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Electromagnetic Compatibility Testing of a Dedicated Short-Range Communication (DSRC) System that Conforms to the Japanese Standard

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U.S. DEPARTMENT OF COMMERCE
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PREFACE

This work was sponsored by the Federal Highway Administration (FHWA), McLean, Virginia, under the direction of J.A. Arnold, FHWA Contracting Officer Technical Representative.

Certain commercial companies, equipment, instruments, and materials are identified in this report to specify adequately the technical aspects of the reported results. In no case does such identification imply recommendation or endorsement by the National Telecommunications and Information Administration, nor does it imply that the material or equipment identified is necessarily the best available for the purpose.

CONTENTS

EXECUTIVE SUMMARY

The Department of Transportation is investigating the feasibility of deploying dedicated short-range communication (DSRC) systems at locations across the United States in the 5850 to 5925 MHz band. This is part of a larger band, 5250-5925 MHz, which is currently allocated to radar services. Deployment of DSRC systems depends upon the electromagnetic compatibility of their operations with radar systems operating in the 5-GHz portion of the spectrum.

Electromagnetic compatibility tests of a DSRC system that conforms to Japanese standards were performed by the Institute for Telecommunication Sciences. The purpose of the tests was to determine to what extent the DSRC system may experience electromagnetic compatibility problems when in close proximity to high-power radars in the 5-GHz spectrum. The tests were performed by injecting simulated radar signals into a DSRC receiver. The radar signals are representative of the range of parameters used by existing and possible future radars.

Thresholds at which the radar signals caused degradations of DSRC system performance were measured for each set of radar signal parameters. These measured interference thresholds were then used to determine the received signal levels at which existing 5-GHz radars would be expected to interfere with DSRC systems deployed in the United States. For each type of radar, the distance at which the radar system would be expected to cause interference to the DSRC system was computed for various conditions of electromagnetic isolation between the two systems. This analysis indicates that for typical conditions of isolation and nominal operating conditions of the DSRC system that was tested, 5-GHz radars are not expected to interfere with DSRC operations for any realistic separations between the systems (greater than several meters).

ELECTROMAGNETIC COMPATIBILITY TESTING OF A DEDICATED SHORT-RANGE COMMUNICATION (DSRC) SYSTEM THAT CONFORMS TO THE JAPANESE STANDARD

John J. Lemmon, Frank H. Sanders, and Brent L. Bedford[1]

Dedicated short-range communication (DSRC) systems, designed to enhance the efficiency of highway travel, have been proposed for operation in the 5850- to 5925-MHz band. The successful operation of these communication systems depends upon their compatibility with high-power search and tracking radars that operate at or near this frequency band and are a potential source of interference. This report presents the methods and results of a series of interference tests performed by the Institute for Telecommunication Sciences to determine the electromagnetic compatibility of a DSRC system and high-power 5-GHz radars.

Key words: dedicated short-range communication (DSRC) systems; high-power radars; electromagnetic compatibility; interference

1.0 INTRODUCTION

1.1 Background

As part of the planning of an intelligent transportation system, the Department of Transportation is evaluating the performance of dedicated short-range communication (DSRC) systems. DSRC systems are wireless communication systems designed for operation in highway environments. Their purpose is to enhance the efficiency of highway travel by providing various vehicle-to-roadside services such as wireless interrogation stations that would collect tolls electronically as vehicles pass through the stations without stopping.

The portion of the spectrum between 5850 MHz and 5925 MHz has been identified as a likely band for deployment of DSRC systems in the United States. This band is part of a larger band (5250-5925 MHz) that is allocated on a primary basis for radiolocation (radar) systems. The band is occupied in the United States by high-power radar systems that could potentially interfere with DSRC systems in highway environments.

The Institute for Telecommunication Sciences (the Institute) recently tested a DSRC system for its response to high incident field strengths in the 5250-5925 MHz band. Tests were performed to determine the interference thresholds at which DSRC performance was degraded. The results of these tests in conjunction with previous measurements of emissions from high-power radars in

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the 5250-5925 MHz portion of the spectrum [1-5] were used to determine the extent of electromagnetic compatibility problems the DSRC device under test may encounter if deployed in the proposed 5850- to 5925-MHz band. The methodology and results of these tests have been discussed in a report by Dalke, Sanders, and Bedford [6].

The DSRC system described in [6] is based on European standards, and will hereafter be referred to as the European DSRC. More recently the Institute performed analogous tests on a DSRC system that conforms to Japanese standards. The purpose of this report is to describe the methods and results of these latter tests.

1.2 Approach

The tests were performed in a laboratory at the Institute for Telecommunication Sciences in Boulder, CO. The basic approach to the tests was to inject simulated radar signals into the DSRC and to determine the interference levels, for various radar signal modulations, at which performance degradations of the DSRC would occur for both co-channel interference and off-frequency interference.

As discussed in [6], radar beams typically scan across any given point in space repetitively, approximately every 3 to 10 seconds, and illuminate any given point (such as a DSRC station) for about 20 ms during a given beam-scan period. The signals consist of a repetitive series of pulses that are characterized by the pulse width and pulse repetition interval. Two related parameters are the duty cycle (pulse width divided by pulse repetition interval) and the pulse repetition frequency (reciprocal of the pulse repetition interval). The pulse parameter combinations that were selected for the interference testing are representative of the parameters for 5-GHz radars in the United States and are shown in Table 1. For each combination of duty cycle and pulse repetition frequency (or pulse repetition interval), the corresponding pulse width is shown in the table.

Table 1. Radar Parameters Used for DSRC Interference Signal Testing (prf = pulse repetition frequency and pri = pulse repetition interval)

	prf = 300 Hz pri = 3.3 ms	prf = 1000 Hz pri = 1 ms	prf = 3000 Hz pri = 330 μs
Duty cycle = -20 dB (1%)	33.3 μs	10 μs	3.3 μs
Duty cycle = -30 dB (0.1%)	3.3 μs	1 μs	0.33 μs
Duty cycle = -40 dB (0.01%)	0.33 μs	0.1 μs	0.03 μs

For each interference signal modulation that was tested, the interference level was initially adjusted to a very low amplitude, well below the level that adversely affects DSRC performance. The amplitude was then gradually increased until an adverse effect on DSRC performance was noted.

1.3 Experimental Configuration

The hardware configuration used for the testing is shown schematically in Figure 1. The units under test, a DSRC roadside unit (RSU) and a DSRC on-board unit (OBU), were mounted in an Institute laboratory and were separated by approximately 2.8 m. The RSU was operated from a Proto H10 computer via a fiber optic link. The RSU transmitted to the OBU at a frequency of 5860 MHz. The OBU responded to the RSU at 5900 MHz. The OBU operated autonomously, its only external connection being for power.

As pointed out in [6], the uplink (signal transmitted by the OBU and received by the RSU) of the European DSRC is more susceptible than the downlink (signal transmitted by the RSU and received by the OBU) to interference signals, so that interference signals were coupled into the RSU receiver. Similar considerations apply to the Japanese system. As in the tests of the European DSRC, the signals were coupled via coaxial cable, rather than via RF radiation, to better control the amplitudes at which the interfering signals were injected into the receiver. A broadband RF combiner was utilized between the RSU antenna and the RSU receiver, as shown in Figure 1.

Interference signals were generated using a pulse-waveform generator. That output was then routed to the input of a signal generator to generate pulsed RF energy at the proper amplitudes and frequencies for the tests. The interfering signal was then coupled into the RSU receiver via the broadband combiner, along with the desired signal from the RSU antenna.

As shown in Figure 1, a calibrated horn antenna was also used in the RSU-OBU propagation path to observe time-domain and frequency domain emissions from the RSU and OBU. The horn antenna output was connected to a spectrum analyzer. Data from the spectrum analyzer were recorded via a GPIB bus interface.

Calibration of the measurement system and of the DSRC performance parameters was discussed in [6], and will not be repeated here.

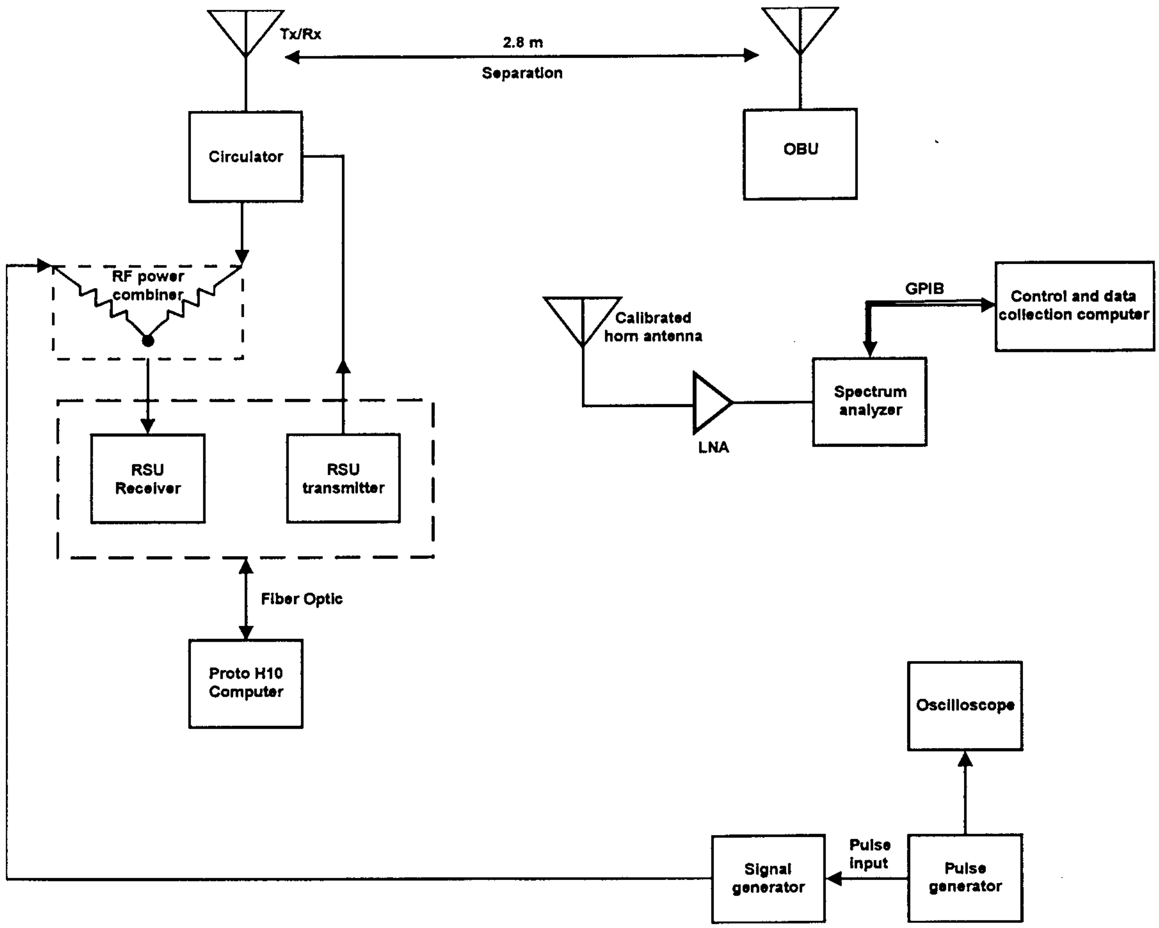

Figure 1. Block diagram of interference testing arrangement.

2.0 DSRC SOFTWARE DESCRIPTION

The DSRC system could not be operated under manual control. The RSU operations were controlled by the software, and the OBU operated autonomously. Test results were obtained through outputs from the DSRC software.

The protocol for communication between the RSU and OBU is based on a synchronous adaptive slotted ALOHA system. This is a time-division multiple access system in which the number of slots in a frame can be varied; for the interference tests the DSRC was operated in an automatic toll collection mode with a frame structure consisting of four slots. Each slot comprises 800 bits at a bit rate of 1 Mb/s. Thus, each frame had a time duration of 3.2 ms. Measurements of time-domain waveforms indicated that signals were not continuously transmitted during each frame. Also, the time between frames is variable and can be specified by the user; however, during the tests the frames were transmitted continuously to minimize the possibility of interference pulses being injected into the DSRC receiver during ‘dead time’.

As explained in [6], the performance parameter that was measured during the tests of the European DSRC is a quantity called wait time, which is essentially the time required for a transaction to take place. In the case of the Japanese DSRC, the wait time is not an output of the software. Instead, the number of frame errors on the DSRC uplink was measured for a user-specified number of transactions. The maximum number of transactions that the system will automatically conduct is 999, which is the number that was used for the tests.

The software also enables the user to specify a maximum number of frames that may be retransmitted during each transaction when one or more frames are in error. The number chosen for the DSRC tests was ten, which is the system default value. The experimenters discovered that the number of uplink "frame errors" is strongly dependent upon the number of retransmitted frames. For example, it was noted that when the number of retransmitted frames was set to zero, the number of uplink frame errors increased to a large value even when no interference was injected into the RSU receiver. Thus, the interference thresholds at which DSRC system performance is adversely affected depend upon the value selected for the number of retransmitted frames. The system default value of ten was selected, because it was concluded that this is representative of actual system deployment.

3.0 MEASUREMENT RESULTS AND DATA ANALYSIS

3.1 System Performance Measurements

Figures 2 and 3 show RSU and OBU spectra measured with a 10 dBi horn antenna located 1.7 m from the DSRC antennas. Institute engineers also measured the effective isotropic radiated powers (EIRP) of the RSU and OBU transmitters and the frequency response of the preselection bandpass filter in the RSU receiver unit. The measured EIRPs are consistent with the values of transmitter output powers and antenna gains specified by the manufacturer. The frequency response of this filter and the RSU antenna gain (approximately 15 dB) are of particular importance, because they are used in the analysis discussed in Section 3.4 below.

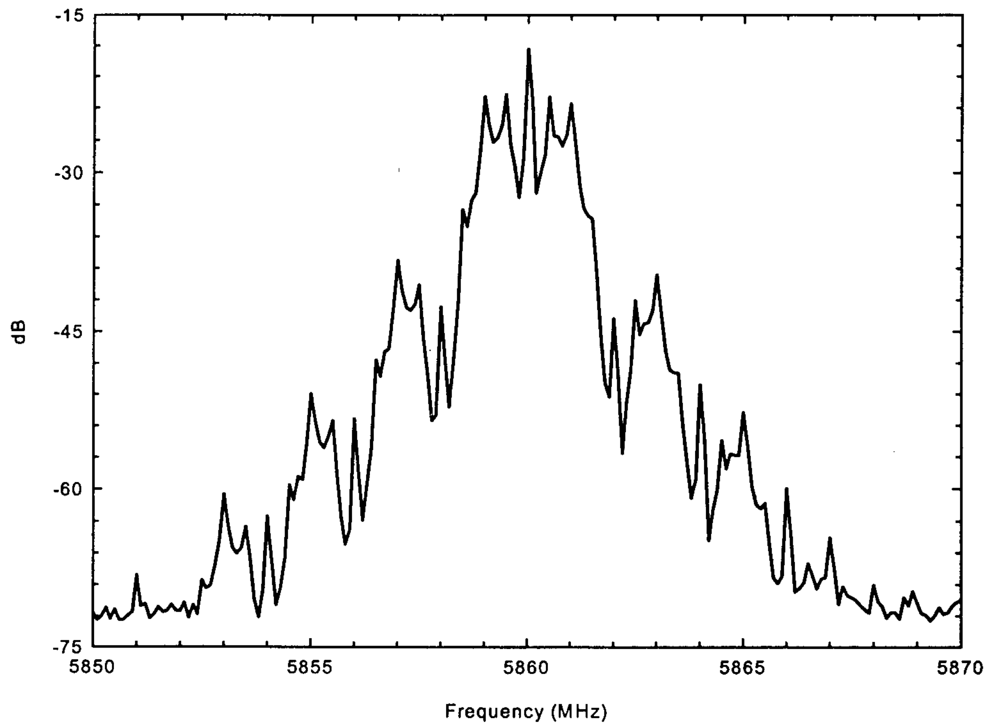

Figure 2. Emission spectrum of the RSU.

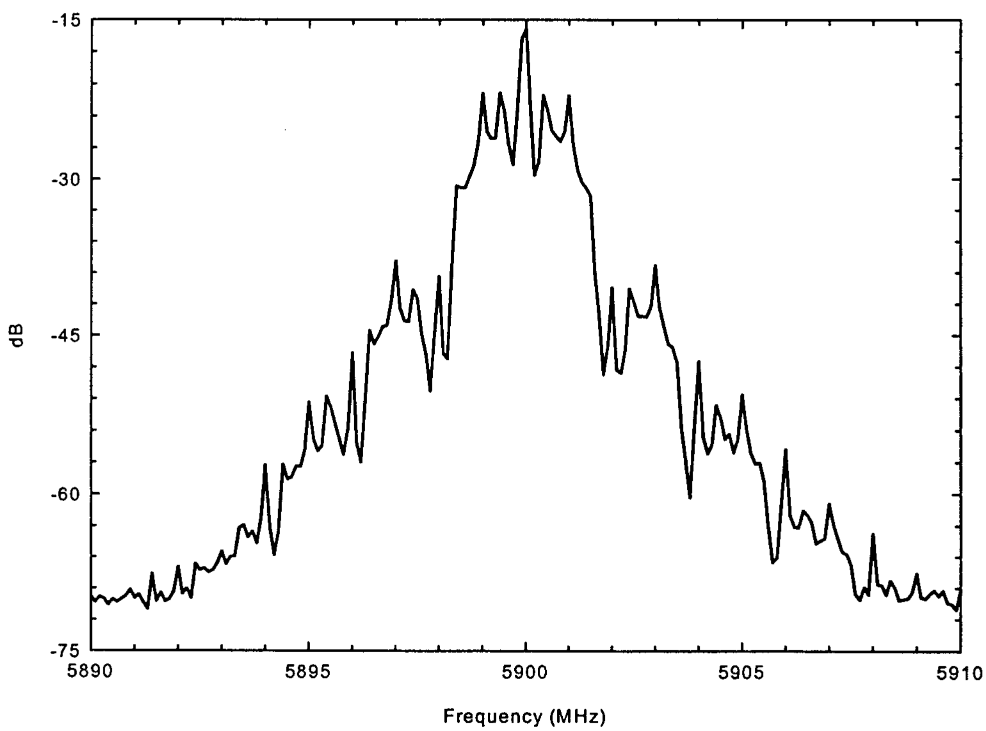

Figure 3. Emission spectrum of the OBU.

3.2 Statistical Measurements of DSRC System Performance in the Presence of Pulsed Radar Interference

The time and phase of a pulsed radar signal are random with respect to the DSRC transmissions. Thus, the number of frame errors is a random variable. Determination of the interference thresholds at which DSRC system performance is degraded therefore requires a statistical characterization. Using the measurement equipment and methods described above, uplink frame error statistics were measured for each of the nine radar signal modulations in Table 1 based on 999 independent transactions.

The interference thresholds at which uplink frame errors were generated are shown in Table 2. The maximum interference signal level that was output from the signal generator was 10 dBm. Subtracting 6 dB for combiner loss and an additional 6 dB for cable loss, a maximum signal level of -2 dBm was injected into the RSU receiver. A possible concern is that this is not a sufficiently high value for the maximum interference level since uplink frame errors were not generated for five of the nine radar signal modulations (this is why five of the interference power levels are designated as >-2 dBm in Table 2). However, as will be seen below, if interference signal levels of -2 dBm do not generate frame errors, the radars in the 5-GHz band and the DSRC system are electromagnetically compatible even at extremely small physical separations (several meters or less). Thus, it was not considered necessary to inject larger interference signal levels for the purposes of these tests.

Table 2. Peak Pulsed Interference Power Levels Resulting in Uplink Frame Errors for Various Radar Parameters (pw = pulse width, dc = duty cycle, and prf = pulse repetition frequency)

Radar Parameters	Interference Power Level (dBm)
prf = 300 Hz pw = 33.3 µs dc = 1%	> -2
prf = 300 Hz pw = 3.3 µs dc = 0.1%	> -2
prf = 300 Hz pw = 0.33 µs dc = 0.01%	> -2
prf = 1 kHz pw = 10 µs dc = 1%	-2
prf = 1 kHz pw = 1 µs dc = 0.1%	-2
prf = 1 kHz pw = 0.1 µs dc = 0.01%	> -2
prf = 3 kHz pw = 3.3 µs dc = 1%	-52
prf = 3 kHz pw = 0.33 µs dc = 0.1%	-12
prf = 3 kHz pw = 0.033 µs dc = 0.01%	>-2

3.3 Frequency Offset Measurements

The measurements described above, in which the interference center frequency is equal to the center frequency of the RSU receiver (co-channel interference) is the worst case scenario, since the RSU receiver has a preselection bandpass filter. To determine the DSRC performance when the interference signal is offset in frequency, the number of uplink frame errors was measured at various frequency offsets. Allowing up to ten retransmitted frames per transaction (as was done for the co-channel testing) resulted in no uplink frame errors for offsets of more than a few megahertz. Therefore, the frequency response of the preselection filter in the RSU receiver was measured to ascertain system performance with frequency offsets. The frequency response is shown in Figure 4. The attenuation of the filter (as a function of frequency) relative to the center frequency provides additional isolation between the DSRC and an interferer that is offset in frequency.

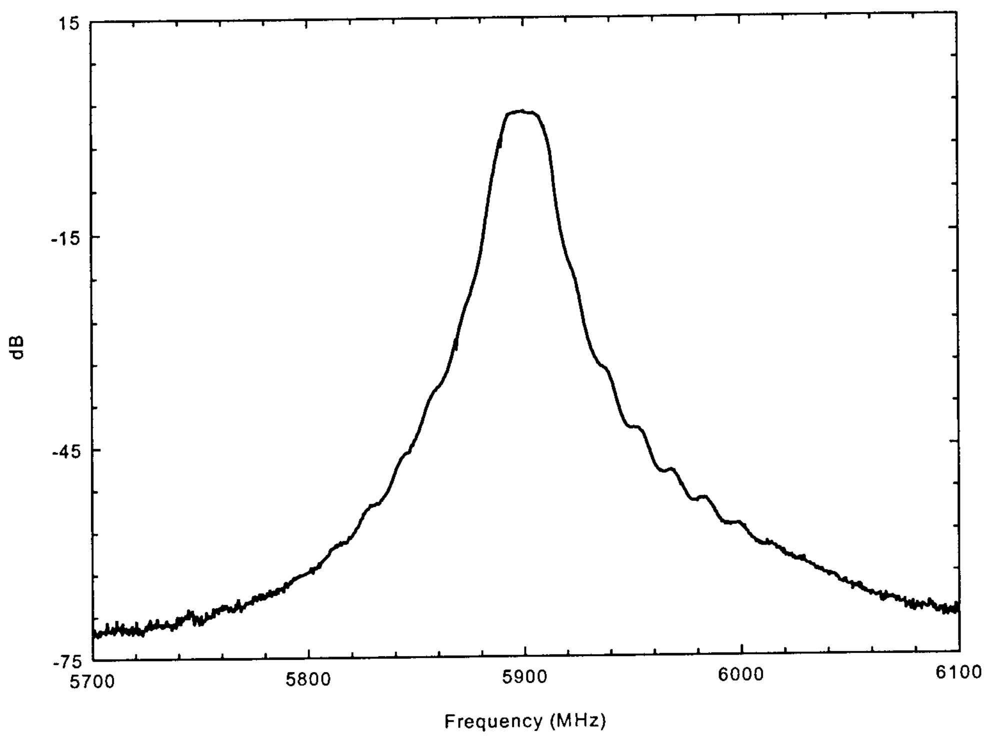

Figure 4. Receiver preselection bandpass filter frequency response.

3.4 Analysis of Results

Using the measurement results described above, the required isolations between the DSRC and an interfering radar have been determined for a variety of cases. High-power radars operating in the 5-GHz band typically have peak effective isotropic radiated power (EIRP) in the range of 113 to 133 dBm. The worst case interference degrades DSRC system performance at power levels as low as -52 dBm, as indicated in Table 2. Assuming an RSU antenna gain of 15 dB, at least 180-200 dB of isolation is required. The best case interference (from Table 2) occurs at power levels greater than -2 dBm, requiring 130 to 150 dB of isolation.

The physical separation between the DSRC system and the interfering radar necessary to achieve the best and worst case isolation is shown in Table 4. These separations correspond to those distances at which the basic transmission loss equals the required isolation. The basic transmission loss as a function of distance was calculated using the ITS Irregular Terrain Model [7] for a typical environment with the parameters shown in Table 3.

Table 3. ITM Parameters Used to Calculate Basic Transmission Loss

Parameter	Value
Frequency	5850 MHz
Polarization	Vertical
Antenna heights	13 m (radar), 6.1 m (DSRC)
Terrain irregularity	90 m
Surface refractivity	301 N-units (4/3 earth)
Climate	Continental temperate
Electrical ground constants	$\sigma = 0.005$ S/m, $\epsilon_r = 15$
Time reliability, location reliability, and confidence level	90%, 90%, 50%

The above estimates of required isolations assume co-channel interference and peak directivity for both the radar transmit antenna and the DSRC receive antenna. Additional isolation can be achieved when the DSRC is installed so that the interferer is out of the receiver antenna main beam. As pointed out in [6], it is estimated that an additional 15 dB of isolation can be achieved for such an installation. It is also estimated that when the DSRC system is well out of the main beam of the radar, an additional 25 dB of isolation may be obtained. Thus, an additional 40 dB of isolation may be realized by antenna alignment.

The measurement of the frequency response of the preselection bandpass filter in the RSU receiver, shown in Figure 4, indicates that about 70 dB of additional isolation may be achieved for frequency offsets of a few hundred megahertz. This attenuation in combination with antenna sidelobe attenuation provides adequate isolation for effective operation of the DSRC system that was tested.

To compare these possibilities, Table 4 gives the required best case and worst case isolations and the corresponding physical separations between the radar and the DSRC system for the following cases:

Case 1, isolation is achieved via physical separation only.

Case 2, isolation is achieved via physical separation and antenna alignment, which provides an additional 40 dB of isolation.

Case 3, isolation is achieved via physical separation and frequency offset, which provides an additional 70 dB of isolation.

Case 4, isolation is achieved via physical separation, frequency offset, and antenna alignment, which provides an additional 110 dB of isolation.

Table 4. Required Separation Between an Interfering Radar and the DSRC System to Achieve Best and Worst Case Isolation

Required isolation	Case 1: Isolation by physical separation only	Case 2: Isolation by physical separation and antenna alignment	Case 3: Isolation by physical separation and frequency offset	Case 4: Isolation by physical separation, frequency offset, and antenna alignment
< 130 dB	< 7.1 km	< 0.133 km	< 0.004 km	< 0.001 km
< 150 dB	< 24.8 km	< 1.1 km	< 0.040 km	< 0.001 km
180 dB	64.4 km	14.0 km	1.1 km	< 0.013 km
200 dB	203.5 km	39.8 km	7.1 km	0.133 km

These results indicate that when the DSRC and radar antennas are aligned so that the radar is viewed with minimum directive gain for both antennas, and the center RF frequencies are offset by a few hundred megahertz, the two systems should be compatible at separation distances of approximately 0.1 km for the worst case required isolation of 200 dB (EIRP = 133 dBm). If 180 dB of isolation is required (EIRP = 113 dBm), the systems should be compatible at distances of approximately 10 m. At these extemely small separation distances, the condition for minimum directive gain should be realized for both antennas.

Table 5 shows the results of interference calculations for specific existing radars that could potentially interfere with DSRC systems in the 5-GHz band. The radars and their operating characteristics were taken from the Government Master File.

Table 5. Required Separation Distances Between Specific Interfering Radars and the DSRC System for Different Isolation Cases

Specific radar	Case 1: Isolation by physical separation only	Case 2: Isolation by physical separation and 40 dB from antenna alignment	Case 3: Isolation by physical separation and frequency offset	Case 4: Isolation by physical separation, frequency offset, and 40 dB from antenna alignment	Case 5: Isolation by physical separation, frequency offset, and 15 dB from antenna alignment
RIR-778C/FRS-16 1 μs, 1 kHz MIP*=4 dBm	24.8 km 150 dB	1.1 km 110 dB	0.007 km Δf=50 MHz 65 dB	<0.001 km 25 dB	<0.001 km 50 dB
Test radar 10 μs, 1 kHz MIP=4 dBm	16.8 km 143 dB	0.54 km 103 dB	<0.001 km Δf=180 MHz 33 dB	<0.001 km -7 dB	<0.001 km 18 dB
Test radar 3.3 μs, 303 Hz MIP>4 dBm	<16.8 km <143 dB	<0.54 km <103 dB	<0.001 km Δf=180 MHz <33 dB	<0.001 km <-7 dB	<0.001 km <18 dB
SPS-10 1 μs, 1 kHz MIP=4dBm	7.1 km 130 dB	0.133 km 90 dB	0.009 km Δf=25 MHz 67 dB	<0.001 km 27 dB	<0.002 km 52 dB
SPS-10 3.3 μs, 303 Hz MIP>4dBm	<7.1 km <130 dB	<0.133 km <90 dB	<0.009 km Δf=25 MHz <67 dB	<0.001 km <27 dB	<0.002 km <52 dB
SPS-67 1 μs, 1 kHz MIP=4dBm	8.2 km 132 dB	0.166 km 92 dB	0.011 km Δf=25 MHz 69 dB	<0.001 29 dB	0.002 km 54 dB
SPS-67 0.33 μs, 3.03 kHz MIP=-6 dBm	15.8 km 142 dB	0.485 km 102 dB	0.036 km Δf=25 MHz 79 dB	<0.001 km 39 dB	0.006 km 64 dB
WSR-74C 1 μs, 1 kHz MTP=4dBm	14.9 km 141 dB	0.435 km 101 dB	<0.001 km Δf=200 MHz 29 dB	<0.001 km -11 dB	<0.001 km 14 dB
WSR-74C 3.3 μs, 303 Hz MIP>4dBm	<14.9 km <141 dB	<0.435 km <101 dB	<0.001 km Δf=200 MHz <29 dB	<0.001 km <-11 dB	<0.001 km <14 dB

*Minimum interference power (MIP)

In the first column we give the specific radar identification, the radar pulse parameters (pulse width and pulse repetition frequency), and the measured minimum interference power (MIP) for the pulse parameters. The pulse parameters were matched as closely as possible to the measurement results in Table 2 to estimate the MIP for each radar. For most of the radars there is a range of possible pulse widths and repetition frequencies, resulting differences in the required isolation. In these cases we have shown the best and worst cases associated with each radar.

In the following columns of Table 5, we give the results for each of the four previously defined cases and for a fifth case, where the DSRC antenna is in the main beam of the radar antenna, and the additional isolation due to antenna alignment is 15 dB. There are two table entries for all cases: the required isolation and the physical separation required to achieve that isolation. For Case 3, there is an additional entry showing the value of the frequency offset (Δf) that was used to estimate the value of isolation due to frequency offset (from Figure 4). These frequency offsets are the minimum offsets based on the radar RF frequency range and the proposed DSRC system RF frequency range.

Cases 4 and 5 have extremely small separation distances (several meters or less). As pointed out in [6], Case 4 should be achievable in most cases. Case 5 could occur if, for example, a non-rotating radar is pointed at the DSRC antenna sidelobe, and requires 25 dB more isolation than Case 4. However, even for this case the required separations are several meters or less.

Case 1 only occurs when the radar and the DSRC are co-channel and when additional isolation due to antenna alignment cannot be achieved. However, even for this worst case scenario, the maximum separation distance is less than 25 km (for the RIR-778C tracking radars).

4.0 SUMMARY

The operation of the DSRC system that was tested was found to be affected by co-channel radars with pulse parameters that are representative of high-power radars operating in the 5-GHz band. To achieve the necessary isolation between the radars and the DSRC system, separation distances of tens of kilometers or less are required. Our results also indicate that significant additional isolation can be achieved when the RF frequencies are offset by more than 25 MHz. When combined with the additional isolation achieved by antenna alignment (estimated to be 40 dB), the engineers found that all of the existing 5-GHz radars should be compatible with the DSRC system that was tested for extremely small separation distances (several meters or less).

One should be cautious in making any quantitative comparison between the results of the tests of the Japanese DSRC system described here and the test results of the European system discussed in [6]. In the tests described here, the performance quantity that was measured was the number of uplink frame errors, whereas wait time was measured in [6]. Without more information than the software of these two systems provided, the engineers were unable to measure the relationship between wait time and uplink frame errors. Thus, a direct comparison of the electromagnetic compatibility of the Japanese and European systems does not appear possible at this time.

It should also be realized that the number of uplink frame errors that was measured is dependent upon the number of retransmitted frames per transaction. For these tests, the system default (maximum of ten retransmitted frames per transaction) was chosen, because this is representative of actual deployment of the DSRC that was tested.

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15. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

Dedicated short-range communication (DSRC) systems, designed to enhance the efficiency of highway travel, have been proposed for operation in the 5850- to 5925-MHz band. The successful operation of these communication systems depends upon their compatibility with high-power search and tracking radars that operate at or near this frequency band and are a potential source of interference. This report presents the methods and results of a series of interference tests performed by the Institute for Telecommunication Sciences to determine the electromagnetic compatibility of a DSRC system and high-power 5-GHz radars.

16. Key Words *(Alphabetical order, separated by semicolons)*

dedicated short-range communication (DSRC) systems; electromagnetic compatibility; high-power radars; interference

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