AN ELECTROMAGNETIC IMMUNITY DIAGNOSTIC TOOL FOR ELECTRONIC CIRCUITS

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ABSTRACT

The electromagnetic immunity of electronic circuits is a significant concern for automotive electronic designers. Many papers have been written concerning the electromagnetic susceptibility (EMS) of electronic modules. However, very little has been written on EMC diagnostic tools and techniques to pinpoint the specific susceptibility problems or immunity levels of electronic circuits. This paper will discuss in detail the use of Direct RF Power Injection as an EMC diagnostic tool over the frequency range of 500 kHz to 500 MHz. This technique offers advantages of improved repeatability and correlation with vehicle results over other methods currently in use. The methodology of Direct RF Power Injection will be detailed so other EMC engineers may benefit from this development.

TEST DEVELOPMENT

The development of this EMC diagnostic tool grew out of concern over the lack of correlation and repeatability of radiated and bulk injection tests. It was thought that improvements could be made in controlling the applied RF, and that this control could be used as part of a conducted test to yield diagnostic information by locating susceptible lines.

Initial efforts were directed at developing an improved isolator to replace the LISN [1]. A high impedance broadband response was desired. The targets were: impedance of 500 ohms or greater over the maximum achievable frequency range starting at 500 kHz, minimum inductance, minimum size and current carrying capacity of 2 amperes without magnetic saturation or excessive voltage drop. Ultimately, other versions were developed that were optimized to other current capacities. Many configurations were experimented with but the most promising employed toroidal inductors. Toroids, with a self contained magnetic field, allowed a more compact configuration without undesired crosstalk between lines. The design that evolved used a cascade of parallel resonant circuits that overlap in frequency response. These parallel resonances are due to the self resonance of a series of "tuned" toroidal inductors. The result is an overall low Q broadband response that exhibits a low pass characteristic below about 100 kHz changing to the desired high impedance by 500 kHz out to beyond 250 MHz.

Utilizing these isolation networks between the DUT lines and those of its power and other support lines eliminates parasitic coupling paths. RF injection can now be accomplished on the DUT side of an isolation network and only that path probed. Critical paths and ineffectively filtered lines can be identified, modified and re-evaluated.

The impedance of the test point is not usually known. The problem of quantifying the RF injection level due to varying impedance at the test path led to using a power rather than a voltage measure. Providing a 10 dB attenuator in the path between the RF power amplifier and the DUT test point allows both the power amplifier and the power sensing device to operate in a 50 ohm system with minimal reflections. This measured input power then becomes the conducted source for the line under test.

Adaptations of the general procedure have to be made due to special circumstances. High speed data lines will tolerate only limited series inductance and shunt capacitance. Variations on the isolator configuration have been developed to reduce series inductance and shunt capacitance, however, these result in some reduction in low frequency impedance. In some applications, the blocking capacitor and 50 ohm attenuator represent too low an impedance to ground across the test point and a smaller value of capacitor must be used.

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DEFINITIONS [3]

Broadband Isolator. A device that presents a controlled impedance over a specified frequency range to the DUT while allowing the DUT to be interfaced to its support system. In this paper it refers to the device developed by engineers at the E/E Systems Compatibility Department of Chrysler Engineering to replace the LISN for RF testing. This device is covered by U. S. patent 4,763,062 [4].

Dedicated Lines. Lines connecting the DUT to a sensor, load, or similar input or output without a conductive path, other than ground, to any other module or the vehicle electrical power system.

Direct RF Power Injection. A conducted RF immunity test technique that involves isolating the DUT so that the RF coupling path is controlled. Also referred to as Single Line Injection.

DUT. Device(s) under test. Can be any electrical or electronic component, module, filter, etc. Also referred to as EUT or equipment under test.

Effect. A detectable change in DUT performance due to an applied stimulus.

LISN. Line Impedance Stabilization Network (5 microhenry) as described in SAE J1113, August 1987, Appendix A [1].

TEST PROCEDURE

Test Description

The DUT is subjected to Direct RF Power Injection on all input and output lines, line by line, over the frequency range of 500 kHz to 500 MHz. This test uses a 10 dB attenuator in the injection network and a broadband isolator between each DUT line and its termination except for dedicated lines. Power is incremented up to the test limit at each frequency step and the DUT is monitored for effects. Specific susceptibility information on a line by line basis is obtained.

I. Safety Precautions

A. The DUT harness and other parts of the test fixture will emit RF fields during the test. The field strength levels are not considered to be hazardous except immediately adjacent to the test fixture. The test operator must avoid handling the test sample and fixture while the test is in progress.

B. An area around the injection site must be marked off with warning tape at a minimum distance of four inches from the test sample, isolation network and injection pad. A warning sign must be displayed at the test bench stating that RF radiation hazards may exist within the taped area when the RF source is in operation.

C. The test must be set up such that the operator can easily monitor the status of the test sample without hovering over the injection site.

D. Safety levels for human exposure to radio frequency electromagnetic fields may be found in American National Standards Institute document C95.1-1982 [2].

II. Setup and Preliminary Information

A. DUT Configuration

The DUT must be configured to perform its required functions with as few leads as possible connected. (Refer to Figure 1.) The test strategy is to conduct RF power from a quantified source directly into the DUT inputs and outputs through a controlled path. Therefore, any leads attached to the DUT must be isolated from the DUT support system. A high impedance broadband isolation network is placed in series with any lead required to operate the DUT. Special considerations apply to dedicated lines. Sensor or load lines that form a closed loop, dedicated to the DUT without any other interconnections, and having the potential of supporting RF circulating currents, shall be injected at the DUT without using an isolator. The lead length between the DUT and the high impedance end of the isolator must be as short as possible, with a maximum allowable length of 10 to 15 cm. Any lead exceeding 10 cm must be routed in a controlled and repeatable manner to minimize cross coupling among leads and to maximize repeatability of test results. The arrangement must be defined and documented. At the other end of the isolation network, lead length is not a factor.

B. Injection Equipment

The power is delivered to the DUT through a 50 ohm, 10 dB attenuator in order to minimize the effect of reflections caused by the impedance discontinuity at the injection point. A DC blocking capacitor is also inserted at the injection point to prevent damage to the test equipment.

C. Measuring Instrument

The preferred measurement instrument is a spectrum analyzer. Alternately, an RF power meter of appropriate bandwidth and dynamic range may be used.

D. Calibration of Test Equipment

1. RF Level Monitor

The spectrum analyzer or power meter must first be calibrated, traceable to the National Bureau of Standards (NBS) and capable of measuring levels provided by the sampling device with a tolerance of ± 1 dB.

2. <u>RF Sampling Device and Injection Equipment</u>

The sampling T, attenuator and DC blocking capacitor in the power line are susceptible to overload and must be calibrated on a regular basis. To calibrate the test station, disconnect the injection apparatus from the DUT injection point and connect it to an NBS traceable, 50 ohm power measurement meter. Compare the level at the sampling T output with the level at the DC block output. The net difference is the correction factor which must be factored into the test system. If the sampling T exhibits in excess of ± 3 dB variation, it must be replaced.

III. Conducting the Test

RF injection power is increased from a low level (10 mw) while power into the 10 dB attenuator pad is monitored via the RF sampling device. The test operator monitors the DUT for affected operation as the power level is incremented at each test frequency. When an effect on DUT functional performance is detected, the operator logs the effect and the RF power level, producing a RF susceptibility curve for the particular line under test. All DUT lines are injected except for the reference ground.

<u>Power Levels and Frequency Steps</u>

A. Increment frequency in 5 MHz steps. When DUT interactions are clustered in a particular range of frequencies, rerun the range of frequencies in smaller steps (0.5 MHz to 2 MHz).

B. Minimum and maximum test frequencies are limited by the isolation networks.

C. Increment power level in 0.1 dB steps maximum.

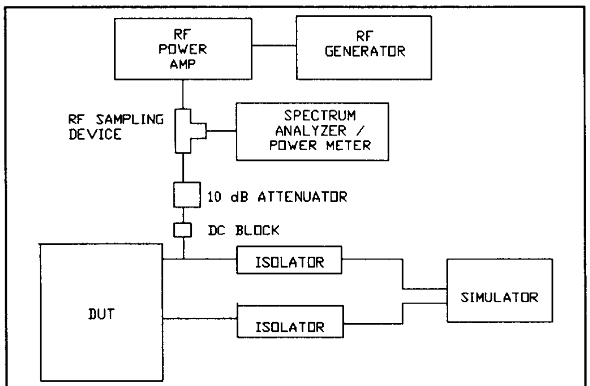


FIGURE 1: BLOCK DIAGRAM OF TEST SET UP

TEST EQUIPMENT

A shielded room is desirable to limit radiated emissions
RF Amplifier output power ≥ 10 watts
RF Power Attenuator: 10 dB, rated to the RF amplifier power level
RF Sampling Device rated to the RF amplifier
Blocking Capacitor: 0.1 μF, through-loss ≤ 0.1 dB, maximum power handling ≥ 0.5 watt
Optional: Instrument controller, CRT monitor, Data acquisition equipment, Plotter
Parameters are to be maintained within the frequency range of 0.5 MHz to 500 MHz.

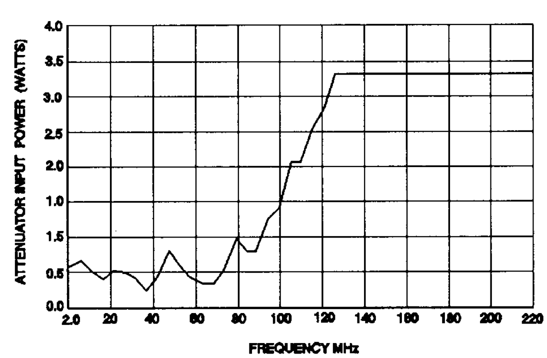
<u>TEST RESULTS</u>

To show the capability of Direct RF Power Injection as an EMC diagnostic tool, electronic modules built by two different suppliers using the same specifications and PC board layout were tested. These modules were known to exhibit different RF immunity characteristics as a result of vehicle testing. Modules A and B were built by suppliers A and B, respectively. Using the Direct RF Power Injection test across the frequency range of 2.0 MHz to 220 MHz, an immunity level of 3.0 watts of power at the attenuator input was desired.

Module A was tested, line by line, and 39 of the 40 lines had the desired immunity. One line, however, indicated susceptibility significantly below the desired level.

Figure 2 shows the response of this susceptible

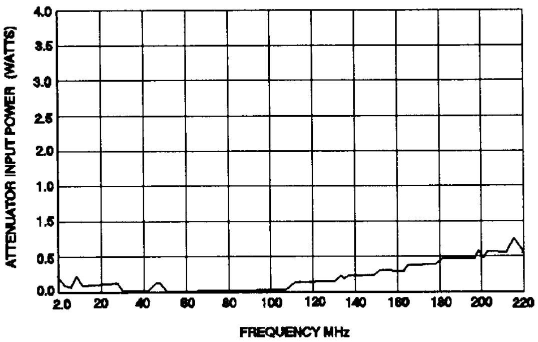
FIGURE 2: MODULE A IMMUNITY PROFILE



line on module A. This module failed to meet the immunity level desired in the frequency range of 2.0 MHz to 127 MHz.

When module B was tested, it failed on the same line as module A, however, the immunity levels were dramatically different. Figure 3 shows how the module failed to achieve the immunity levels throughout the RF range.

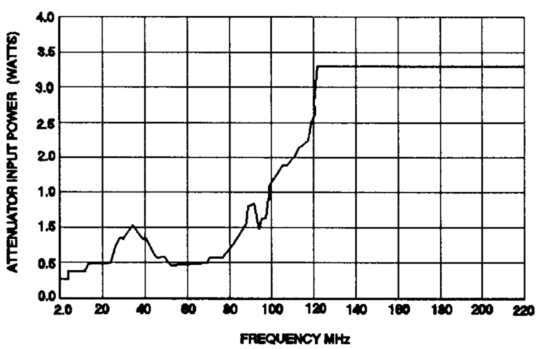
FIGURE 3: MODULE B IMMUNTIY PROFILE



To determine the cause of the differences in immunity levels, the connector pin and PC board trace were analyzed in both modules. The only observable difference was that module A had a slow speed switching diode where module B had a high speed switching diode. To verify that the diodes had an effect on the immunity levels, the diode from module A was substituted for the one in module B.

Fiqure 4 confirms that when the diode was

FIGURE 4: MODULE B WITH MODULE A SWITCHING DIODE



changed, module B immunity levels were very similar to those of module A.

Because the desired immunity level was not obtained in either module, a 0.01 μF capacitor was placed across the PC board trace to ground on the susceptible line. Figure 5 shows the results of adding the capacitor. The desired immunity level was achieved for both modules.

FIGURE 5: MODULE A & B WITH CAPACITOR

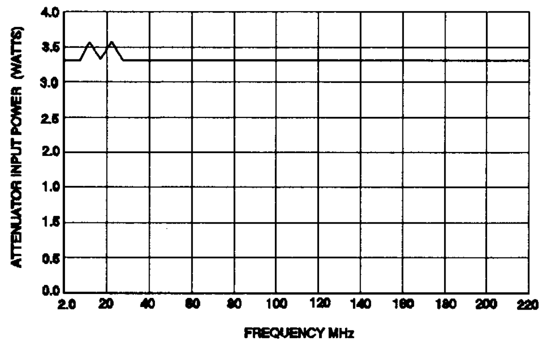
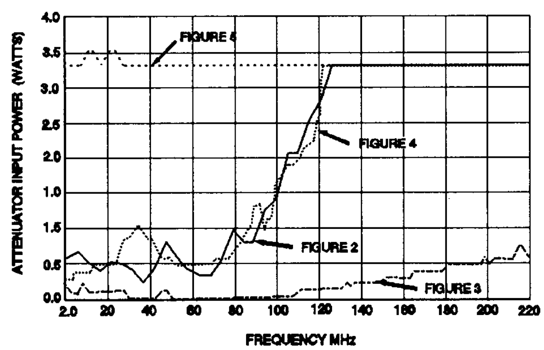


Figure 6 was generated to show a composite of figures 2 through 5. The data shown in this report confirms that Direct RF Power Injection is a very valuable EMC diagnostic tool for pinpointing the cause of immunity failures in the electronic design cycle.

FIGURE 6: COMPOSITE OF FIGURES 2 - 5



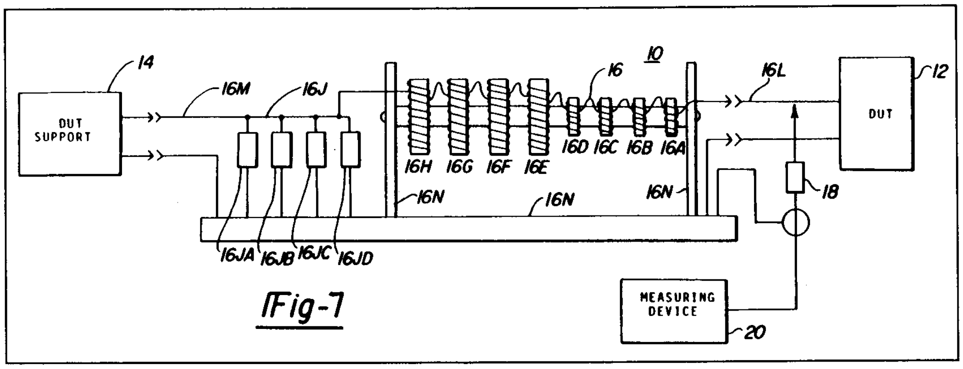


Figure 7: BROADBAND ISOLATOR CONFIGURATION

BROADBAND ISOLATOR DESCRIPTION

LABEL	CORE	# TURNS	L (µH)	Q (1 kHz)	RES FREQ
16A	T-80-26	7	3	.4	300
16B	T-80-26	12	7	1	100
16C	T-80-26	22	24	2	46
16D	T-80-26	35	63	4	18
16E	T-106-26	41	175	7	7.5
16F	T-106-26	60	374	9	3.0
16G	T-106-26	75	582	11	1.5
16H	T-106-26	100	1025	16	.8

Note: Toroid cores are powdered iron and wire used is #22 gauge enameled.
Inductance (L) and Q are measured at 1kHz and are typical values.
Resonant frequency, in MHz, is approximate.
Label 16N represents a ground plane.
Label 16JA-JD are bypass capacitors, typical values are 0.1 µF, 0.01 µF and 0.001 µF.

SUMMARY

The Direct RF Power Injection test is intended for use on electronic modules to discover and improve their RF immunity threshold. This technique is especially useful for determining the impact of design modifications on RF susceptibility. It is also very helpful in determining immunity thresholds that may vary depending on component sourcing from one supplier to another. In cases where an electronic module is completely shielded and radiated susceptibility tests are problematic, Direct RF Power Injection provides a controlled means of testing the module for RF immunity. Correlation between module immunity level, determined from Direct RF Power Injection, and vehicle immunity level, determined by vehicle tests, has been demonstrated in a number of cases.

ACKNOWLEDGEMENTS

We would like to acknowledge the contributions of David J. Trzcinski, EMC engineer, who was the originator of many of the ideas expressed here and is the co-author of the broadband isolator patent.

Acknowledgement is also made for the contributions of Gary W. Liddell, who wrote much of the test procedure for the Direct RF Power Injection test.

REFERENCES

[1] Electromagnetic Susceptibility Measurement Procedures for Vehicle Components, SAE J1113, August 1987, Society of Automotive Engineers

[2] American National Standard Safety Levels with Respect to Human Exposure to Radio Frequency Fields, ANSI C95.1-1982, (300 kHz to 100 GHz)

[3] Chrysler Corporation Performance Standard, PF-8925, Electrical and Electromagnetic Compatibility Specifications

[4] U. S. Patent 4,763,062 issued August 9, 1988.