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ELECTROMAGNETIC INTERFERENCE EFFECTS ON MOTOR VEHICLE ELECTRONIC CONTROL AND SAFETY DEVICES

Volume I-Summary

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16. Abstract

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A series of susceptibility tests were performed on an electronic speed control system and an antiskid control module to determine functional upset levels of injected signals at critical circuit ports on these devices. The upset criteria were based on performance departures from normal, resulting from the injection of interfering signals. The injected signals were designed to represent levels and durations characteristic of those generated within the vehicle or coupled from external sources.

A set of basic guidelines to promote EMC in the use of electronic control and safety devices in automobiles are presented.

The applications and technological developments concerned with current automotive electronics are discussed. The research conducted by the automotive industry to explore the feasibility of a central processor or control system and potential problem areas are reviewed.

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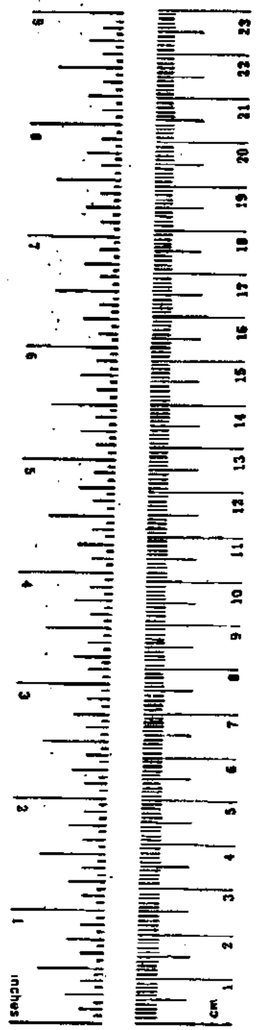
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

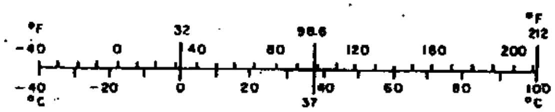
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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ELECTROMAGNETIC INTERFERENCE EFFECTS ON MOTOR VEHICLE ELECTRONIC CONTROL AND SAFETY DEVICES

VOLUME 1 - Summary

R.H. Espeland, D.H. Layton, B.D. Warner, L.R. Teters, and E.L. Morrison, Jr.*

ABSTRACT

This report summarizes the analysis and measurement tasks accomplished for this phase of the DoT Road Vehicle EMC/EMI program, and the contents of EMC Guidelines proposed for the design and maintenance phases of electronic safety and control systems.

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Key Words: Electrical signals, interference, coupled signals, measurements, transients, power supply variations, aperture size, shielding, susceptibility testing, EMC guidelines, and automotive electronic systems.

*The authors are with the U.S. Dept. of Commerce, Office of Telecommunications, Institute for Telecommunication Sciences, Boulder, Colorado 80302.

1. Introduction

This report is the culmination of the second phase of an investigation of potential EMC/EMI problems associated with the use of electronic systems for control and safety of road vehicles. These studies have been performed by the Institute for Telecommunication Sciences for the National Highway Traffic Safety Administration of DoT.

The first phase of this investigation (Espeland et al., 1975) provided an assessment of potential inteference sources, analysis of conducted and coupled energy transfer in the cabling and wiring circuits of a vehicle, an analysis of electronic circuit and subsystem sensitivities, and a set of preliminary EMC guidelines and testing procedures.

This executive summary briefly reviews the results of the Phase I study, the results and conclusions of the Phase II (current) study, and recommends areas of future research.

The complete report of the Phase II study, entitled "Electromagnetic Interference Effects on Motor Vehicle Electronic Control and Safety Devices" is produced in three volumes:

Volume 1 - Summary

Volume 2 - Measurements, Analysis and Testing

Volume 3 - Automotive EMC Guidelines

Phase I produced technical material as follows:

1) The survey which produced the file on potential interference sources internal to the vehicle dealt principally with normal variations of the primary power supply (battery, alternator, and regulator) and with transient signals produced from normal operation and abnormal functioning of the loads and systems connected to the primary power supply. For example, within the automobile the power supply voltage has been known to vary from 4.5 V to 17 V. Transients of over 200 V amplitude have been measured from the switching of inductive loads (SAE, 1974).

2) High-powered radar and broadcast facilities, as well as industrial installations and power lines, are among the interference sources external to the vehicle. The electromagnetic fields generated by these sources were evaluated as potential threats in terms of worst case conditions resulting from normal vehicle operations. Field strengths

of 1400 V/m were estimated at a distance of 600 m from an airport radar and fields of 1700 V/m were estimated from lightning in the frequency range below 20 kHz at a distance of 500 m.

3) Current automotive wiring practices such as parallel unshielded wires in a bundle, provide little protection from signal transfer by coupling. One of the computerized analysis programs (Bagdanor, et al., 1971) used for study of this problem was a wire-to-wire coupling analysis program (WTWCAP). The analysis showed that significant signal levels occurred on adjacent wires using a model of a typical instrument panel harness and characteristic source waveforms such as a step function, rectangular function and exponental decay (spike) function. Coupled levels greater than 150 dBμV/MHz were predicted from these normal vehicle signal sources. These levels, which vary as a function of frequency, are highly dependent upon the source and load impedances, and cable routing.

4) The Electronic Circuit Analysis Program (ECAP) developed by IBM was used to determine potential upset levels of selected circuits (IBM Corp., 1965). These evaluations, in addition to published circuit immunity levels provide a basis for assessing subsystem susceptibility levels of characteristic automotive electronics. This information was useful in the development and planning of the Phase II test program.

5) A set of preliminary EMC guidelines resulted from the Phase I program. Those areas for which guidelines were outlined included internal interference source control, power and signal transmission, circuit selection and design, subsystem packaging and installation, and system validation and testing procedures.

On the basis of these results, the following areas were recommended as requiring investigation:

1) measurements of typical signals generated within a vehicle, both at the source and at transfer points due to coupling and conduction,
2) testing of selected automotive subsystems to determine characteristic susceptibility (upset) levels.

3) a study and analysis of field-to-wire coupling potential using a computerized model, and

4) a refinement of the EMC guidelines.

2. Measurement and Test Results

The Phase II study specified a research effort to expand the general guidelines for packaging and installation of electronic safety and control devices on motor vehicles so as to assure electromagnetic compatibility among the devices and the electromagnetic and electrical environment of the vehicle. These guidelines are based on the results of tests and measurements conducted to evaluate the electrical environment of motor vehicles, on conductive and radiative susceptibility tests of selected electronic subsystems, and on studies conducted by the automotive and electronics industries. The results obtained from the measurements (electrical environment), the analysis of coupled signals, and the subsystem susceptibility testing are contained in Volume 2. The extension and clarification of the work on automotive EMC guidelines is reported in Volume 3.

Internal Electrical Environment

The results of the source and coupled signal measurements and the data from the motor vehicle (internal and external) source files describe a typical motor vehicle electrical and electromagnetic environment. This compilation of data was very useful in the planning of susceptibility tests and in the preparation of EMC guidelines. It is a documentation of the levels, frequency range, and characteristics of signals encountered by automotive electronic systems under typical operating conditions.

Summaries of the signal source and coupled waveforms are shown in Tables 1 and 2. In Table 1, the source is identified by function or a typical switching action. The resulting wave forms are further characterized by duration or frequency response and by signal amplitudes. The data in Table 2 are similarly identified and a description is given of

Table 1. Source Waveforms

EQUIPMENT (SOURCE)	WAVEFORM	DURATION (FREQUENCY)	AMPLITUDE
Light Switch	1.) Switching Transient (Low Beam)	.2 s	≈1.0 V
	2.) Switching Transient (High Beam)	.2 s	≈1.0 V
	3.) Switching Transient (High Beam)	.2 s	≈1.0 V
	4.) Switching Transient (High Beam)	.2 s	≈1.0 V
Air Conditioner Clutch	Switching Transient (On-Off)	60 ms	70 V
Starter Solenoid and Starter	1.) Starter Solenoid (Switching Pulse)	(On-Off)	12 V
	2.) Main Bus (Disabled)	(On-Off)	12 V
Ignition System	1.) Ignition Spark	(RPM Dependent)	9 V
	2.) Breaker Points	(RPM Dependent)	700 V
	3.) Distributor Output	(RPM Dependent)	≈15 KV
	4.) Spark Plug	(RPM Dependent)	≈12 KV
Turn-Signal and Emergency Flashers	1.) T.S. Flasher Output (On-Off)	.25 s	≈12 V
	2.) Emergency Flasher		≈12 V
Transient Simulator	Simulated Transient	250 ms	≈50 V
Fan Motor	1.) Fan Motor	(555 Hz)	≈100 mV
	2.) Switching Transient and Decaying Sinewave	.4 ms (Variable)	≈7 V ≈2.5 V
Alternator	Alternator Output	(RPM Dependent ≈900 Hz)	60 mv
Windshield Wiper	1.) Motor	(RPM Dependent ≈500 Hz)	≈.3 V
	2.) Switching Waveform	.1 s	12 V
Horn	Horn	(≈350 Hz)	≈3 V
Broadband Noise (measured on the main power bus)	1.) Ignition Key Buzzer	0-100 MHz	-22 dBm 0-5 MHz
	2.) Horn	0-100 MHz	-40 dBm near 50 MHz
	3.) Engine Idling	0-100 MHz	-15 dBmW near 1 MHz

Table 2. Coupled Waveforms

EQUIPMENT (SOURCE)	LOCATION	WAVEFORM	DURATION (FREQUENCY)	AMPLITUDE
Light Switch	1.) Turn Signal Lamp	Spike	100 ms	150 mV
	2.) Turn Signal Lamp	Spike	100 ms	300 mV
	3.) Low Beam Lamp	Spike	100 ms	200 mV
	4.) Low Beam Lamp (Bulb Removed).	Spike	5 ms	+700 mV -1.2 V
Air Conditioner Clutch	) Main Bus	Spike (Noise)	250 ms	300 mV
Starter Solenoid and Starter	Battery	Spike and Cogging	(While Cranking)	7 V 1 V
Ignition System	1.) Battery Plus Terminal	Pulse	(RPM Dependent)	50 mV
	2.) Main Bus	Pulse	(RPM Dependent)	1 V
	3.) Spark Plus Wire (No Arc Across Plug)	Damped Sinewave	(RPM Dependent)	≈35 KV
Turn-Signal and Emergency Flashers	1.) Lamp Ground Wire	Spike	40 usec	≈100 mV
	2.) Parking Lamp Wire	Spike	20 usec	≈600 mV
	3.) Back-Up Lamp Wire	Spike	20 usec	≈300 mV
	4.) Back-Up Lamp Wire (Lamp Removed)	Spike	10 usec	≈750 mV
Transient Simulator	Windshield Wiper	Spike	200 ms	150 mV
Fan Motor	Main Bus Right Front Parking Lamp	Sinewave	(555 Hz)	50 mV
Alternator	1.) Main Bus	Ripple	(≈900 Hz)	20 mV
	2.) Main Bus (Abnormal)	Ripple	(≈900 Hz)	≈6 V
Windshield Wiper	1.) Main Bus	Ripple	(≈500 Hz)	.2 V
	2.) Battery Terminal	Ripple	(≈500 Hz)	≈30 mV
Horn	Main Bus	Periodic (Noisy)	(≈350 Hz)	60 mV
Broadband Noise (measured on the main power bus)	1.) Main Bus	(Broadband Noise)	0-100 MHz	-22 dBm 0.5 MHz
	2.) Main Bus	(Broadband Noise)	0-100 MHz	-40 dBm near 50 MHz
	3.) Main Bus	(Broadband	0-100 MHz	-15 dBm near 1 MHz

the location at which the coupled signal was measured. The data in the two tables are related in that the waveforms recorded in Table 2 are the result of signal coupled from the sources identified in Table 1.

External Electromagnetic Environment

The field strengths and frequency ranges of electromagnetic fields encountered by automobiles under normal operating conditions are shown in Table 3. The pictorial diagram in Figure 1 illustrates both radiating external sources and major transient and voltage variations that characterize the automobile electrical and electromagnetic environment.

Subsystem Interference Tests

An electronic speed control system and an antiskid control module were tested to determine functional upset levels of injected (conducted) signals at critical circuit ports on these devices. The upset criteria were based on performance departure from normal, resulting from the injection of the interfering signals. The interfering signals were representive of the levels, duration, and characteristics of those generated within the vehicle or coupled from external sources. The methodology used includes an analysis of the anticipated circuit susceptibility, selection of the critical circuit ports, definition of the injected signals characteristic and a mock-up of the test object for functional simulation.

A direct drive test facility operated by the Air Force Weapons Laboratory (AFWL) at Kirtland AFB, NM was utilized for these tests (Greaves et al, 1975). The test ports of the speed control system were the dc power line, a sensor input line, and a control input line. Injection signals consisted of rf pulses in the 1 to 75 MHz range and cw signals of the same range. The dc pulses were also injected at these ports. The rf pulses and cw signals are representative of electromagnetic coupled energy for transmitters and other radiating sources. The dc pulses represent internally generated signals. The results obtained show that the susceptibility (upset) characteristics are highly variable as a function of signal characteristics and level. Representative data are shown in Figures 2 and 3.

Table 3. External Electromagnetic Fields

Source	Frequency	Distance	Field Strength
Broadcast Signal			
AM (Commercial)	535-1605 kHz	160 m	40 V/m @ 50 kW
FM (Commercial)	88-108 MHz	160 m	10 V/m @ 100 kW
TV (UHF)	470-806 MHz	160 m	76.1 V/m @ 5000 kW
Radar	1-10 GHz		
Military (AN/FPS-16)		310 m	200 V/m
Airport (ARSR-2)		600 m	1378 V/m
Mobile Radio			
HF-VHF	25-50 MHz	2 meters	27 V/m @ 100 W
VHF	150-174 MHz		
UHF	406-512 MHz		
Power Transmission Lines	20 Hz to 1 kHz	underneath the line	greater than 1 V/m (values as high as 1000 V/m @ 60 Hz)
Industrial Sources			
Arc Welders	2-3 MHz	300 meters	0.1 mV/m
Wood Gluer	10-20 MHz	300 m	1.0 mV/m
Fluorescent Lamp	10 kHz	1 meter	0.1 V/m
Lightning	1 kHz to 18 kHz	500 meters	1700 V/m
		1000 m	1000 V/m

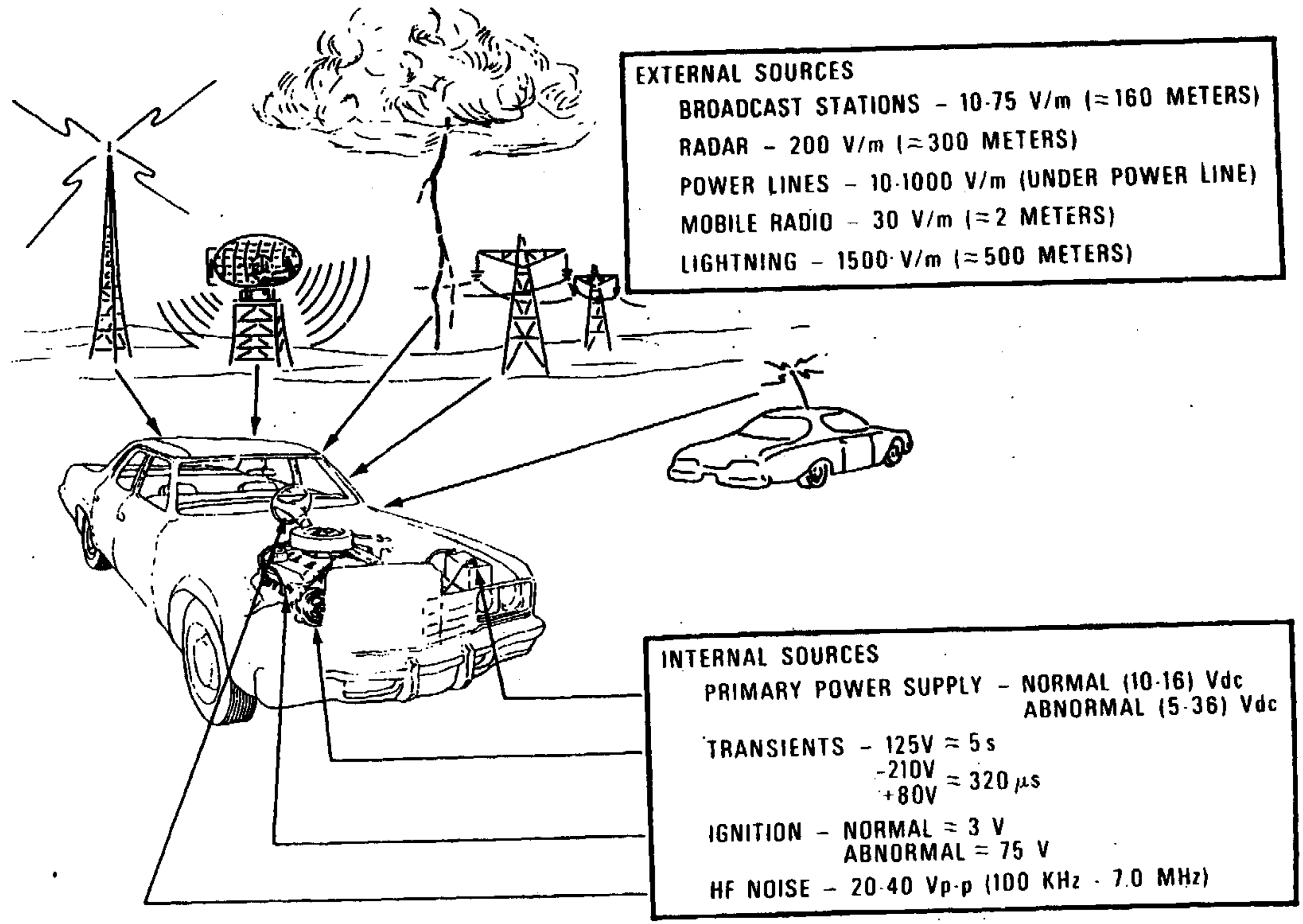

Figure 1. Potential Interference Signal Sources

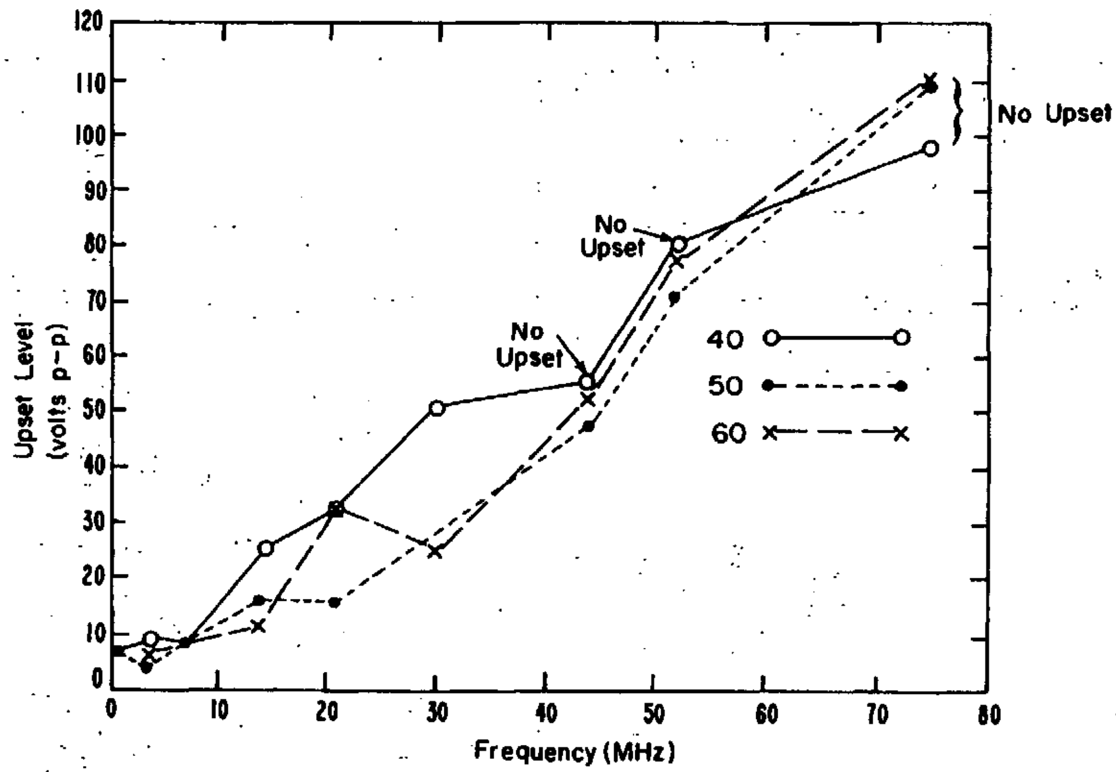

Figure 2. Speed Control System Test Results at Sensor Line Input (Data points indicate interference levels at which upset occurred or maximum level if no upset was observed.)

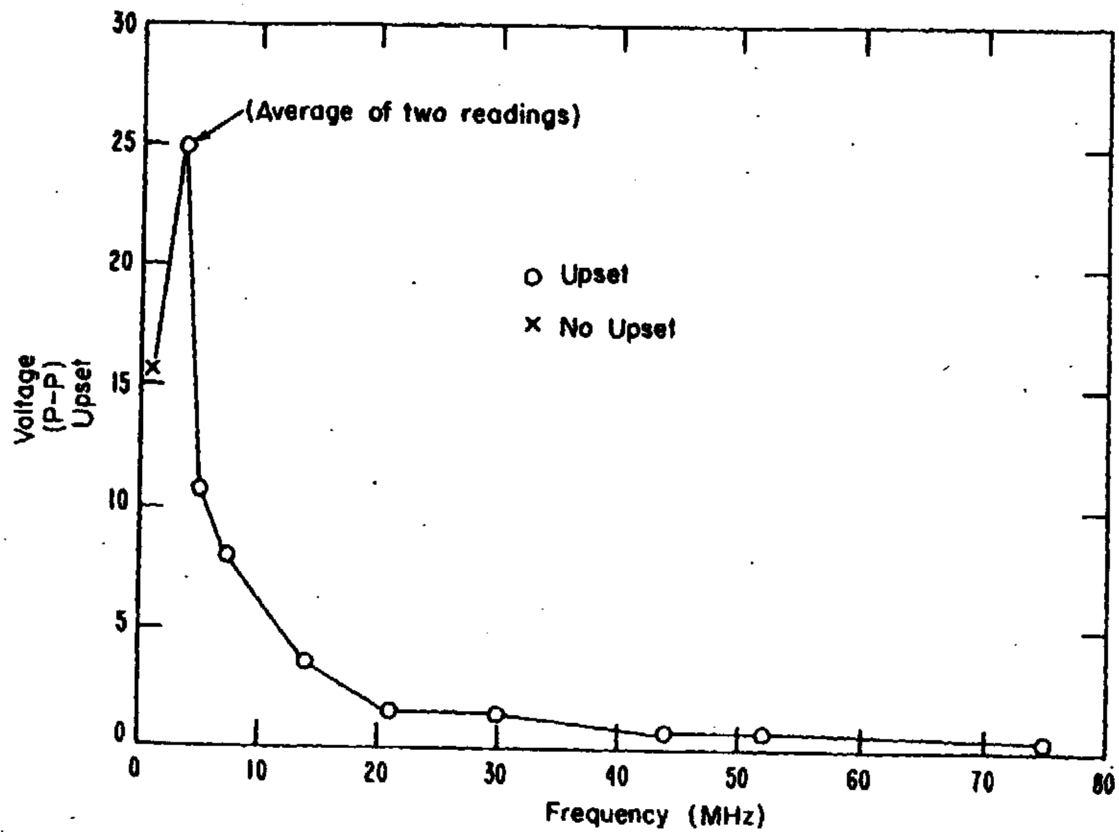

Figure 3. Antiskid Module Test Results at Sensor Line Input (Data points indicate interference levels at which upset occurred or maximum level if no upset was observed.)

The data in these two figures resulted from the presence of interfering pulse signals (25% duty cycle) at sensor line input ports of the respective devices being tested. The frequency range of injected signals was the same for both tests, however the maximum injected levels were different. The upset criterion was defined as a variation in controlled speed of 4 mph from the set value. The sensor line results obtained from testing the speed control system (Figure 2) show that signal levels of approximately 4 to 50 V (p-p) were required to obtain an upset in the frequency range from 1 to 45 MHz, and even greater levels were injected above 45 MHz, at some points without upset. The upset tests were conducted at vehicle speeds of 40, 50, and 60 mph.

The data in Figure 3 (antiskid module) show comparatively high upset immunity in the low frequency range and relatively high susceptibility at frequencies above 40 MHz. The criterion for upset was defined as a departure from anticipated brake modulation during deceleration, comparing the results of a non-interference run with an interference run.

The overall conclusions of this test are that a facility such as the direct drive equipment at AFWL is a readily adaptable and versatile facility for module and sub-system susceptibility testing. The concept of injecting signals of increasing level until an upset occurs or a maximum level is reached generates easily definable susceptibility curves. Parametric variations such as frequency, pulse shape, etc., can be used. It is also possible to extend this technique to in-situ testing. The principal restriction would be actual highway motoring.

The data obtained from the speed control tests indicate that this device is not very susceptibile to cw and pulsed cw type signals. Earliest upset levels recorded at any of the test ports (sensor line, control line, and power supply line) were at about 4 V (p-p in the test frequency range of 1 to 75 MHz). The susceptibility curves generated in these tests were very different for each of the test ports. At the upper range of the susceptibility curves, signal levels as great as 100 V were injected without a recorded upset.

The data obtained using dc pulse injection at the sensor line showed that upset occured when these signal levels reached an average level of about 1.5 V. The range of interference levels 0.9 to 1.7 V (positive polarity) and 1.1 to 2.4 V (negative polarity) to cause upset showed very little dependence upon the pulse repetition rate and pulse width of the injected signals and upon vehicle velocity. The control line port, also tested with dc pulses, was much less susceptible. The lowest level interference signal to register an upset was 7 V (negative polarity).

The test series (sensor input and power supply line) conducted on the antiskid brake module showed this device to be more susceptible to cw signals than was the speed control system. It was less susceptible to dc pulses. The data in Figure 3 is typical of the results obtained while injecting cw and pulsed cw interference signals at the sensor lines. High immunity (about 5 V) is displayed at frequencies below 10 MHz. At frequencies above 10 MHz, the susceptibility curves reach levels as low as 0.5 V (p-p). The power supply line was highly susceptible across the test frequency range. Upsets were observed at levels of 0.1 V. The sensor line (the only port tested with dc pulses) upset at injected levels of 3.4 V (positive polarity) and 1.75 V (negative polarity).

Energy Coupling Analysis

The analysis of the potential of coupling of electromagnetic fields onto the cables and wiring harnesses of a vehicle indicated that the degree of coupling is highly dependent upon the signal frequency, body and cable shielding, aperture size, cable length, and distance from the source to the cable. The data in Figure 4 shows the magnitude of the cw coupled signal resulting from a transmitter located 60 in from the aperture and radiating 100 W. The data is parametric in aperture size. The overall cable length used for this evaluation was 132 in. Figure 4 shows that the degree of coupling is more dependent upon the largest aperture dimension than upon the aperture area. Hence a close grouping

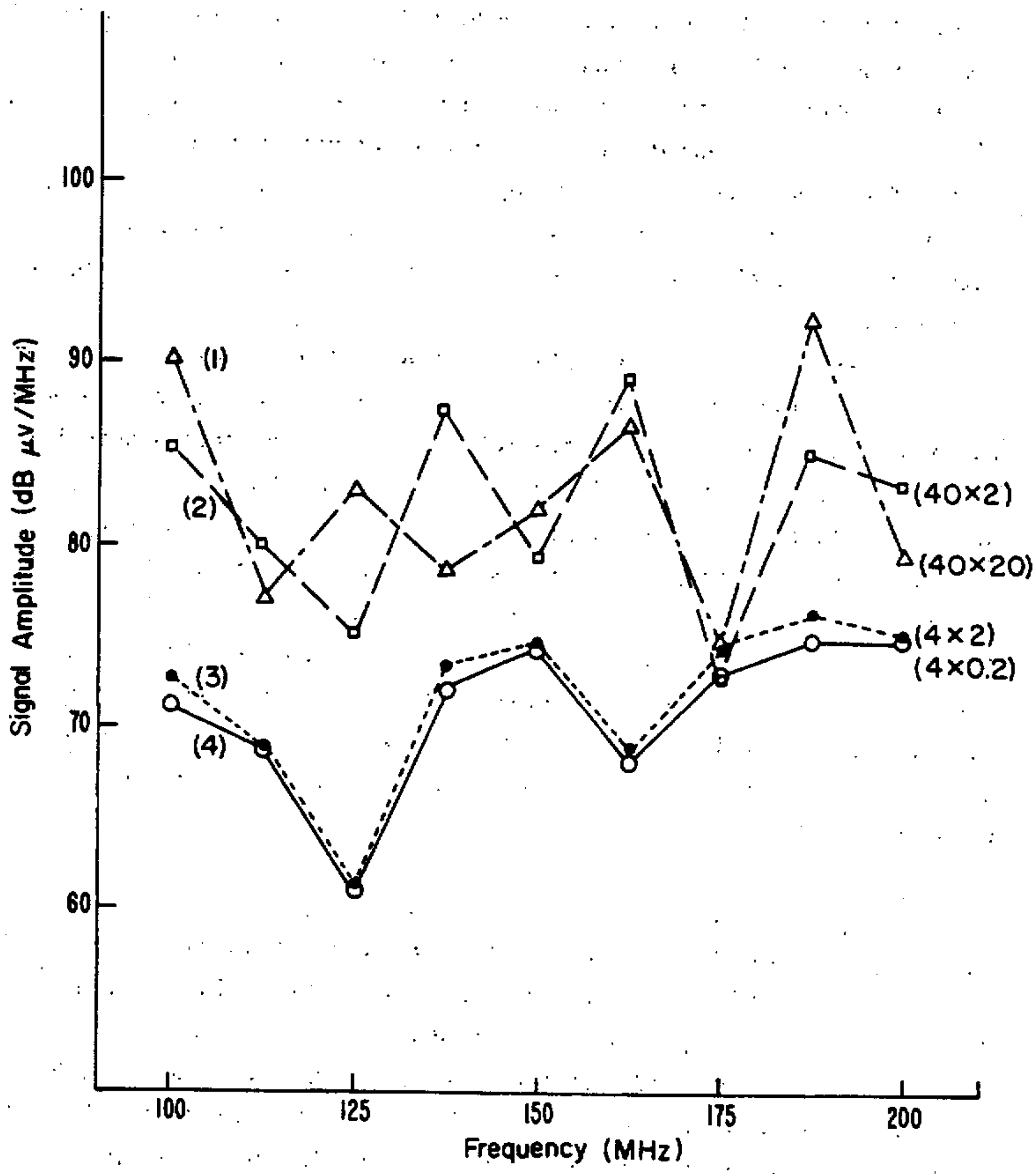

Figure 4. Signal Amplitude at a Wire Termination as a Function of Aperture Dimension. (Data points indicate coupled signal variation with frequency as a function of body shield apertures.)

of data in curves 1 and 2 (largest dimension 40 in) and a similar grouping in curves 3 and 4 (largest dimension 4 in). These sets of data were for rectangular apertures of 40 in and 4 in, respectively, in the largest dimension. The field-to-wire coupling analysis program (FTWCAP) also predicted a greater than 40 dB attenuation of signal due to cable shielding (Bagdanor et al., 1971). The relevance of this analysis is that when shielding and cable placement are considered in system design, care must be taken to assure enclosure integrity and cable routing.

EMC Guidelines

The guidelines (Volume 3) will serve to emphasize and highlight those factors in the use of electronics for automotive safety and control that are important to the accomplishment of EMC among the various subsystems. In considering rules or standards for electronics in automobiles, it is important to remember that the applications of electronics for safety and control purposes are in early stages and that the trend for greater application could certainly be toward a modular or central processor concept. The modular concept of itself can augment compatibility because an overall design concept can be applied. At the same time, it could create a condition of greater susceptibility because of the increased use of digital components and the increase in demand for signal transmission within the vehicle in order to utilize a central control device.

The guidelines for design, installation, and testing describe the several factors of importance to general EMC in each of these areas and also specific practices and considerations pertinent to automotive electronics. An important feature to accomplish EMC is to integrate and coordinate all aspects. In other words, shielding, bonding, packaging, filtering and signal transmission requirements should be an integral part of the system design.

The automotive and electronic industries are very much alert to the challenge of using electronics systems in automobiles. New ruggedized electronic components have been designed to meet the demands of the severe automobile environment (Cohen, 1975; Vonderschmitt, 1974). Single package sensors and transducers are being designed to simplify the interface of sensor and reference devices to the digital control systems (Patstone, 1974; Zeisler, 1973). Several of the major automobile industries have supported research in the areas of an overall (central processor) control system which, when implemented, affords an economy in multiple use of sensor functions and multiplexing capabilities of the computer (processor). The research efforts indicate system feasibility, but not without further work, particularly in the area of interface between the control units and the vehicle (Oswald, et al., 1975; Jones, 1975).

Testing for susceptibility at the component and subsystem level can be very useful for design and installation purposes. However, it is impossible, or at least very difficult, to completely simulate the automobile environment and the interaction between the electrical and electronic systems outside the vehicle itself. Testing for conducted susceptibility is not too difficult to perform. Similar testing for radiated signals requires special facilities. Piece-wise testing, where signal coupling to cables and circuits is first accomplished, followed by conductive upset testing, may reduce facility requirements.

3. Recommendations for Further Research

A Phase III study should emphasize testing and measurements of automotive electronic units and subsystems, to evaluate and validate the guidelines proposed in Phase II. The principal testing would be directed toward functional units (IC's, sensors, etc) to support EMC management for design, system engineering, and normal maintenance phases, and also be responsive to DOT requirements for testing and evaluation of special subsystems. This proposed direction in testing and evaluation is considered to be in harmony with the feasibility studies of the major automotive manufacturers which propose future applications of various levels of central processor (computer) control systems for integrated electronics applications (Oswald et al, 1975; Jones, 1975). To continue a testing program that only includes currently used subsystems does not properly address the expected trend in the development of automotive safety and control electronics applications, and will provide very limited information usable for equipment design guidance to mimimize internal and external EMC operational problems. This would also provide marginal guidance for acceptance tests and maintenance measurement planning.

An integrated (radiation and conduction) susceptibility modeling and measurement program will provide sets of functional degradation descriptors that indicate the combined effects of all coupling mechanisms. Design and application guidelines that reflect undesired response or performance characteristics in relation to separate radiative and conductive stimulus and combined mode stimulation will result. Sensitivity analysis will be provided by the simulation programs (ECAP, WTWCAP, FTWCAP), with the measurement effort allowing validation and required parametric specifications. The measurements are necessary to assure credibility of the simulation exercises and the resultant EMC guidelines.

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