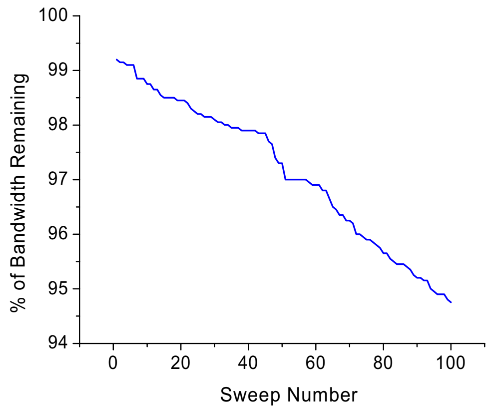

Figure 3. Remaining Bandwidth as a Function of Sweep Number.

Because the focus of the work presented here relates to interference in the VHF police band, the sweep range used is in the vicinity of that band (150- 160 MHz). The frequency step size is 5 KHz, and the resolution bandwidth is 17 KHz. These parameters result in a sweep time of roughly 2 minutes for the 10 MHz frequency span. Convergence times in bands were signal transmission is not intermittent, such as the FM radio band, tend to be significantly less than the time reported here.

3. Analysis of EMI Data

After the bypass list has been created, the EUT is turned on, and the frequency range is again swept, bypassing the frequencies on the list. The signal level for un-bypassed frequencies is averaged, and that average represents the EMI plus ambient noise in the frequency range. The same frequency range is swept and averaged a second time to ensure that no unaccounted-for external sources were radiated when the EUT measurements were being performed. If the two EUT measurements disagree by more than 2 dB, the user is notified.

An example of the result of an EMI measurement is shown in Figure 4, which plots the spectra of radiation from the onboard computer system with the vehicle engine running and ambient noise. These measurements were performed in an electromagnetically quiet setting, and hence the ambient noise threshold is lower than -110 dBm.

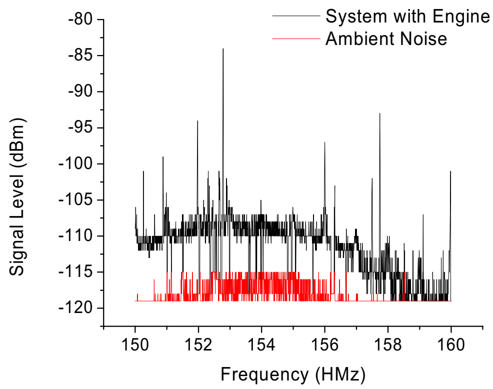

Figure 4. Spectra of Ambient Noise When Known Radiation Sources Are Bypassed and EMI from Onboard Equipment and Engine.

In addition to providing the Spectra of EMI, the measurement system also provides tabular data of the EMI averaged over the scanned frequencies. An example of tabular data is given in Table 1 for several in-vehicle components. As seen, some of these components would have a significant impact on radio reception.

Device	EMI Level, dBm
Computer and Monitor	-106.23
Radio Control Head	-112.81
Light bar	-105.65
Entire System	-107.65
Entire System w. Engine Running	-106.08

Table 1. Averaged EMI from In-Vehicle Devices

4. Accuracy and Repeatability

The concern about accuracy using this technique is that large spectral components of EMI might exist at frequencies bypassed in the measurement process. Were that to happen, the reported EMI averaged over the frequency range would be less than the actual EMI. However, the EMI spectra of all in-vehicle electronic devices investigated in this study tend to be distributed throughout the frequency range, similar to what is seen in the Figure 4. Consequently, errors resulting from the elimination of less than 10% of the frequency range are considered to be negligible for this application.

Even though external radiation sources and ambient noise can vary considerably with location, the repeatability observed using this technique is within 2 dB. Measurements of EMI on the same vehicle in significantly different electromagnetic environments provided very similar (i.e., within 2 dB) results. The explanation for this repeatability is that the EMI tends to be spread out over the frequency range and hence its average value is not changed when small segments of the spectrum are bypassed.

5. Conclusion

As stated, the objective of this work is to develop an affordable and easy to use tool that can be used by installers to determine if the equipment that they installed will interfere with radio reception. This approach has sufficient accuracy to detect common installation faults, such as the omission of ferrite beads or shielded covers and ground faults. The total cost of the equipment (under $4,000 US), the time required to perform measurements and the user-friendliness make this an attractive and affordable method for assessing EMI impact. This same approach should prove useful in other frequency bands and for other applications.

References

[1] The web site for Project 54 is: http://www.project54.unh.edu/about/
[2] The computer-controlled radio selected for this project is called the WiNRADiO, which is described in detail at http://www.winradio.com/
[3] Information about the FCC Frequency Assignment Database is given at: http://www.fcc.gov/oet/info/database/
[4] "Man-Made Noise Power Measurements at VHF and UHF Frequencies", Robert Achaz and Roger Dalke, National Telecommunications and Information Administration, U.S. Dept. of Commerce, NTIA Report 02-390, December, 2001.
[5] Man-Made Noise in the 136-138 MHz. VHF Meteorological Satellite Band, Achatz, Lo, Papazian, Dalke, and Hufford, National Telecommunications and Information Administration, U.S. Dept. of Commerce, NTIA Report 98-355, September, 1998