NBS Special Publication 480-44

Methods of Suppressing Automotive Interference

Law Enforcement Technology

U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards

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FOREWORD

The Law Enforcement Standards Laboratory (LESL) of the National Bureau of Standards (NBS) furnishes technical support to the National Institute of Justice (NIJ) program to strengthen law enforcement and criminal justice in the United States. LESL's function is to conduct research that will assist law enforcement and criminal justice agencies in the selection and procurement of quality equipment.

LESL is: (1) Subjecting existing equipment to laboratory testing and evaluation, and (2) conducting research leading to the development of several series of documents, including national voluntary equipment standards, user guides, and technical reports.

This document is a law enforcement equipment report developed by LESL under the sponsorship of NIJ as part of the Technology Assessment Program, which is described on the inside front cover of this report. Additional reports as well as other documents are being issued under the LESL program in the areas of protective equipment, communications equipment, security systems, weapons, emergency equipment, investigative aids, vehicles, and clothing.

Technical comments and suggestions concerning this report are invited from all interested parties. They may be addressed to the Law Enforcement Standards Laboratory, National Bureau of Standards, Washington, DC 20234.

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EXECUTIVE SUMMARY

The effort to review previously developed techniques for suppressing automotive electromagnetic interference (EMI) and to investigate newer methods of accomplishing this suppression was initiated in response to a series of requests from users of mobile communications equipment. Most of the requests were of a general nature, i.e., asking for assistance in reducing or eliminating the loss of range by communications equipment installed in vehicles, whatever the cause. Several users asked specifically for help in eliminating degradation known to be due to electromagnetic interference, primarily from the vehicle in which the radio was installed.

Personnel involved in this project reviewed the previous work in this field, visited a jurisdiction with a severe electromagnetic interference problem and a partial solution, and initiated a laboratory test effort to (1) simulate a typical EMI problem, and (2) investigate possible solutions to this problem.

This report discusses previous pertinent work in the field of EMI suppression techniques and equipment such as resistor spark plugs and cables, the use of capacitors as filters, and grounding straps. Most new automobiles are equipped with this equipment as a routine procedure, and the amount of EMI suppression obtained almost always allows the vehicle to meet the requirements of SAE Standard J551g [1]*. More recent suppression efforts, such as the use of silicone grease in the distributor and the use of conductive fan belt discharge and tire static-charge reduction techniques, are also included in this report. These techniques are not normally applied to the average automobile, but may be encountered in vehicles specifically purchased for law enforcement use. Suppression techniques detailed in the literature but not usually implemented in any vehicle, such as low-pass filters built into the distributor, ferrite beads, metal-plating, and "three point effect," are also included.

The reader wishing to reduce EMI should select those techniques of interest, based on the type of system used and frequency range of operation. Most of these techniques are effective at frequencies from 30 to 1000 MHz, having a greater effect at the higher frequencies. A measurement technique is described whereby the amount of degradation to a typical narrow band FM receiver, such as the type used by law enforcement agencies, can be measured. The EMI from a new production automobile can usually be reduced by as much as 10 to 15 dB below the requirements of SAE Standard J551g when the techniques described in this report are employed.

*Numbers in brackets refer to references in section 8.

METHODS OF SUPPRESSING AUTOMOTIVE INTERFERENCE

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The purpose of this report is to (1) review the sources of electromagnetic interference (EMI) within a vehicle so that the reader will have a basic understanding of the EMI problem; (2) discuss the techniques that have been used successfully by the auto industry to suppress EMI, and (3) suggest some newer techniques for suppressing EMI within an automobile.

The automotive manufacturers utilize several techiques to reduce EMI emanating from the vehicle. The techniques include resistor spark plugs, resistor spark plug cables, use of silicone lubricant in the distributor, use of capacitors as filters, placement of grounding straps at key locations, conductive fan belt discharge, and tire static-charge reduction. If even further reduction of EMI is needed to obtain the maximum capability of a specific mobile communication system, there are additional suppression techniques discussed herein that can be employed to achieve this goal. These techniques are effective at frequencies from approximately 30 to 1000 MHz. Measurement results show that the EMI from a new production-line automobile, measured in accordance with SAE Standard J551g, can be reduced as much as 10 to 15 dB by employing these new suppression techniques. The amount of degradation to a mobile narrow-band FM receiver, such as the type used by law enforcement agencies, can be measured using the measurement technique described. This same technique can then be used as a tool to further reduce EMI from the vehicle components.

Key words: automotive; electromagnetic interference; ignition; interference reduction; suppression techniques.

1. INTRODUCTION

The automobile with an internal combustion engine generates a large amount of electromagnetic interference. The engine utilizes a high voltage ignition system to ignite the fuel. The ignition system produces short impulses that generate a broad spectrum of frequencies. Other sources of EMI located within vehicles include motors that are used for blowers, windshield wipers, buzzers used for ignition and seat belt warnings, and voltage regulators that utilize points that open and close frequently. All of these devices generate interference in a frequency spectrum from the kilohertz range up to the gigahertz range. The fact that vehicles generate EMI has been known since the advent of AM radio in the 1930's, when noise generated by the engine was readily detectable by the automobile radio.

An electromagnetic compatibility problem has arisen between the EMI generated by the automobile and the electronic systems used in the automobile. The auto industry has been incorporating various EMI reduction techniques in the design and construction of their vehicles for many years. The purpose of this report is to review all known sources of EMI within a vehicle, discuss techniques that are being used by the auto industry to suppress this EMI, and suggest some newer techniques for suppressing EMI within an automobile. Although the EMI spectrum emanating from the automobile is from a few kilohertz to frequencies in the gigahertz range, this report will concentrate on radio systems utilizing narrow-band FM communications in the frequency bands commonly used for public-safety communications, 25 MHz to 900 MHz.

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2. BASIC IGNITION SYSTEM

A basic inductive discharge ignition system used in automobiles is shown in figure 1.

The system consists of a low voltage dc power supply (the battery), a high voltage generator (the coil and distributor breaker points), a switching mechanism to supply voltage to the proper spark plugs (the distributor), and spark plugs to provide a spark to each cylinder of the engine. Because of the high voltage, the opening and closing of the various points and the firing of the spark plugs, this system generates radio frequency interference over a broad frequency range. The rise times of these high voltage pulses are usually only a few nanoseconds, which result in a broad spectrum of frequencies. The number of impulses generated is a function of the number of cylinders and the engine RPM. For instance, an eight cylinder engine at 4000 RPM will have approximately 267 spark plug firings per second. The spark plug firings are NR/120 where N is the number of cylinders and R is engine RPM.

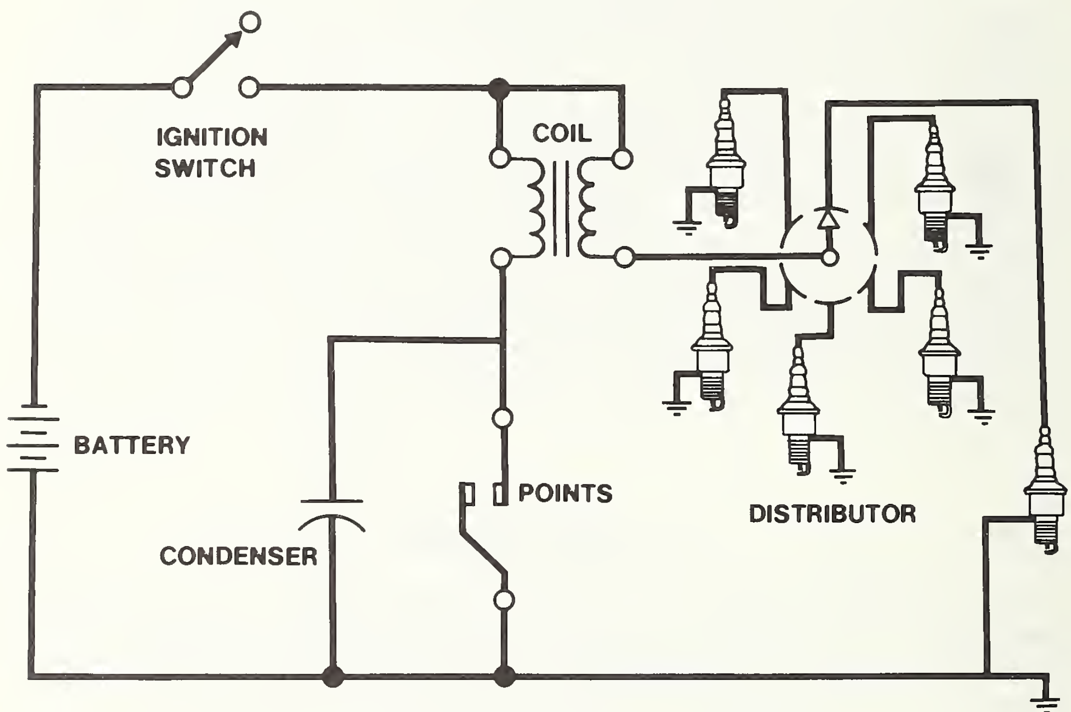

FIGURE 1. *Typical inductive discharge ignition system.*

The generation of a high voltage pulse for the spark plug occurs when the distributor points open and the collapsing field in the primary winding of the high voltage coil induces a high voltage in the secondary winding, which is connected to the spark plug gap via the distributor rotor switch and the spark plug wires.

There are three events that occur during the firing of each plug that cause the generation of EMI. These are:

(1) the air gap between the distributor rotor and stator breaks down, extending the high voltage to the spark plug;

(2) the air gap of the spark plug breaks down and the plug fires; and

(3) the distributor breaker points close to pass current through the primary winding of the high voltage coil.

These three distinct events produce independent sources of EMI, and their respective spectra can be isolated and measured with special instrumentation. However, the three sources will appear to the mobile radio as only one source of interference because they occur within a few ms of each other. The procedure of identifying all three as separate events will enable the investigator to take the proper steps to reduce the EMI at each source.

Some of the newer ignition systems use an electronic switching network to replace the distributor breaker points (see fig. 2). There are several variations in design, but each employs solid state devices to control the primary current in the high voltage transformer. Although there are several types of electronic ignition systems now available, they all appear similar as far as interference generating capability is concerned because the electronic networks essentially replace the distributor breaker points. The breaker points are the least significant EMI contributor of the three, so no significant reduction in EMI over the conventional ignition system is realized when an electronic switching network is used.

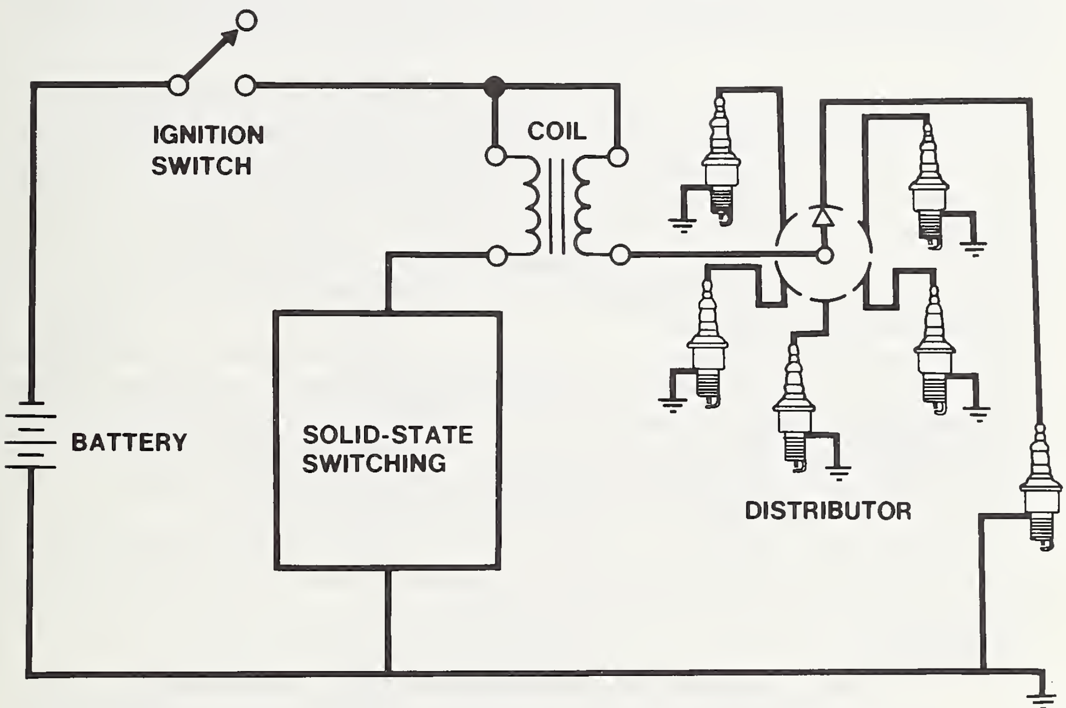

FIGURE 2. *Typical electronic switching ignition system.*

3. ADDITIONAL SOURCES OF EMI

In addition to the ignition system, there are other sources of EMI in a vehicle, especially a law enforcement or emergency vehicle. Electric motors are used to operate many devices such as windshield wipers, heater and air-conditioning fans, and rotating warning lights, just to mention a few. In addition to the motors, there are warning buzzers of various types and turn indicators that are basically switching networks. All of these devices are sources of EMI that can interfere with the operation of mobile radios.

4. FACTORS THAT INFLUENCE EMI

Assuming that all sources of EMI in the vehicle can be identified, how do these sources interfere with the operation of a mobile receiver? First, the EMI can be passed to the mobile receiver via the wiring within the vehicle as conducted interference. Next, the EMI can radiate from the sources and wiring within the vehicle to the receiver antenna via free-space as radiated interference.

Conducted interference can be controlled rather easily. By the proper use of line filters and/or bypass capacitors, most conducted interference in mobile radios can be reduced to the point that its effects are not detectable.

Radiated interference is more complex. The magnitude of the EMI radiating from a vehicle is a function of the size and shape of the vehicle, the material used to build the vehicle, and the design of the wiring system. The wiring within a vehicle serves as antennas that launch the radiated EMI into free-space. When wires in a harness approach one-fourth wavelength or more, they often serve as good antennas at these frequencies. For this reason, one type of vehicle may radiate strongly at certain frequencies while another style vehicle may have a completely different radiation spectrum. The radiation from vehicles of the same style may also have different radiation spectra if the vehicles are equipped with accessories that change the wiring harness configuration or length.

A metal enclosure will usually attenuate radiated EMI. Vehicles that are constructed of metal provide a natural shield to EMI. However, for a metal enclosure to function properly as an EMI shield, it is essential that the metal be electrically bonded together (metal-to-metal contact). A vehicle body may not be an ideally shielded enclosure. For instance, the hood may not be electrically connected to the rest of the vehicle because of paint or other substances. In cases such as this, it is possible for the hood to act as an antenna at certain frequencies and actually increase the EMI rather than attenuate it. This same analogy applies to other parts of the vehicle such as its bumpers, tail pipes, and trunk lid.

Other factors that may influence the magnitude of EMI emanating from a vehicle include humidity, temperature, and the location of the vehicle. The temperature and humidity can affect the magnitude of breakdown voltages within the distributor and spark plug, thereby influencing the radiated EMI. It is possible that a vehicle traveling or parked on a metallic surface such as a bridge or near a large metallic surface may generate an EMI spectrum quite different from that generated in another environment.

It becomes readily apparent that radiated EMI is a complex subject and must be treated accordingly. However, by understanding some of the principal causes of radiated EMI, one is better prepared to undertake the task of suppressing EMI.

5. EMI SUPPRESSION EQUIPMENT AND TECHNIQUES

Within an automobile, the ignition system generates the most EMI, and automobiles coming off the assembly line usually have some EMI reduction devices as standard equipment. These devices are necessary to satisfy the voluntary standard used by the auto industry, which is SAE Standard J551g, Limits and Methods of Measurement of Radio Interference Characteristics of Vehicles and Devices (20–1000 MHz) [1][1]. However, if maximum performance of communication transceivers is needed, this reduction in EMI may not be adequate. A discussion of presently used and proposed suppression equipment and techniques follows.

5.1 Ignition Suppression

The resistor spark plug technique employs the use of an internal resistor built into the body of the spark plug and is usually standard equipment on automobiles. The resistor attenuates EMI that is generated when the spark plug fires.

[1] Numbers in brackets refer to references in section 8.

Resistor cable is used to connect the spark plugs to the distributor and consists of a high voltage cable with a distributed resistance of usually 3000 to 7000 ohms per foot. Resistor cable is more effective at suppressing radiated EMI at the higher frequencies. At 25 to 30 MHz, the attenuation of a section of cable is about 10 dB less than the attenuation at 100 MHz and about 18 dB less than the attenuation at 500 MHz. Another cable that is sometimes used in place of resistor cable is one that possesses some magnetic properties. It is called magnetic cable and consists of a magnetic material surrounded by a coil of wire. Both the magnetic material and the inductance of the coil suppress the ignition EMI.

5.2 Stanford Research Institute Suppression System

R. A. Shepherd et al. [2] describe in their paper a technique of reducing automobile ignition EMI that was developed at Stanford Research Institute (SRI). This technique utilizes a low-pass filter system that can be built into a standard resistor plug. The improved filter spark plug reduced the radiated EMI by an additional 10 dB at 100 MHz and 20 dB at 500 MHz. However, there was very little EMI reduction in the 10 to 20 MHz frequency range.

A method of modifying a distributor by building a low-pass filter into the distributor ignition system was also described in [2]. This modification, which provides additional radiated EMI suppression, consists of adding a resistor to the rotor conductor and metallizing the exterior of the distributor cap to form a coaxial capacitor at each plug tower.

A breaker-point filter was built into the distributor base by adding ferrite beads to the wire leading to the breaker points and also adding a feed-through capacitor at this point. The ferrite beads act as a series inductor, thus attenuating the higher frequencies.

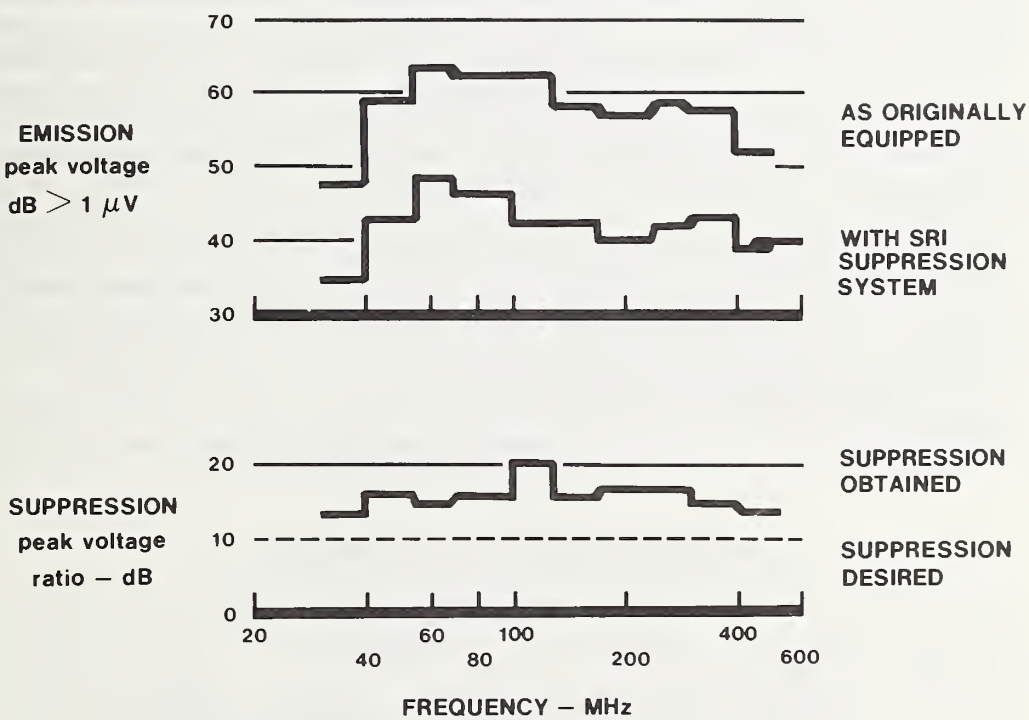

FIGURE 3. *Summarized EMI suppression results using the SRI suppression system [2].* The unit of measurement is dB above 1 μV per MHz of receiver bandwidth.

Measured results using the SRI suppression system, which included filters for the spark plug, the distributor and the breaker points, show that radiated EMI is reduced from 10 to 20 dB at frequencies from 30 to 1000 MHz. Figure 3 summarizes the results using the SRI suppression system.

5.3 Distributor Suppression Systems

Wey-Chaung Kuo [3] describes in his paper a method of suppressing the EMI from the distributor by modifying the distributor rotor. This technique utilizes an old theory called the "three point effect" which is accomplished by placing an additional (third) electrode near the main gap of the rotor. The presence of the third electrode, either floating or grounded, reduces the gap breakdown voltage, which results in lower EMI. The presence of this electrode has produced measured results that show that distributor EMI is suppressed by as much as 10 dB at frequencies from about 50 to 800 MHz. However, there was very little suppression at frequencies from 20 to 40 MHz.

Another method of reducing the breakdown voltage in the distributor (thus reducing radiated EMI) by simply applying a dielectric material to the rotor segment of the distributor was also described in [3]. Various dielectric materials can be used, such as silicon oxide, zinc oxide or various ceramics. Silicon oxides, in bulk form, can be applied directly to the rotor. A rather commonly used dielectric material is silicone lubricant. Two important features of this technique are: (1) the dielectric must be applied to the negative electrode; for negative-polarized ignition systems the dielectric is applied to the rotor, and (2) the dielectric material used should have a dielectric constant of three or greater in order to provide adequate radiated EMI suppression.

The dielectric material is usually applied to the top of the rotor with a minimum of material in the gap between the rotor and the stator. An excess of material in the gap will occasionally have the opposite effect and produce more radiated EMI at certain frequencies. In cases like this, removal of the excess material will usually reduce the EMI emitted. Silicone products are quite difficult to remove. To remove silicone grease from a surface, it is essential to use a cleaning solution that will dissolve the silicone, such as methyl-ethyl ketone. Other commonly used solvents, such as alcohol or acetone, will not remove the silicone but will merely move it around.

As discussed earlier in this report, the EMI emanating from a vehicle is very complex, and certain vehicles will radiate more EMI than others. For example, if a vehicle has an excessively noisy ignition system, the application of the dielectric material to the distributor rotor may have little or no effect on suppressing the total ignition EMI, because the distributor is not the major EMI contributor.

In order to determine the effectiveness of the dielectric material in suppressing ignition EMI, tests can be conducted using each transceiver in the vehicle. A suggested equipment setup and measurement technique is discussed in the section on measuring receiver degradation. By performing the measurement first with and then without the dielectric material, the effectiveness of the dielectric can be readily determined.

The amount of expected suppression of ignition interference by certain of these suppression techniques is summarized in table 1 for each of the four public-safety frequency bands.

TABLE 1. *Expected interference suppression per technique*

Suppression technique	Frequency band (MHz)			
	25–50	150–174	400–512	806–896
SRI system	10–12 dB	15–20 dB	10–12 dB	---
Third electrode	1–2 dB	5–10 dB	5–10 dB	1–2 dB
Bulk dielectric	1–2 dB	5–10 dB	5–10 dB	1–2 dB

5.4 Grounding

The metal in an automobile can be utilized effectively to attenuate the EMI generated within the vehicle. However, when automobiles are assembled, and the hood, trunk lids, fenders, and other automobile components are bolted together, there is usually a coat of paint between the surfaces that prevents a good electrical contact. An ungrounded metallic surface, such as a hood or trunk lid, can be a very efficient antenna at certain frequencies. Using a metallic strap to ground the various parts of a vehicle can be a very effective way of reducing EMI.

An ungrounded muffler system can be an excellent antenna when it is a fractional wavelength, such as a one-quarter or one-half wavelength, and becomes resonant. Proper grounding of the muffler system to the automobile chassis will eliminate this effect. More than one ground strap may be required.

Other parts of the automobile that may have this "antenna effect" include the hood, trunk lid, firewall, engine and fenders. The type of grounding required will vary depending on the make and model of the automobile. Multiple ground straps from the engine to the firewall may be necessary on one model and not necessary on another. Placement of the ground straps is sometimes critical, requiring more than one. With the prolific use of plastics in the newer automobiles, the shielding produced by the automobile chassis becomes less effective. The increased use of plastic material in automobiles will create new EMI problems; however, they are problems solvable by the proper application of good engineering techniques.

5.5 Other EMI Sources

In addition to the ignition system, which is usually the largest source, there are many other EMI generating components in an automobile. Any time there is an intermittent contact, such as that exhibited by motor brushes or relays, the resulting impulse can generate a broadband interference signal that will degrade communications operations.

The EMI generated by devices such as motors, relays, thermal controls, and buzzers can usually be suppressed by the placement of capacitors at critical locations. For example, the EMI from a windshield wiper motor can be reduced significantly by placing a coaxial capacitor in the power leads to the motor. Sometimes it is also necessary to place a capacitor between the brushes and the vehicle ground. Other sources of EMI that are normally suppressed by the automotive manufacturer are fan belt static and static charge build-up due to the tire contact on the roadway during periods of low humidity. The former is discharged through the use of conductor rubber insulators and the latter is reduced by the use of collector springs in the wheel bearing caps.

It is difficult to give explicit methods of reducing EMI for all automobile components because the interference is a function of physical location, geometry, size and shape of the automobile, and the composition of parts. This presents a very complex problem. Often trial and error techniques are necessary to find the best solution to the problem.

6. MEASURING RECEIVER DEGRADATION

Many law enforcement vehicles operate in close proximity to their base stations or other mobile units; thus, they have a good signal-to-noise ratio at their receivers and do not experience any significant degradation due to ignition or other types of EMI. Law enforcement officers that must operate vehicles in remote areas, where the signal-to-noise ratio at their receivers is marginal, may not realize that EMI from their own vehicle is reducing the effectiveness of their entire communication system. Upon discovery, this type of receiver degradation can be measured and reduced using the suppression techniques discussed in this report.

To measure receiver degradation, connect the test equipment to the receiver under test as shown in figure 4. The antenna and receiver must be installed in the vehicle being tested in their normal places. The coupler should be placed adjacent to the receiver input terminals so that the mobile antenna is coupled directly to the receiver. The signal generator should be loosely coupled

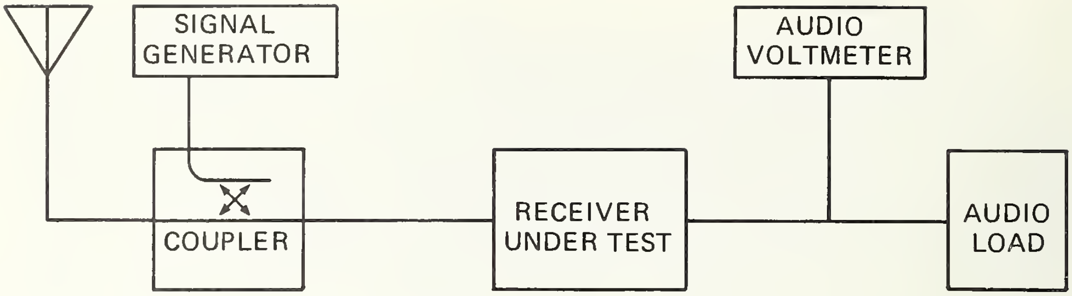

Figure 4. *Test setup for measuring receiver degradation with equipment mounted in the vehicle.*

(20 to 30 dB) to both the antenna and receiver. It is not necessary to know the exact coupling of the generator. The audio voltmeter should be connected across the audio load, which can be either the receiver speaker or a dummy load.

With the engine of the vehicle turned "off," and all electrical equipment in the vehicle turned "off" except the mobile receiver under test, tune the frequency of the unmodulated signal generator to the frequency of the receiver, and adjust the voltage output of the signal generator so that the signal-to-noise ratio of the receiver is 10:1 (20 dB quieting), as indicated by the audio voltmeter. The squelch control should be adjusted so there is no squelch, and the receiver volume control should be used to set the voltmeter level to a convenient reading. Record the generator output in dB above 1 μV. Start engine and/or turn on individual electrical devices; again adjust the signal generator for a signal-to-noise ratio of 10:1 (20 dB quieting). Again record the generator output in dB above 1 μV. If both signal generator readings are identical, there is no receiver degradation. The difference between the second and first readings of the signal generator is the receiver degradation in decibels due to the EMI.

When using this method to measure receiver degradation, it is important that the vehicle be placed in an EMI quiet area during the measurement. If the vehicle is near sources of EMI such as power lines, electrical motors or heavy traffic, the high ambient noise background may mask the EMI emanating from within the vehicle, and you will be unable to perform the measurements successfully. To determine if the ambient noisy background is too high, measure the unsquelched audio output from the receiver with the mobile antenna disconnected from the receiver input. Connect the antenna to the receiver input and measure the audio output again. If the audio output increased significantly when the antenna was connected, the ambient background noise level is too high.

Some FM mobile communication receivers used by law enforcement agencies have blanking circuits that are designed to reduce the effect of impulsive noise. Different techniques are employed, but usually the blanking circuit of a receiver detects a series of impulses entering the receiver input and by proper timing sequences, the receiver is periodically silenced so that the effect of the impulses is reduced. This basic technique, although effective under some conditions, is not always effective for all types of interference.

7. SUMMARY

Automotive manufacturers presently utilize several techniques to reduce EMI emanating from a vehicle. These techniques include resistor spark plugs, resistor spark plug cables, use of silicone lubricant in the distributor, use of capacitors as filters, placement of grounding straps at key locations, conductive fan belt discharge, and tire static-charge reduction. The auto industry uses SAE Standard J551g as a voluntary standard, utilizing both the measurement methods and radiation limits described therein.

If even further reduction of EMI is needed to obtain the maximum capability of a specific mobile communication system, there are additional suppression techniques that can be employed to achieve this goal. These are described in paragraphs 5.2 and 5.3 and include modification of the distributor. For example, a low pass filter can be built into the distributor utilizing coaxial capacitors, ferrite beads, and metal-plating techniques. Another approach is to apply a dielectric material to the rotor segment of the distributor, while a third method involves placing a additional electrode near the main gap of the rotor. These techniques are most effective a frequencies from approximately 30 to 1000 MHz. Measurement results show that the EMI from a new production-line automobile, measured in accordance with SAE J551g, can be reduced as much as 10 to 15 dB by employing these new suppression techniques. Table 1 illustrates the ignition suppression that can be expected if these additional suppression techniques are added to a production-line automobile that satisfies the limits of SAE J551g.

The amount of degradation to a mobile narrow-band FM receiver, such as the type used by law enforcement agencies, can be measured using the measurement technique described. This same technique can then be used as a tool to further reduce EMI from vehicle components.

It is evident that suppression of the higher frequency components of the EMI emanating from an automobile is easier to accomplish than suppression of the lower frequencies (below 50 MHz). Therefore, the suppression techniques employed should be selected only after a thorough analysis of the band or bands of frequencies being used for mobile communications.

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Special Publications—Include proceedings of conferences sponsored by NBS, NBS annual reports, and other special publications appropriate to this grouping such as wall charts, pocket cards, and bibliographies.

Applied Mathematics Series—Mathematical tables, manuals, and studies of special interest to physicists, engineers, chemists, biologists, mathematicians, computer programmers, and others engaged in scientific and technical work.

National Standard Reference Data Series—Provides quantitative data on the physical and chemical properties of materials, compiled from the world's literature and critically evaluated. Developed under a worldwide program coordinated by NBS under the authority of the National Standard Data Act (Public Law 90-396).

NOTE: The principal publication outlet for the foregoing data is the Journal of Physical and Chemical Reference Data (JPCRD) published quarterly for NBS by the American Chemical Society (ACS) and the American Institute of Physics (AIP). Subscriptions, reprints, and supplements available from ACS, 1155 Sixteenth St., NW, Washington, DC 20056.

Building Science Series—Disseminates technical information developed at the Bureau on building materials, components, systems, and whole structures. The series presents research results, test methods, and performance criteria related to the structural and environmental functions and the durability and safety characteristics of building elements and systems.

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Consumer Information Series—Practical information, based on NBS research and experience, covering areas of interest to the consumer. Easily understandable language and illustrations provide useful background knowledge for shopping in today's technological marketplace.

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NBS Interagency Reports (NBSIR)—A special series of interim or final reports on work performed by NBS for outside sponsors (both government and non-government). In general, initial distribution is handled by the sponsor; public distribution is by the National Technical Information Services, Springfield, VA 22161, in paper copy or microfiche form.