ANALYSIS OF AUTOMOTIVE CONDUCTED ELECTRICAL TRANSIENTS

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ABSTRACT

This paper reports on recent work at GM related to bench-level component test procedures for evaluating the electromagnetic interference (EMI) signal susceptibility characteristics of electrical/electronic components. In-vehicle generated EMI transients captured at sources and receivers in a vehicle that had no known EMI problems were analyzed. Frequency domain spectra were compared with the spectra of ISO waveforms[1]. Results showed that by comparing the spectra of measured transients with those from the Standards, such as ISO, realistic waveform amplitudes can be set to reflect transient levels prevalent in a late model automobile.

INTRODUCTION

The traditional way of ensuring automotive electromagnetic compatibility (EMC) has been through an iterative test-and-fix type of an approach that consists of fixing electromagnetic interference (EMI) problems discovered during whole system testing. Before system integration, care is usually taken in order to reduce the likelihood of EMI problems. This is achieved through good EMC practices, as well as through component specifications such as Delco Electronics Engineering Specification No. T2000[2]. Nonetheless, several iterations may be required to assure system EMC, with the accompanying cost and schedule penalties. Scheduling for testing is becoming a more difficult problem to deal with. The increased demand for whole vehicle EMC testings has been largely due to the increase in the number of electrical/electronic components, and to the increase of automotive electrical/electronic system complexity. To minimize the need for iterative-type whole vehicle testing, bench-level test procedures for evaluating the EMI susceptibility characteristics of components are being developed by both domestic and foreign automakers. Components under test would have to meet emission and susceptibility specifications, both conducted and radiated, that are chosen to reduce the likelihood of EMI problems after system integration.

This paper addresses the conducted susceptibility parts of the bench-level tests. In a typical conducted EMI occurrence, an electrical/electronic component that acts as a source of interference generates transient signals that are coupled to one or more components that act as receivers of interference. In the conducted susceptibility test, a number of specified transient waveforms are injected into the receiver of EMI that is being tested. The receiver passes the test if it can tolerate the injected signals without significant deviation from its normal functioning. The signals to be injected must be selected so as to span as broad a spectrum of the transient signals that a component is likely to be subjected to in the car environment, as possible.

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The purpose of our work was to capture and analyze in-vehicle generated transients in order to identify waveforms and compare to those proposed for conducted susceptibility bench-level testing specifications.

IN-VEHICLE TRANSIENTS

Electrical transients with significant amplitude have been known to be generated when electrical devices are switched[3]. When a device is turned on, the inrush power can momentarily lower the supply voltage to another device until equilibrium is restored. On the other hand, when a device is turned off, the switching operation terminates the power flow into the device. The stored energy in both the harness and the device must be dissipated. If the dissipation is done smoothly, the perturbation to the rest of the system can be small. However, sudden changes in current can generate large voltage spikes due to inherent inductive elements in the circuit.

The vehicle used for capturing transients was a 1986 Buick LeSabre. This vehicle had a high level of electrical option content giving a wide selection of sources and receivers. The sources selected for our study were:

- Coolant fan
- Power window motor
- Air conditioning (A/C) compressor clutch coil

These sources represented a high current device (fan motor), small motor (window motor), and a high inductance solenoid (A/C clutch coil). The receivers selected were:

- Electronic control module (ECM)
- Radio (power and memory)
- Digital cluster
- Electronic spark control module
- Battery
- Chime module
- Blower control module
- A/C control head
- Computer controlled coil ignition module
- Decoder module
- Wiper/washer control

With the exception of the battery, all receivers were electronic devices thought to be most susceptible to transients. The battery was selected because it is a common point for all electrical and electronic devices powered by it.

The waveform measurements at the sources were performed at the power input into the source, and similarly for the receivers, at one of its power inputs.

Figure 1 shows examples of transient voltage and current at the source when switched from on to off for the coolant fan motor. Here, the sampling rates were set to capture the entire switching operation or the "big picture". Note that at each event where a large current level change occurs, voltage spikes are evident.

To capture the details of each transient, faster sampling rates were used. Figure 2 shows examples of the voltage waveform for the power window going up to off at three different sampling rates exhibiting the various levels of details. It is important to point out that the actual peak voltage level may not be detected when the sampling rate is not short enough. Therefore, we followed the procedure of first capturing the "big picture," then focusing on the events which produced the large spikes at the appropriate sampling rate and trigger level.

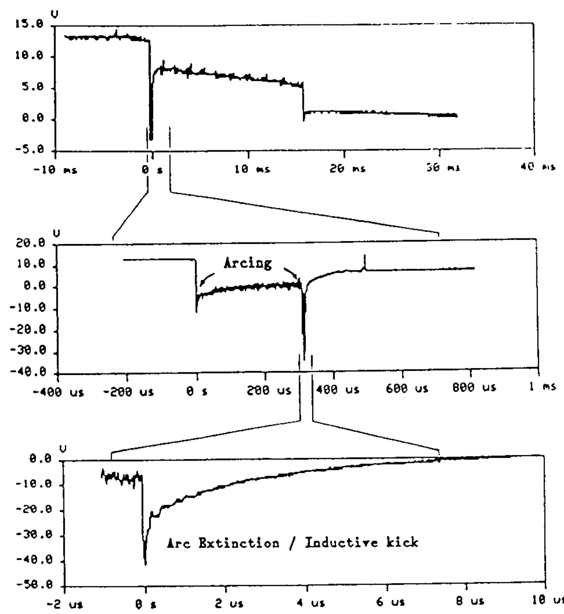

Fig. 2. Source transient of power window motor operated from up to off at three data acquisition sampling rates. The region of expansion is indicated for the next faster sampling.

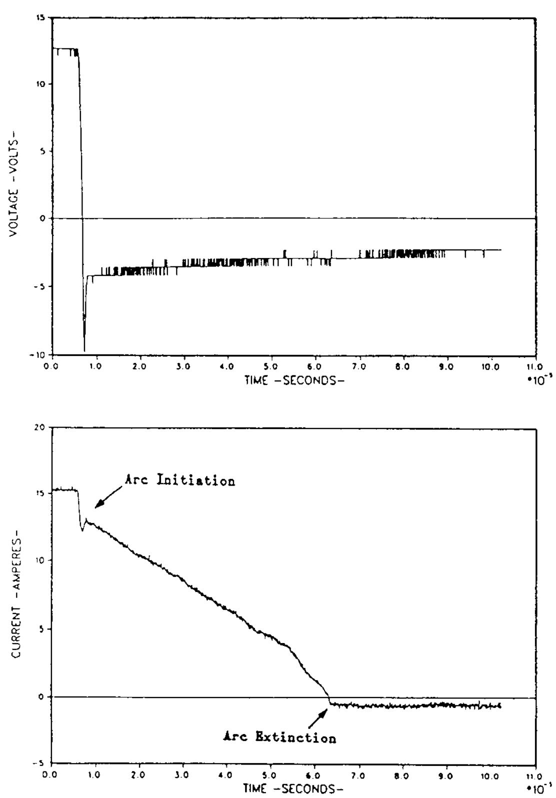

Fig. 1. On to off source transient at the coolant fan motor.

WAVEFORM ANALYSIS

The voltages and currents caused by the operation of the three sources were measured at eleven electrical components in the vehicle. The measured transients did not cause any malfunctions and, in that respect, can be considered as waveforms which fall below the susceptibility threshold of the tested components.

A logical scheme for generating specifications for conducted susceptibility testing is to select the worst case waveforms that in-vehicle components are likely to be subjected to. Components, however, can be susceptible to one or more measurable transient waveform parameters such as peak voltage or current, rise and fall time, energy content, etc. In other words, one must know what transient parameters are critical for each component. This fact makes the selection of worst case waveforms device dependent, thus complicating the task and maybe increasing the number of waveforms to be injected into devices for conducted susceptibility testing. An alternative approach would be to synthesize a number of worst case waveforms by assuming that all parameters are important.

The International Standards Organization (ISO) has selected six different voltage waveforms for injection into components for such test[1]. A component passes the test if its function does not deviate when injected with the specified waveforms. These voltage waveforms were compared to the ones observed in the vehicle. It was found that some of the ISO waveforms had some resemblance with the in-vehicle transients, but in general, the ISO waveforms could not account for all the observed transients.

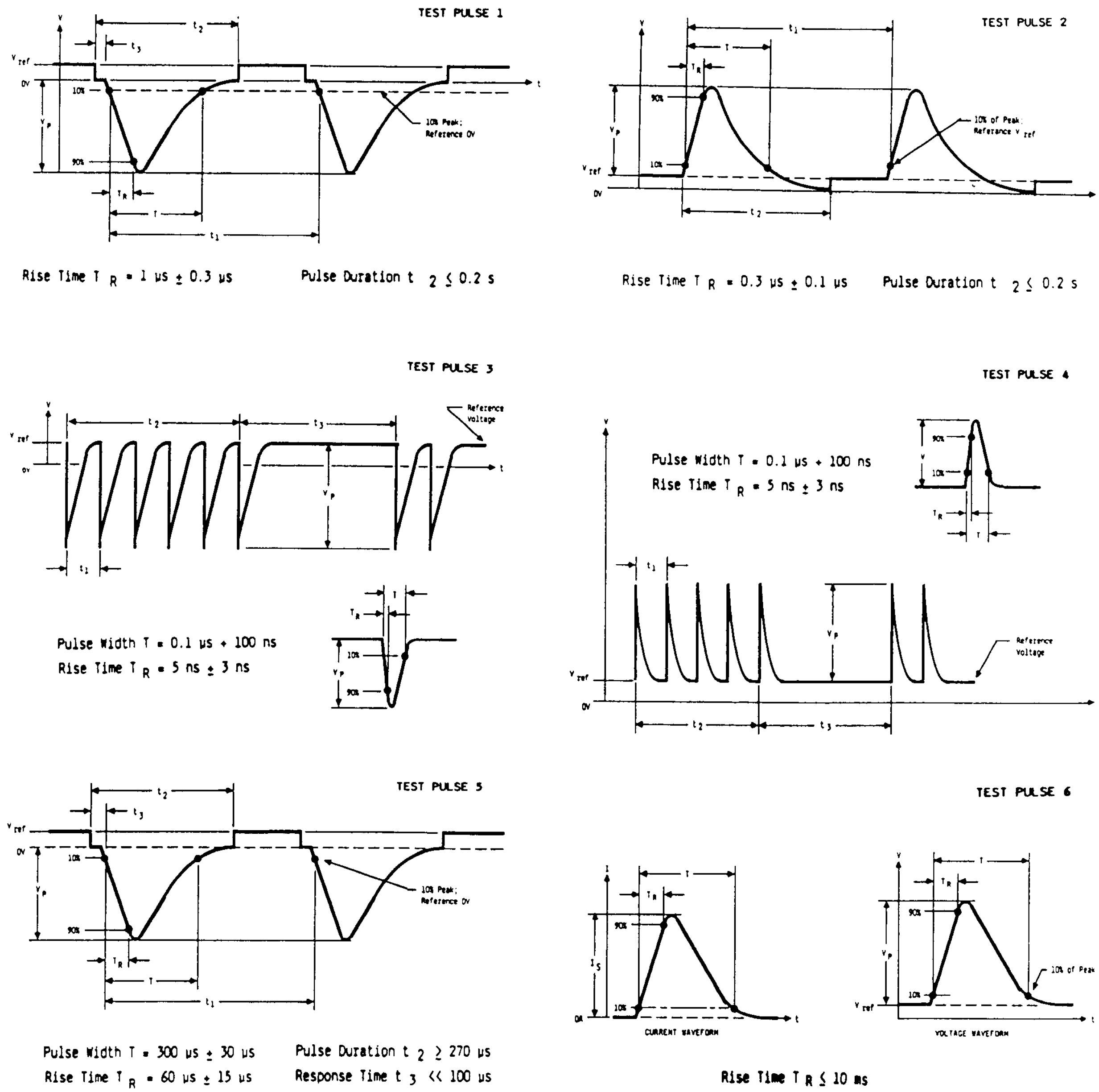

Fig. 3 ISO waveforms for conducted susceptibility testing.

Spectral representation of component susceptibility characteristics would seem to be much more convenient than time domain representation, because amplitude and frequency information only are needed. However, it is difficult to account for phase information and hence valuable information can be lost. For example, nonlinearities associated with the operation of switches and digital devices are best described in the time domain. One of the advantages of the spectral representation approach is that it is convenient for dividing the spectrum into required and nonrequired regions. Required regions are frequency bands that account for input or output signals that are required for normal operation of the device. Using specifications in the frequency domain the susceptibility of the component in the required domain can be checked in a straightforward manner. Another advantage is that such susceptibility threshold spectra play an important role in the system-level approach for automotive EMC [4]. However, the fact that the captured transients did not cause malfunctions prevents us from using their spectra as realistic susceptibility threshold spectra for the specific components.

As mentioned earlier some resemblance was found between the ISO waveforms and the in-vehicle captured transients at the ports of the various receivers. The six ISO waveforms used for conducted susceptibility testing are shown in Fig. 3 (The exact values of their parameters can be found in Ref. [1]. It was felt that instead of modifying the ISO waveforms a more practical approach would be to extract from the captured transients information that could be used to adjust the amplitudes of the six ISO waveforms. To accomplish this the spectra of all the voltage transients were found. These spectra were used to generate the two envelopes shown in Fig. 4. These envelopes should be interpreted as follows. The upper envelope (solid line) shows the maximum voltage as a function of frequency observed at one (or more) of the tested receivers. The lower envelope (dashed line) represents the minimum voltage as a function of frequency observed at one (or more) of the tested receivers. In that sense one can say safely that this lower envelope provides information about the voltages as a function of frequency that all the eleven receivers can be exposed to without any deviations occurring. However, one should be reluctant in using such an envelope as the susceptibility threshold for these receivers. A more realistic interpretation and use of these envelopes is as envelopes of spectra of transients observed at various component in today's automobile. Adopting this point of view, it is then reasonable to ask how these envelopes compare with the spectra of the ISO waveforms. To answer this question the ISO waveforms were approximated analytically using double exponential curves,

$$g(t) = V_{ref} + A\left(e^{-\alpha t} - e^{-\beta t}\right) .$$

Only the pulses 1, 2, 5 and 6 were considered because we did not capture any transient that resembled waveforms 3 or 4 from the three selected sources. The parameter A was taken as a variable, while α and β were chosen in such a way that the rise times and pulse widths of the waveforms were approximated as closely as possible. Their values are listed in Table 1.

Table 1. List of α and β values for the ISO waveforms.

Pulse No.	α (10^3 sec^{-1})	β (10^6 sec^{-1})
1	1.2	6.0
2	50.0	150.0
5	7.5	200.0
6	0.0115	0.00035

The amplitude A was adjusted so that the spectrum of the specific pulse would fall under the envelopes of Fig. 4. The results are shown in Fig. 5. The absolute amplitudes $|A|$ found are shown in Table 2.

Table 2. Calculated amplitude values for the ISO waveforms.

Pulse No.	$\lvert A_{up}\rvert$ (Volt)	$\lvert A_{low}\rvert$ (Volt)
1	4.7	0.5
2	6.5	0.3
5	12.4	0.3
6	3.2	0.3

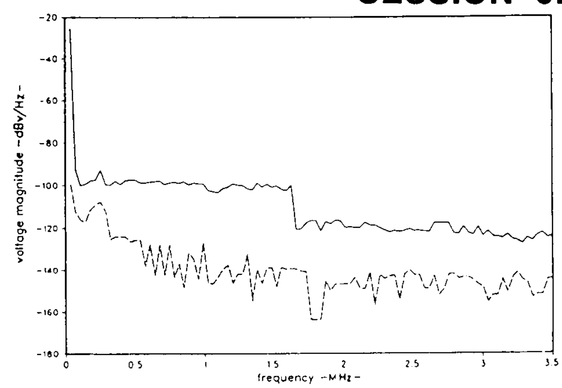

Fig. 4. Spectrum envelopes generated from the transient voltages observed at eleven EMI receivers.

where $|A_{up}|$ is for the upper and $|A_{low}|$ is for the lower envelope. These values measured in the vehicle are up to an order of magnitude lower than the values that are recommended by ISO and that have been proposed in a preliminary procedure, the GM9100P specifications for conducted susceptibility[5]. It must be mentioned, however, that the above envelopes have been generated from transients that have undergone enough filtering on their way through the wiring harness to the ports of the receivers. Also, the sources of these transients were shielded sources and therefore, the amplitudes of the emitted transients were already low enough, in fact much lower than the GM 9100P specifications.

CONCLUSIONS

Our measurement and analysis have demonstrated that:

- The proposed ISO waveforms could not account for all observed transients.
- Based on spectral analysis, in-vehicle acquired transients can be used as a guide to set the waveform amplitudes for component conducted susceptibility bench-level testing.
- The GM 9100P specifications for conducted susceptibility are conservative and represent prudent practice to insure component compatibility.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the encouragement and technical support of our colleagues, Al Meduvsky, Stan Rawski, Dirk Swanson, Mark Laskowski, Doug Constance, Bill Sperber, Mark Krage, T. C. Wang, John Hile, and Carl Speck. Last, but certainly not least, we like to thank Howard Kendall, Rozalina Ebrahimian and Don Seyerle for many stimulating and fruitful discussions.

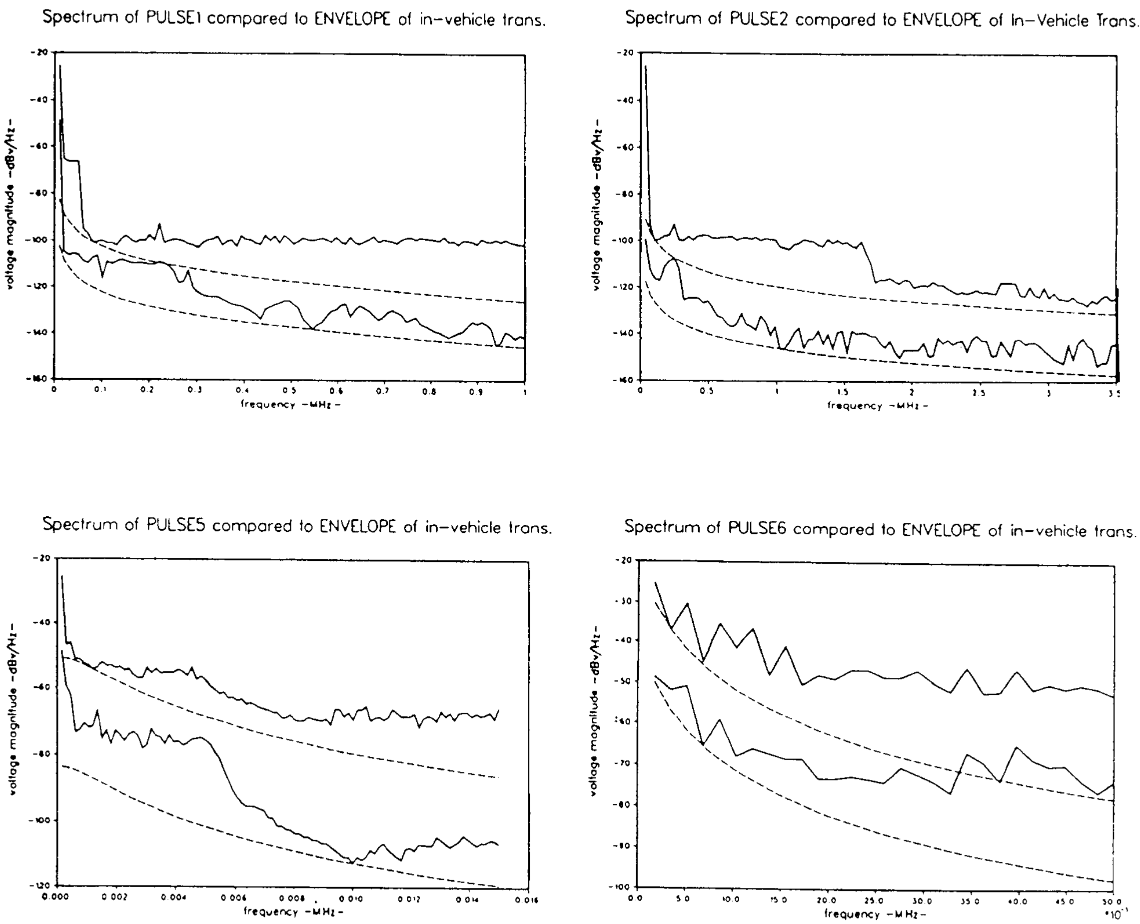

Fig. 5. Comparisons of amplitude spectra of ISO waveforms with the spectrum envelopes of the voltage transients captured at eleven EMI receivers.

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