

# **Spectrum Sharing Innovation Test-Bed Pilot Program**

## **Phase II/III Test Plan**

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# 1 INTRODUCTION

## 1.1 Background

The National Telecommunications and Information Administration (NTIA), in coordination with the Federal Communications Commission (FCC) and federal agencies, has established a Spectrum Sharing Innovation Test-Bed pilot program to examine the feasibility of increased sharing between federal and non-federal users. The pilot program is evaluating the ability of dynamic spectrum access (DSA) devices employing spectrum sensing and/or geo-location technologies to share spectrum with land mobile radio (LMR) systems operating in the 410-420 MHz band, allocated for federal use.

Since NTIA published the test-bed Phase I test plan on its website in February 2009, NTIA has been engaged in testing DSA devices at its laboratory, the Institute for Telecommunication Sciences (ITS), in Boulder, Colorado. The Phase I tests assess the performance and behavior of DSA devices in response to simulated LMR environment signals within a laboratory setting.

The Phase I test plan document<sup>1</sup> provided a notional definition of subsequent Phase II and III field testing. Phase II will assess the spectrum sensing capabilities of DSA devices in a live LMR environment with sufficient DSA transmitter attenuation to prevent interference to LMR systems. In Phase III the DSA devices' transmitter attenuation will be removed and the devices will be allowed to operate freely in a variety of live LMR radiofrequency signal environments.

## 1.2 Overview

This test plan covers Phases II and III of the test-bed and is organized as follows. Section 2 describes the Phase II test. This test assesses the devices' behavior in a live LMR environment with their transmissions isolated from the LMRs. NTIA will examine the Phase II test data for the frequency and severity of potential co-channel interference with LMR systems. Provided the DSA devices detect and avoid LMRs, they will proceed to the less controlled Phase III test conditions. The remainder of the test plan encompasses Phase III.

Phase III testing will follow a coexistence analysis approach as defined in IEEE 1900.2-2008. A coexistence analysis—as opposed to an interference analysis—is a system level test intended to evaluate the ability of an incumbent system, e.g., LMR, to perform its intended function in the presence of emissions from a secondary system, e.g., DSA. Sections 3.1 and 3.2 examine the performance of DSA devices in the presence of a hidden node on the downlink and uplink, respectively. These tests will provide, under repeatable test conditions, an estimate of the minimum separation distance required to prevent DSA to LMR interference, i.e., the *interference range*. The results may be used to adjust DSA policy databases or test procedures in preparation for subsequent Phase III tests. For example, a DSA device may be reconfigured to lock out critical LMR channels or a drive test route modified to guarantee a minimum separation between DSA devices and critical LMR systems. Devices that do not exhibit anomalous behaviors in the Section 3 tests will proceed to Section 4.

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<sup>1</sup> See [http://www.ntia.doc.gov/frnotices/2006/spectrumshare/Phase\\_I\\_Test\\_Plan\\_Final\\_Version\\_NTIA\\_Website.pdf](http://www.ntia.doc.gov/frnotices/2006/spectrumshare/Phase_I_Test_Plan_Final_Version_NTIA_Website.pdf).

Section 4 tests DSA devices operating under less controlled conditions within the coverage area of a live conventional voice LMR network. Similarly, Section 5 examines the potential impact of DSA devices on a trunked LMR system with particular emphasis on compatibility with LMR control channel signaling. Section 6 describes a geo-location test for suitably equipped devices. Section 7 completes the test plan with lists of acronyms and abbreviations, definitions, and references.

### 1.3 Terminology

Two different types of radio systems are involved in these tests. Land mobile radio is the largest primary use within the band. DSA transceivers are the secondary use being evaluated for compatibility with the primary one. Hereafter DSA transceivers will be referred to as the device under test (DUT). Some DUTs employ master/slave communications architectures. Wherever this functional distinction may be significant, the master will be termed the *DUT base* and the slave termed the *DUT subscriber*.

Similarly, LMR transceivers are divided into *LMR base stations* and *LMR subscriber units*. An LMR base station is a fixed station with an elevated antenna(s). They may be deployed in multichannel configurations and operate in either trunked or conventional configurations. LMR subscriber units are divided into mobiles and portables. *LMR mobiles* are typically vehicle mounted while *LMR portables* are typically handheld. An LMR subscriber unit can support both conventional and trunked mode operation.

### 1.4 Scope

This document describes NTIA's plan to assess the ability of DUTs to share spectrum with LMR systems in the 410-420 MHz frequency band. The test procedures and resultant test data complement the Phase I test results. The Phase I lab tests methodically characterized several key operating parameters of each DUT type for spectrum sensor performance, channel abandonment, and emissions characteristics. Numerous test trials were required to derive statistically valid measurements of these parameters. Assessing these parameters in a dynamic field test environment would be logistically infeasible and would introduce unmanageable measurement uncertainties. Instead, the Phase II and III tests will focus on DUT to LMR system interactions that could not be replicated in a controlled laboratory test environment. Also, this plan will test hypotheses that emerged from the interpretation of the Phase I test results, in particular, a field assessment of DUT and LMR responses to hidden node conditions.

The DUTs in the test-bed employ a variety of sensor-based detect and avoid technologies. They use unique RF sensors, modulations, channel access schemes, and time division duplex schemes. Phase I test results indicate that wide variations in equipment behavior are likely. Therefore, the type and depth of testing described herein is of a general nature. Detailed test procedures derived from these general plans will be tailored to each DUT.

Testing will be limited to the assessment of DUT interactions with LMR systems. Limited performance characteristics of DUTs were observed during Phase I testing with two transceiver systems. However, with DUTs in limited availability, a meaningful assessment or

characterization of DUT system performance in the field is not feasible. Also, assessment of the compatibility between different types of DUTs is also outside the scope of this plan.

The tests described in this document will assess particular phenomena such as the hidden node condition or characteristics unique to particular DUTs. Therefore, some of the tests described in this document will not be applicable to all DUTs. Furthermore, additional test procedures to examine unexpected DUT behaviors may be required.

Nothing in this test plan should be construed as a final rule, interference criteria, or acceptable use policy. While the results of these field tests will inform the rulemaking process, they will not necessarily establish specific precedents or pass/fail criteria. Further system modeling and testing may be required to establish a complete set of criteria required for establishing rules.

## **1.5 DUT to LMR Interference Mechanisms**

Physical layer interactions between LMR transmitters and LMR receivers are well understood. Conformity assessment criteria are documented in standards TIA-603-C, TIA-102.CAAA-B, and TIA-102.CAAB-B. Methods to model interactions between various types of narrowband emissions and different LMR receiver types are described in depth in TSB-88.1-C. LMR-to-LMR interactions can provide a model for assessing DUT-to-LMR interactions.

The simplest interaction is a co-channel transmission. The corresponding standard LMR test procedure is the co-channel rejection test. This test measures the performance of a receiver when unwanted signals are present on the operating frequency and are thus passed without attenuation through the receiver's IF stage filter. In the LMR-to-LMR case, the test is performed with a steady state unwanted signal, which yields a carrier to interference (C/I) ratio on the order of 8-9 dB. DUT-to-LMR co-channel interference is similar except that meaningful measures of C/I must consider the power spectral density of the DUT emission within the equivalent noise bandwidth (ENBW) of the LMR receiver. In addition, a DUT waveform's lower duty cycle should have less of an impact on an LMR receiver.

An adjacent channel DUT-to-LMR interaction is also possible. The standard LMR test for this is the adjacent-channel rejection measurement. When an LMR receiver is in the proximity of an adjacent-channel transmitter some of the modulated signal passes through the receiver's IF filter. Adjacent-channel interference is more difficult to examine in the context of a DUT transmitter in a field environment. Since DUTs are not constrained to operate on a fixed channel, the same test trial may contain co-channel, adjacent-channel and possibly other interactions. The test conditions cannot be controlled to the degree necessary to separate and quantify each interaction.

Another interference mechanism is out of band emissions (OOBE). LMRs have very low OOBE, so there is no standard test for the interaction of out of band LMR emissions with LMR receivers. Some DUT transmitters are broadband and may have significant out of band emissions. Phase I testing suggests that the impact of OOBE on an LMR can be determined analytically by calculating the amount of energy that passes through the ENBW of the LMR IF stage filter at a given frequency offset from the center of the DUT channel.

Finally, LMR receiver desensitization is possible in the presence of strong DUT transmissions. In a field test it will probably be impossible to distinguish the effects of DUT OOB from LMR receiver desensitization due to the DUT carrier itself. Even so, incidences of DUT impairment to LMR receivers will be fully investigated.

## **1.6 DUT Operating Channel Restrictions**

The DUTs participating in the test-bed employ unique methods of opportunistically selecting and, in some cases, aggregating narrowband segments of spectrum. Different types of carrier aggregation are supported. One approach is to aggregate adjoining subcarriers to form a single broadband carrier. Another approach is to notch out selected subcarriers from what is otherwise a contiguous broadband transmission. Finally, some systems aggregate non-contiguous narrowband carriers into a coordinated set of transmissions. The subcarriers do not necessarily align with the LMR channelization scheme or match the LMR channel bandwidths. DUT transmissions may consist of one or more subcarriers that span all or part of the 410-420 MHz test-bed band. For each DUT there is a minimum set of subcarriers that is required for the device to function normally, which was defined in Phase I as the minimum DUT operating channel. From the LMR channelization perspective the minimum DUT operating channel intersects a corresponding set of LMR channels. The DUT may use one or more sets of LMR channels to span the 410-420 MHz band.

During Phase III testing NTIA will restrict the DUTs to operation on one or two sets of LMR channels. LMR systems that are actively involved in the test-bed will be aggregated in one set of channels. A second set of channels available for DUT operation may contain non-participating LMR systems. All other LMR channels in the band will be Locked-Out LMR Channels that the DUTs cannot use. This restriction will constrain DUT operation to a reduced number of LMR channels to improve spectrum monitoring of measurement events.

## **1.7 DUT Fixed Station Operations**

Some of the DUTs in the test-bed normally operate with fixed base and subscriber stations. These DUTs will remain stationary during data collection. The base station and subscriber unit may be repositioned to simulate various separation distances from LMR transmitters. If necessary, the link between base station and subscriber unit will be reestablished after a DUT is repositioned.

## **1.8 LMR Operating Parameters**

This test plan assesses the performance of DUT detection of LMR downlink transmissions separately from LMR uplink transmissions. While some DUTs implement policies that ensure the DUTs avoid operation on one frequency based on the detection of a paired transmission on a different, paired frequency, it is assumed throughout this test plan (with the exception of the Section 6 test procedure) that frequency assignment data of this nature are not generally available. Such a capability is predicated on routine DUT access to data abstracted from the Government Master File (GMF), the federal government's list of frequency assignments. Access to the GMF is outside the scope of this test plan.

The Telecommunications Industry Association has documented interference protection criteria for LMRs in TIA TSB-88.1-C. TSB-88.1-C catalogs the delivered audio quality (DAQ) for a variety of LMR modulation and vocoder combinations including the Project 25 configuration considered in this test plan. It indicates that a given carrier to noise (C/N) ratio will provide a perceived audio quality and intelligibility which meets public safety requirements. This corresponds to a DAQ of 3.4 which is present when a Project 25 LMR has a mean bit error rate (BER) of 2% and a C/N of approximately 18 dB in a noise-limited mobile environment. The 2% BER value is defined in TSB-88.1-C as a pass/fail threshold for system acceptance testing when a DAQ of 3.4 is stipulated. Under this condition, test locations where BER values are just below the 2% threshold represent the edge of coverage. This plan used this 2% BER criterion throughout to establish the operating range of the LMR system in the presence of actual environmental factors such as man-made noise.

### **1.9 DUT Operating Parameter Restrictions**

Consistent with the methodology adopted for Phase I testing, prior to Phase II and III testing the test-bed participant will be permitted to evaluate its DUTs to ensure that they are functioning properly. After this point, the test-bed participant will not be allowed to change them, including the operational parameters, without prior coordination with NTIA.

### **1.10 Test Location and Pre-qualification**

NTIA will select test sites in the greater Denver metropolitan area for the Phase II and III tests. Spectrum surveys will be used to determine the suitability of proposed test locations. The spectrum surveys will be conducted using ITS's Radio Spectrum Measurement System (RSMS). RSMS employs custom-built low noise pre-selectors with FFT-based spectrum analyzers. Customized signal processing of the RSMS data reduces in-band impulsive noise for an accurate determination of usage profiles for each LMR channel in the band. A detailed description of the test system is provided in an NTIA report.<sup>2</sup>

The spectrum surveys will permit NTIA to confirm the source of all emissions in the 410-420 MHz band, characterize their amplitudes and temporal characteristics, and assign one or two sets of LMR channels for each DUT appropriate to the various test procedures. Prior to testing of each DUT, NTIA will perform an updated spectrum survey.

### **1.11 Test equipment disclaimer**

Certain commercial equipment and materials are identified in this test plan to accurately describe the technical aspects of the test equipment. In no case does such identification imply recommendations or endorsement by NTIA, nor does it imply that the material or equipment identified is the best available for this purpose.

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<sup>2</sup> See NTIA Report TR-07-448, *Measurements to Characterize Land Mobile Channel Occupancy for Federal Bands 162-174 MHz and 406-420 MHz in the Washington, D.C. Area* (July 2007), available at <http://www.its.bldrdoc.gov/pub/ntia-rpt/07-448/>.



## 1.12 Comment Resolution

On March 28, 2012, NTIA published a Notice in the Federal Register seeking public comment on the types and depth of testing to be conducted in Phase II and Phase III of the Test-Bed pilot program, as described in the draft Phase II/III test plan.<sup>3</sup> The Center for Advanced Engineering and Research (CAER); Datodp; Dr. Juan D. Deaton, Ph.D.; Motorola Solutions, Inc. (MSI); Shared Spectrum Company (SSC); and the Telecommunications Industry Association (TIA) submitted comments in response to the Federal Register Notice.<sup>4</sup>

The CAER recommended that NTIA perform testing to assess the feasibility of using the FCC White Spaces regulations in the 410-420 MHz and 470-512 MHz bands. The physical and operating characteristics of LMR systems, however, are substantially different from those of TV broadcast stations and wireless microphones. The TV White Spaces devices rely on a database of location information to determine the conditions under which they may operate. The location information pertaining to federal systems is not releasable to the public at this time.

The CAER also recommended that the principal objective of testing should be gathering data that can be used to develop a methodology for establishing exclusion contours. NTIA believes that the approaches to allow sharing between DSA devices and LMR systems are not necessarily limited to the use of exclusion contours. NTIA's testing to determine the interference range of the DSA devices in Section 3 of this draft test plan could be used to establish exclusion contours, if that is determined to be the most appropriate approach to sharing. The determination of exclusion contours can also be addressed through computer modeling and simulation.

Datod questioned the ability of the DSA devices and the measurement instrumentation used by NTIA to provide accurate spectral component estimation. Datod believes that this could lead to a potential waste of spectrum or errors in performing measurements. NTIA has verified through laboratory testing that the Vector Signal Analyzer called for in this draft test plan can be used to record and differentiate the individual LMR signals that can occur on the defined LMR channels within the testing environment. The frequency resolution is sufficient to determine if the DSA devices use a particular LMR channel.

Dr. Juan D. Deaton recommended that the draft test plan be more specific, the test cases be more precise, and the testing be as automated as possible. The draft Phase II/III test plan has to encompass a wide range of technical approaches to DSA; therefore, additional detail would have to be uniquely provided for each implementation of DSA technology. NTIA does not intend to

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<sup>3</sup> See Spectrum Sharing Innovation Test-Bed Pilot Program -- Notice, Request for Comments, 77 Fed. Reg. 18,793 (Mar. 28, 2012). A copy of the draft Phase II/III test plan for the Test-Bed pilot program is available at: <http://ntia.doc.gov/other-publication/2012/spectrum-sharing-innovation-test-bed-pilot-program-phase-ii-iii-test-plan>.

<sup>4</sup> The Center for Advanced Engineering and Research Comments in Docket No. 120322212-2212-01 (Apr. 27, 2012); Datod Comments in Docket No. 120322212-2212-01 (Apr. 27, 2012); Dr. Juan D. Deaton, Ph.D. Comments in Docket No. 120322212-2212-01 (Apr. 30, 2012); Motorola Solutions, Inc. Comments in Docket No. 120322212-2212-01 (Apr. 27, 2012); Shared Spectrum Company Comments in Docket No. 120322212-2212-01 (Apr. 28, 2012); Telecommunications Industry Association Comments in Docket No. 120322212-2212-01 (Apr. 27, 2012). All comments are posted on NTIA's website at <http://www.ntia.doc.gov/federal-register-notice/2012/comments-spectrum-sharing-innovation-test-bed-pilot-program>.

include the detailed test procedures specific to each Test-Bed participant's DSA devices in the draft Phase II/III test plan.

A few parties provided comments on the pass/fail criteria. Dr. Juan D. Deaton pointed out that the pass/fail criteria are vague and ambiguous. SSC commented that Section 2.6 of the draft test plan does not present clear success/fail criteria. Further, SSC suggested that the NTIA tests are a validation type test, yet there are no industry- or government-approved LMR-DSA parameters. NTIA's Phase II/III testing is not intended to make pass/fail decisions on the DSA devices that are participating in the Test-Bed pilot program. The purpose of this testing is to examine the feasibility of the DSA devices employing spectrum sensing and/or geo-location technologies to share spectrum with LMR systems. NTIA intends to try to move DSA devices from Phase II to Phase III of the draft test plan, unless Phase II testing shows that the DSA devices are unlikely to reliably detect LMR signals at levels above the DSA device's detection threshold and evacuate the LMR channel. NTIA will initially perform the Phase II test with the DSA parameters that were used in Phase I laboratory testing. NTIA will perform the Phase II/III tests with an additional set of mutually agreeable, Test-Bed participant-recommended DSA parameters, if the Test-Bed participant so chooses. Further system modeling and testing may be required to establish a complete set of criteria for establishing service rules.

MSI pointed out that the different propagation paths between the LMR transmitter and the DSA device and between the LMR transmitter and receiver may require 30 to 50 dB of additional sensing margin in the DSA devices. MSI feels that the DSA devices' sensing levels need to be in the range of -150 dBm or lower. This suggestion is one of many possible outcomes; however, it does not appear to consider the use of cooperative sensing by the DSA devices to improve the overall DSA system's ability to detect. Developing a sensor to detect LMR transmissions at levels as low as -150 dBm is a very difficult technical challenge. Finally, the adoption of sensing levels on the order of -150 dBm would still not address the problem of LMR stations that operate in a listen-only mode, such as in telemetry applications.

MSI commented that it is critically important to test both LMR uplink and downlink weak signal hidden node cases, as well as direct-mode (unit-to-unit) communications cases. Although NTIA does test the LMR uplink and downlink cases mentioned by MSI, the challenge with implementing the direct-mode scenario in field testing is determining a representative propagation environment for this scenario. There would likely need to be a large number of cases that would have to be examined to gain meaningful insight into this scenario. NTIA believes that the direct-mode scenario can be more effectively examined using computer modeling and simulation.

SSC recommended replacing the tests in Phase III of the draft test plan with a test that measures a LMR system without the presence of DSA devices as a baseline, and then introduces DSA devices into the environment and measures the impact on the LMR system. NTIA believes the Phase III tests are appropriate to further its understanding of DSA technology and inform the regulatory process. In all of the Phase III tests, NTIA first establishes the baseline condition for the LMR receivers operating without the DSA devices in the environment, and then introduces the DSA devices into the environment and monitors the LMR system performance.

SSC commented that NTIA has focused on cases that occur infrequently (e.g., cases where the desired LMR signal is low, hidden node) and not on operational scenarios. SSC believes that tests using operational scenarios offer much better decision-maker input and equivalent engineering value. NTIA believes that many federal LMR systems can be characterized as being noise-limited over a significant portion of their coverage area and as such this represents valid operational scenarios.<sup>5</sup> NTIA believes that modeling and simulation can be used to examine a wide range of LMR signal conditions, which will provide a clear understanding of the potential for and the conditions under which sharing between LMR systems and DSA systems can take place.

SSC pointed out that in the geo-location test, the test plan does not describe how the exclusion zones will be calculated. SSC also identified a small number of statements in the draft Phase II/III test plan that were unclear or created unrealistic test conditions. In response to the comment, NTIA updated the description of the geo-location test in Section 6 to clarify how the exclusion zones will be determined. In addition, NTIA incorporated changes into the test plan to improve its clarity.

The TIA proposed that DSA mechanisms with respect to the 470-512 MHz (T-Band) be limited in participation to those public safety licensees already authorized in the T-Band. NTIA will bring only DSA technology into the band for Phase II/III testing under a Special Temporary Authority (STA) coordinated with the FCC. NTIA will not test against other systems in the band beyond the planned testing with LMR systems.

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<sup>5</sup> A noise-limited situation is defined as one in which the performance is limited by the receiver noise level. The signal-to-noise ratio is slightly greater than the minimum required for acceptable receiver performance.

## 2 PHASE II: DUT SENSOR BEHAVIOR

### 2.1 Purpose

In this stage of testing NTIA will assess the DUT sensor behavior in the presence of live LMR systems of varying complexity. The DUTs will be isolated from the LMR systems using a custom test system that will simultaneously log DUT and LMR transmissions. Test engineers will review the logs and assess the spectrum access behavior of the DUTs. Knowledge of the spectrum signature of each DUT type will differentiate DUT and LMR transmissions.

This test will act as a coarse filter of DUT behavior in a complex RF environment. It will record and identify any serious interference events and provide an indication of the DUTs' ability to operate in a congested LMR environment. Assessment of the DUTs' ability to detect weak LMR signals is reserved for Section 3.

### 2.2 Pre-conditions

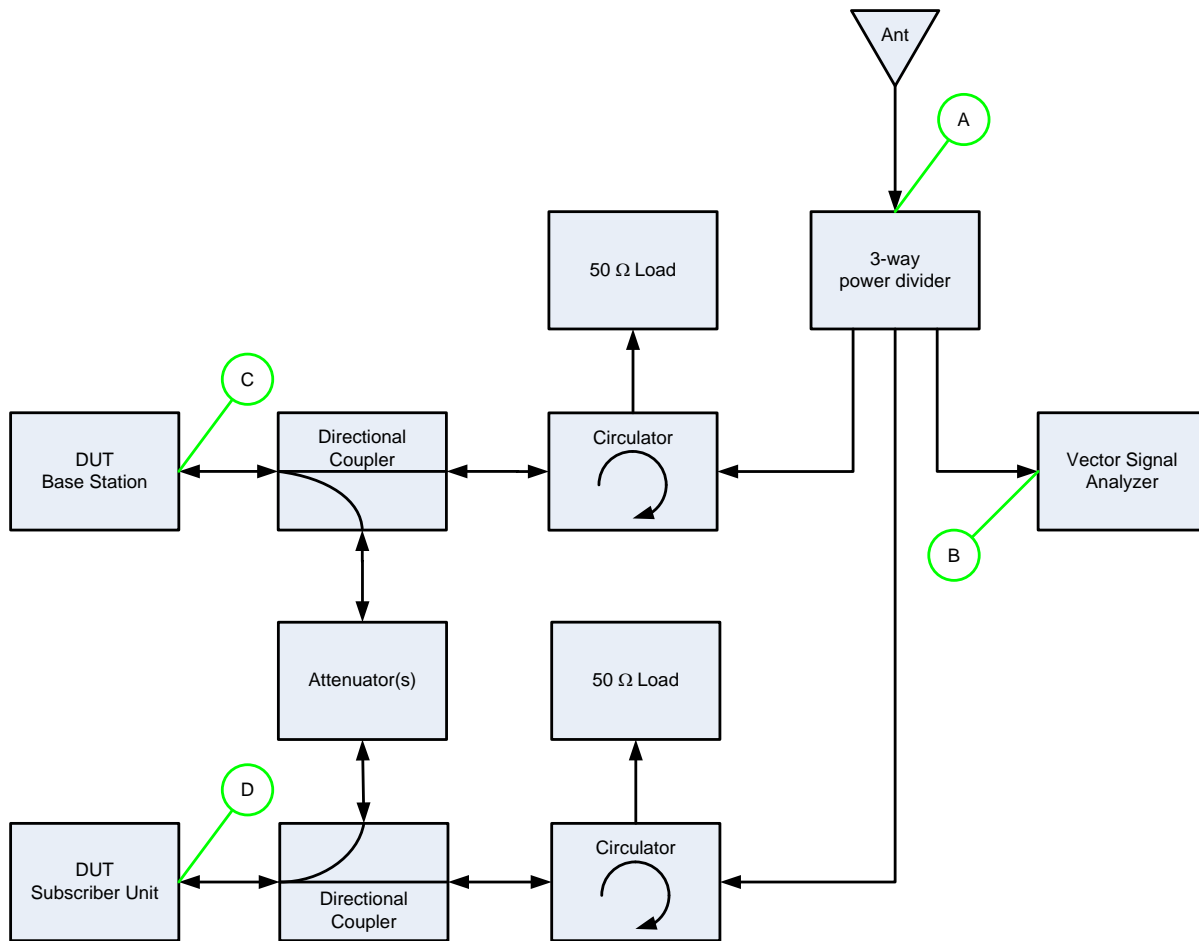
The test system minimizes radiated DUT emissions while passing ambient LMR transmissions to the DUTs with negligible attenuation. This will reduce the possibility of harmful interference from DUTs into the LMR system. The two DUTs will communicate with each other via a conducted path as illustrated in Figure 1. The circulators will attenuate the DUT radiated emissions by more than 50 dB rendering their emissions harmless. Additional port-to-port isolation inherent to the 3-way power divider will further attenuate the DUT emissions to permit the vector signal analyzer (VSA) to simultaneously record low-level LMR signals. Test engineers will assess the performance of the DUTs' sensors by reviewing spectrogram data captured by the VSA.<sup>6</sup>

DUT testing will be conducted from stationary vehicles, which will be positioned in various locations that provide increasingly complex LMR signal environments. For DUTs that use fixed stations, two tests will be performed. In the first test, the antenna will be raised to approximately 10 m AGL to represent the DUT base station's perspective of the environment. In the second set of measurements, the antenna will be lowered to approximately 2 m AGL to represent the DUT subscriber unit's perspective.

Initial tests will occur at the perimeter of an LMR system where the influence of a single LMR transmitter on a DUT sensor can be studied in isolation. Another test topology of interest is a sub-band within the 410-420 MHz frequency range that contains a limited number of LMR transmitters. Subsequent testing will expose the DUTs to LMR portable and mobile subscriber units and conventional and trunked base stations.

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<sup>6</sup> See <http://www.agilent.com/about/newsroom/tmnews/background/89600B/index.html>, Figure 2 for a description of the VSA spectrogram display.



**Figure 1: Block diagram of a conceptual DUT system emissions monitoring system for Phase II.**

### 2.3 Scenario Assumptions

- All transceivers will operate in the 410-420 MHz frequency range.
- No assessment will be made regarding the interference range of the DUT. See Sections 3.1 and 3.2 for further discussion of the interference range.
- The DUTs will be restricted to one or two sets of LMR channels by locking out all other LMR channels. This will permit test engineers to focus on DUT sensor performance with controlled co-channel emissions.
- If necessary to increase the possibility of DUT collisions on an LMR channel a controlled LMR emission will be generated. In particular, a portable LMR will be operated with an approximately 33% transmission duty cycle and an average message length on the order of 3-5 seconds.
- Attenuation along each of the conducted paths shown in Figure 1 (A-B, A-C, A-D, B-D, C-D, and B-C) will be measured prior to testing to permit calibration of the measurement. Power levels will be referenced to the input of the DUTs.

## **2.4 Test Procedure**

### **2.4.1 Channel Availability Check**

The DUTs will be configured to operate on one set of LMR channels which contains co-channel LMR portables, conventional base stations, and trunked base stations. The LMRs may be manually operated to simulate high channel occupancy conditions. The DUTs will be initialized and their ability to detect LMR activity will be examined.

### **2.4.2 In-service Monitoring**

The DUTs will be configured to operate on two sets of LMR channels. The first set will contain controlled LMR sources while the LMR transceivers in the second set will be uncontrolled. With communications links established between the DUTs, they will be transported in the test vehicle in the proximity of a variety of LMR transmission sources and their detect-and-avoid capability examined.

## **2.5 Data Capture and Review**

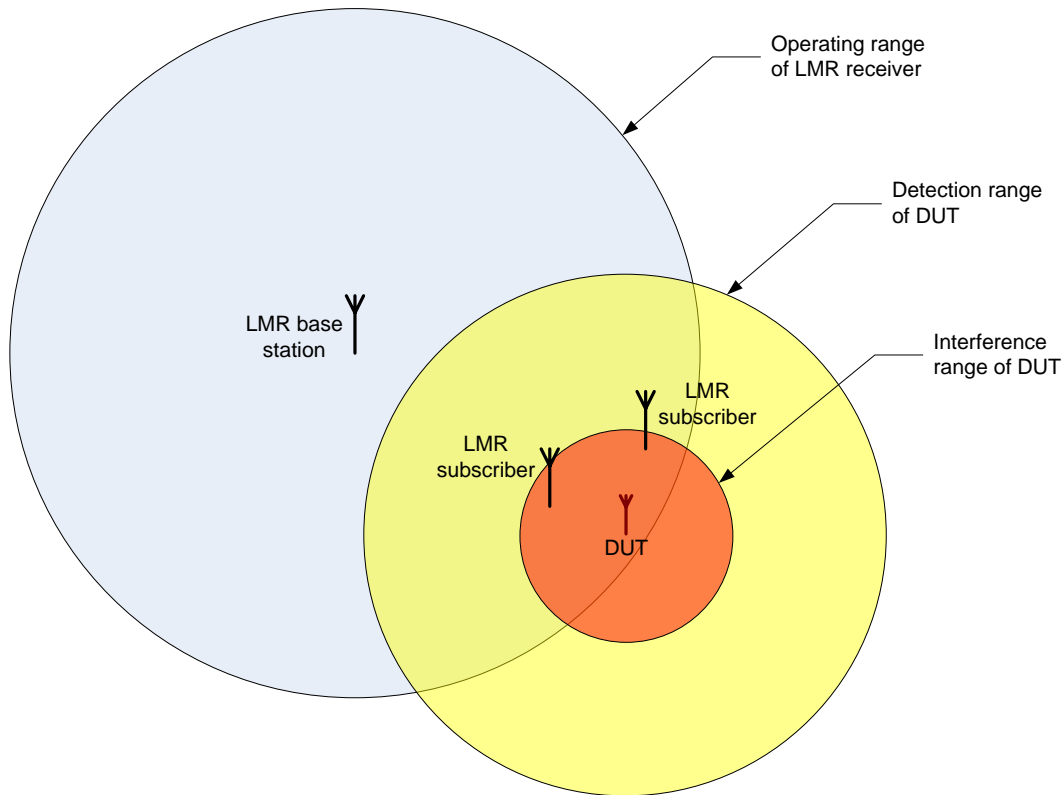
Spectrum monitor data captures will be stored electronically for later analysis. Data logs will be reviewed and assessed for possible interference events such as collisions between DUT and LMR transmissions. A DUT transmission that occurs coincident with an LMR transmission will constitute a possible interference event. Since the spectrum monitoring equipment will not be as sensitive as an actual LMR receiver, it is assumed that any observed LMR transmissions received by a collocated LMR receiver would be intelligible. The frequency and degree of DUT to LMR co-channel transmissions will be assessed and a determination made regarding the potential for harmful interference to LMRs. NTIA will collaborate with the participating Test-Bed vendor to assess under which conditions introduction of their DSA devices will sufficiently protect incumbent LMR users when the DSA devices move to Phase III testing. Sufficient protection in this instance refers to protection of incumbent LMR systems in the immediate vicinity of Phase III testing in and about the Boulder, Colorado test-bed area.

### 3 PHASE III: LMR HIDDEN NODE TEST

#### 3.1 Downlink Test

##### 3.1.1 Background

This test is intended to answer the question: What is the effect of in-band emissions from DUTs on LMR systems' downlink performance when the LMR transmitter is a *hidden node*? To isolate the hidden node from non-participating LMR systems, an experimental conventional mode LMR system will be constructed in a portion of the 410-420 MHz band. On the LMR downlink the hidden node scenario presents itself in the following manner. Consider an LMR base station with an idealized coverage area as depicted in Figure 2. The operating range of an LMR subscriber unit is depicted in the figure as a circular service area boundary. Assume that the detection range of the DUT, i.e., the range at which the DUT can reliably detect LMR transmissions, is less than the reception range of LMR subscriber units. This is depicted as a smaller yellow circle that overlaps the operating region of the base station. Furthermore, the DUT has an *interference range* within which any undetected LMR subscriber units are susceptible to DUT induced interference. This is depicted by the orange circle.



**Figure 2: Typical LMR downlink hidden node scenario**

In this scenario the LMR base station is a hidden node, because it is outside the DUT's detection range. In addition, the subscriber unit which transmits infrequently may go undetected for

extended periods of time even though it is near the DUT. In fact, this situation is common. In typical LMR operations, base station traffic levels are typically much greater than subscriber unit traffic levels. For example, the 1996 Public Safety Wireless Advisory Committee study concluded that downlink traffic is more than six times greater than combined uplink traffic of all subscriber units. In addition, uplink transmissions typically occur in a series of short bursts each spaced several minutes apart.<sup>7</sup> Considering subscriber unit mobility, LMRs may regularly encroach undetected upon a DUT's interference range.

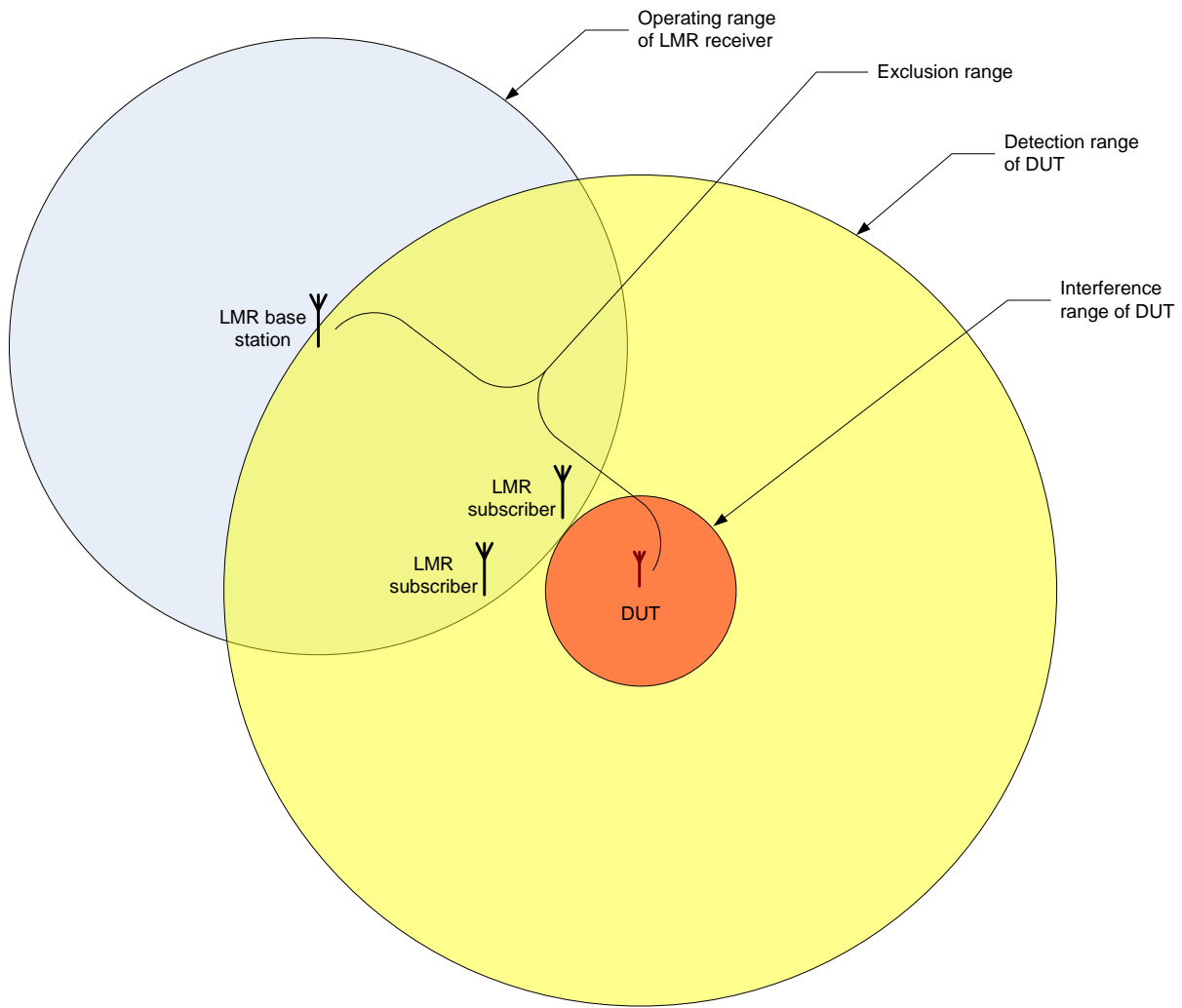
Figure 3 depicts another scenario that suggests bounds for DUT transmissions and sensor performance to prevent interference during LMR operations. If the DUT is restricted to operating outside some *exclusion range* defined as the sum of the LMR system operating range and the DUT interference range, then no interference to LMR system receivers should occur.

The scenario in Figure 3 depicts an idealized bound for sensor performance for the DUT and an interference range criterion that will comprise the first round of Phase III tests. Due to the sensitivity of narrowband LMR receivers, which is on the order of -120 dBm, DUTs may not consistently detect LMR base station transmissions within the exclusion range. Therefore, this test procedure will assess the degree, duration, and probability of *interference events* caused by DUTs in this scenario. (Interference events are defined in Section 3.1.5.)

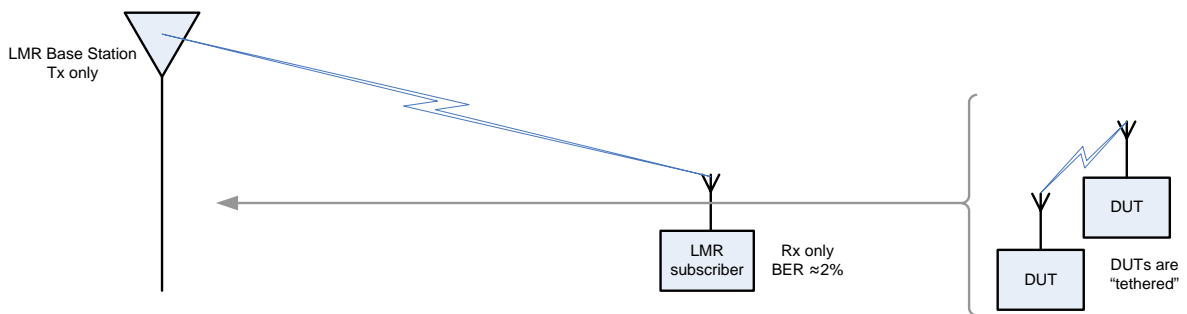
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<sup>7</sup> Final Report of the Public Safety Wireless Advisory Committee to the Federal Communications Commission, Appendix D, Section 2 (Sept. 11, 1996).



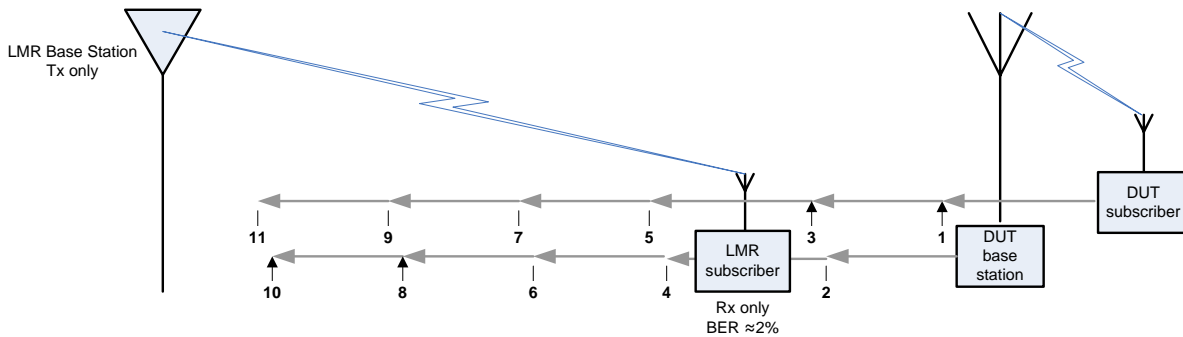


**Figure 3: DUT system minimum detection range to avoid interference**



**Figure 4: Topology for LMR system downlink test**

Figure 4 provides another view of this topology, which for completeness includes the communications link between two DUTs. A downlink transmission is established between the LMR base station transmitter and the subscriber unit. The DUTs will move in conjunction toward the LMR base station and pass by a LMR subscriber along the path. Monitors at the LMR receiver will record any interference encountered. Figure 5 shows an alternate measurement approach for DUTs that have fixed stations. In the alternate measurement configuration, the DUT fixed stations will be repositioned in a leapfrog pattern in between data collection periods. The numbered benchmark indicators represent the stopping point following either a base station or subscriber unit repositioning.



**Figure 5: Alternate topology for LMR system downlink test for DUTs with fixed base stations**

### 3.1.2 Pre-conditions

The site of this test will be geographically isolated from the core of the LMR system in the Denver metropolitan area. Preliminary spectrum surveys and GMF records indicate that the Boulder valley northwest of Denver is sufficiently isolated from Denver by terrain and offers a segment of relatively vacant spectrum within the 410-420 MHz band. The ideal location for controlled testing will have minimal LMR activity in a block of LMR channels large enough for one DUT carrier. Ambient uncontrolled LMR transmissions within this channel block should be lower than the threshold of the DUT system under test. This will permit the DUT's response to a temporary experimental LMR base station transmitter operated within the sub-band to be isolated from outside factors.

The temporary LMR base station transmitter's position will be chosen based on the following criteria. It will serve a coverage area with an approximately a two mile coverage radius. A drive test route consisting of a relatively straight and level road leading away from the base station will exhibit monotonically decreasing received power with distance. The base station transmitter's power will be adjusted to limit its effective range and reduce the required driving distances.

The location of the LMR subscriber unit will be selected in the following manner. The base station transmitter will be configured to continuously generate a known bit sequence which permits the subscriber unit to compute a bit error rate (BER). The subscriber unit will be driven along the test route while the BER is recorded. A test location will be selected where the BER is just below 2%, which is defined as the LMR coverage area as described in Section 1.8. With the subscriber unit remaining stationary at this test location the transmitter power will be adjusted to

achieve a long term average BER of 1.5-2.0%. Thereafter, the transmitter power and resultant system EIRP shall remain fixed.

The base station transmitter will be reconfigured to transmit a sequence of three unique, equal length Project 25 voice transmissions on three distinct frequencies. The transmission will use three distinct settings for which late entry performance specifications are specified: talk group only, encryption only, and talk group and encryption.<sup>8</sup> The transmitter will repeat each transmission in a continuous loop so each frequency will have an effective channel occupancy of approximately 33%. Three separate LMR subscriber units will be located within the test vehicle. Each will be tuned and configured to receive one of the transmissions described above. Since the transmissions will repeat without interruption, an observer should be able to readily ascertain whether the LMR channel is impaired by noting either garbled voice or, in more extreme cases, the truncation or obstruction of a voice transmission. (Project 25 LMRs simply mute as a result of excessive interference.)

A VSA monitoring system will be installed in the LMR test vehicle to enable test engineers to correlate transmission impairments to simultaneous DUT system emissions. The VSA and LMR will share a common input from an external antenna. A video camera will record the VSA spectrogram and the received audio simultaneously. The VSA data will also be electronically recorded for later playback and analysis. See Figure 6 for a block diagram of the monitoring system. The front-end pre-selector contains a bandpass filter and a low noise amplifier (LNA) and is designed to overcome the loss in the splitter chain preceding the three LMRs. The preselector will be adjusted so that the reference sensitivity of an LMR at test point B will match the sensitivity at test point A. The arrangement of the power dividers and the additional LNA preceding the VSA at test point C will improve the sensitivity of the measurement system.

Measurement data will be time stamped and synchronized in the following manner. The camcorder will be manually time synchronized to GPS time at the beginning of each day. The VSA control computer will be synchronized to GPS time accurate to within one second. Each trial run will occasion a separate VSA capture. Computer time at the beginning of each capture is automatically recorded by the VSA. Finally, each DUT vehicle will be equipped with a GPS tracking system which records the absolute time, location, and speed at one second intervals.

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<sup>8</sup> Late entry occurs when an LMR receiver joins an LMR transmission in progress. The corruption or obstruction of an LMR transmission's header can cause late entry. See ANSI/TIA-102.CAAB-B-2004, Section 3.1.17, Late Entry Unsilence Delay, for performance specifications.

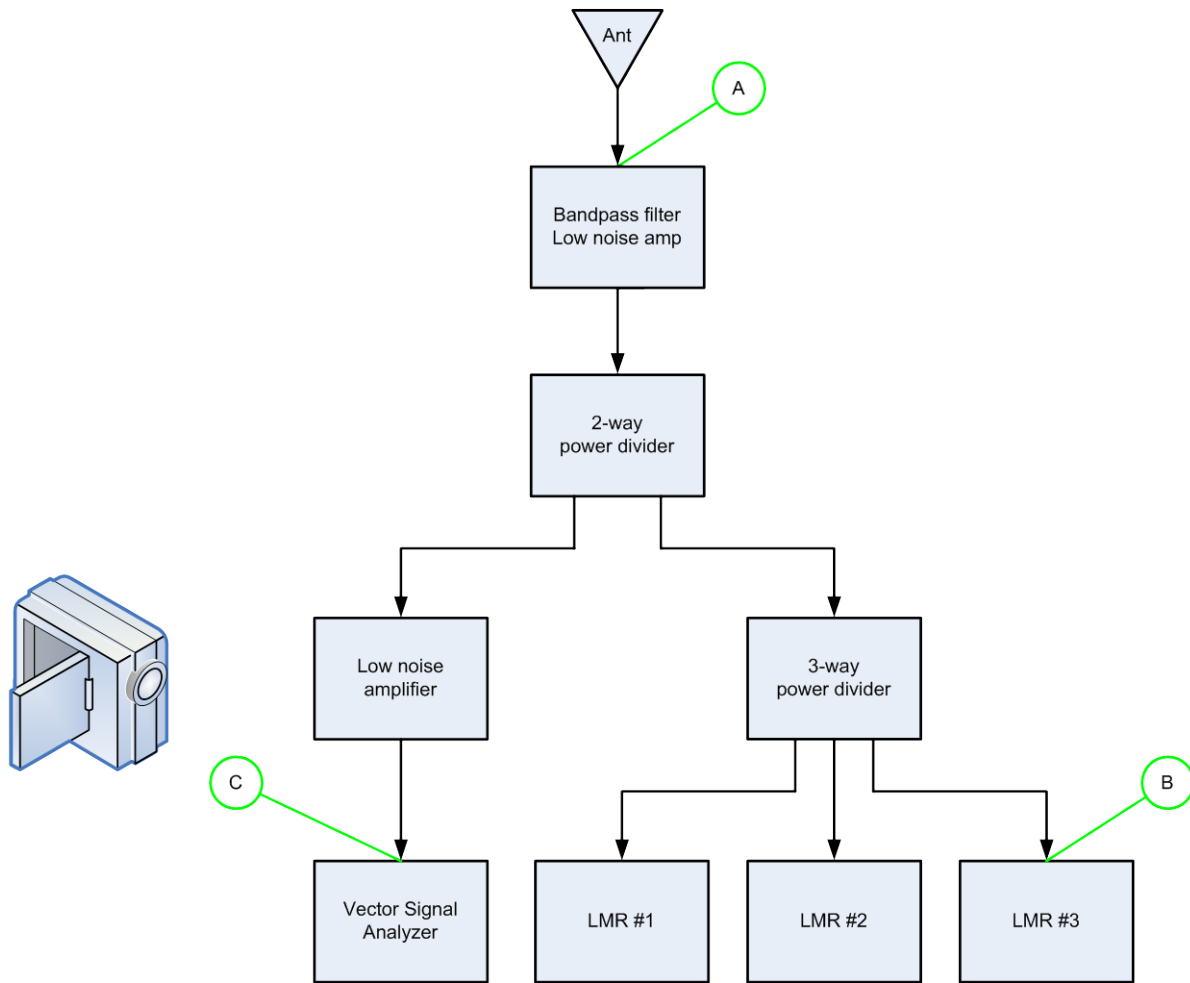


Figure 6: Block diagram of the monitoring system for Section 3 testing

### 3.1.3 Scenario Assumptions

General assumptions of this scenario are as follows:

- a) All transceivers will operate in the 410-420 MHz frequency range.
- b) The nature of possible *interference events* is described in Section 3.1.5.
- c) All measurements will be conducted outdoors on roadways. Vehicle speeds will range from 0-45 miles per hour.
- d) Testing will begin with co-channel frequency relationships. Should testing show significant co-channel interference the procedures may be repeated to further assess the impact of other DUT emissions interactions as described in Section 1.5.
- e) All antennas will be omnidirectional.
- f) Attenuation along each of the conducted paths shown in Figure 6 (A-B and A-C) will be measured prior to testing.

Assumptions particular to the LMR system are as follows:

- g) The LMR system will use the Project 25 Common Air Interface.
- h) All LMR subscriber units will be commercial off the shelf equipment operated in digital Project 25 mode.
- i) The LMR transmitter will be implemented using a vector signal generator and a linear power amplifier. This will facilitate the cyclical transmission of three unique voice transmissions on distinct LMR channels.
- j) The LMR transmitter and subscriber units will be stationary.
- k) The LMR transmitter frequencies will all be co-channel with the DUT.
- l) The LMR subscriber units will be programmed to operate in half-duplex mode.
- m) The LMR system is assumed to be a mobile-only system which does not provide for in-building coverage. No margin is provided in the scenario design to account for building penetration losses.
- n) Simulcast LMR systems will not be investigated.
- o) Testing will be restricted to LMR voice channel operation. LMR data performance will not be assessed.

Assumptions particular to the DUT system are as follows:

- p) The DUT channel will be loaded using an Internet Protocol traffic generator. The packet rate will be the one determined during Phase I testing.
- q) The DUTs will be configured to transmit at their maximum power.

### **3.1.4 Test Procedure**

This test will permit NTIA to assess the nature and impact DUT induced interference and to estimate their detection range and interference range on the LMR downlink. This information may be used to configure the DUTs for subsequent testing which will occur within the core of an LMR network as described in Section 4.

From the perspective of the LMR base station, the two DUTs will be on the same azimuth as the LMR subscriber units but at a greater distance, so the subscriber units will receive no discernable interference. A link will be established between the DUTs that is co-channel with the LMRs. While maintaining a uniform separation between DUTs to maintain a consistently reliable link, hereafter referred to as a *tethered link*, the DUTs will travel toward the base station until they detect the LMR emissions and cease transmitting on its frequencies. Voice transmissions received at the LMR subscriber units will be recorded to assess any impairment of receiver performance caused by the DUTs. At the completion of a test run, the DUTs will be returned to their starting positions, a reliable link between them reestablished if necessary, and the test repeated.

### **3.1.5 Performance Metrics**

For the purposes of this test procedure a *measurement event* shall constitute a test trial which comprises a single drive past the LMR receivers.

An *interference event* shall be defined as any impairment to intelligibility or fidelity of LMR voice communications which can be correlated to simultaneous DUT transmissions within a conceivable interference range.

The nature of interference events may vary depending on propagation channel conditions, LMR signaling, the time division duplex nature of DUT emissions, etc. The test operators will document the severity and nature of interference by categorizing interference events using one or more of the following descriptions:

- a) *Loss of fidelity*—the message is understood but the voice was distorted and unnatural sounding.
- b) *Partly unintelligible*—the message was received in its entirety, but parts of the message, such as syllables or perhaps shorter words, were severely distorted and unintelligible.
- c) *Mostly unintelligible*—the message was received, but most of it was distorted and unintelligible. Only certain syllables or words were discernible.
- d) *Completely unintelligible*—the transmission was received, but the voice is completely distorted and none of the words were discernible.
- e) *Message truncated*—the beginning or end of the message is not received, but the message was otherwise intelligible.
- f) *Message lost*—the entire message is not received. This would be indicated by the context of the base to subscriber conversation.

### **3.1.6 Data Analysis and Interpretation**

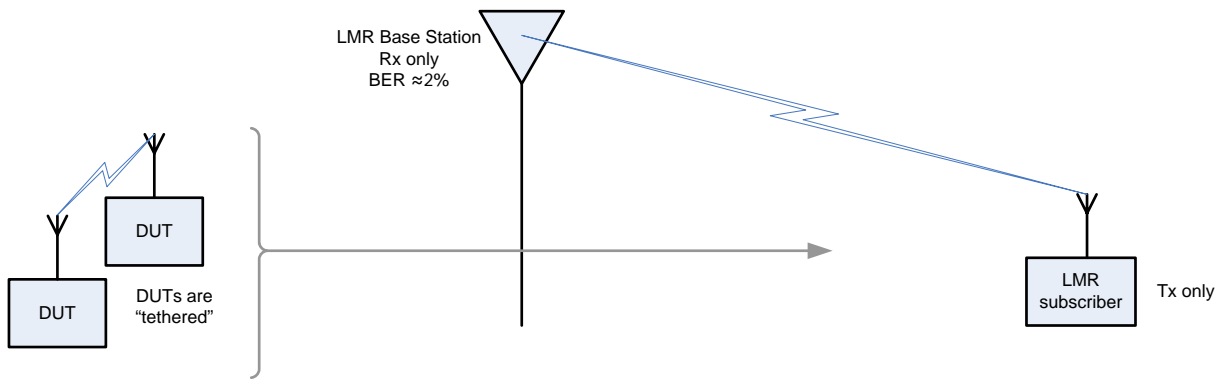
Spectrum monitoring equipment collocated with the LMR receivers will record all measurement events. GPS tracking data from the DUT vehicles will be synchronized to VSA captures and will permit the determination of the range from each DUT to the LMR receivers for the duration of each trial run.

## **3.2 Uplink Test**

### **3.2.1 Background**

This test is intended to answer the question: What is the effect of in-band emissions from DUTs on LMR systems' uplink performance when the LMR transmitter is a subscriber unit with a low antenna height that is a hidden node? The ability of a DUT to detect LMR subscriber units' uplink transmissions poses a unique challenge, since the DUT must detect the LMRs through a low elevation, mobile-to-mobile propagation channel with greater ground clutter while the propagation path from the DUT to the LMR base station receiver will typically have fewer obstructions and potentially much lower pathloss. As a result, the LMR receiver may be particularly susceptible to interference in this scenario.

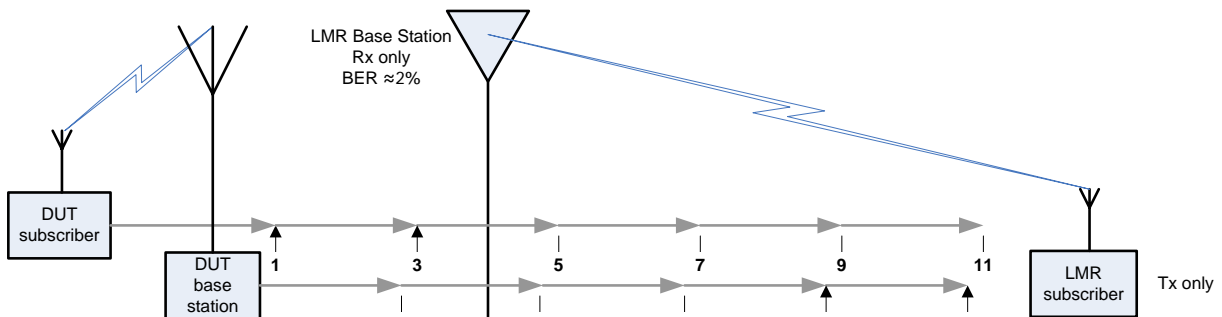
The effect of the DUTs upon the LMR uplink will be evaluated in a similar fashion to the downlink test. An acceptable radio channel link from LMR subscriber unit to a fixed LMR base station will be established using the aforementioned 1.5-2.0% BER criterion. Concurrently, two DUTs will travel past the LMR receiver while engineers monitor the LMR base station receiver for channel impairments. See Figure 7.



**Figure 7: Topology for LMR system uplink test**

The LMR base station, LMR subscriber unit, and DUTs will be located on or adjacent to a straight and level roadway leading outward from the LMR base station. From the perspective of the LMR base station the DUTs will initially be positioned opposite the LMR subscriber unit as shown in the figure. DUT positioning will be such that the LMR transmitter's emissions are indiscernible and the LMR base station receiver is outside the DUT's interference range. A link that is co-channel with the LMRs will be established between the DUTs. While maintaining a tethered link the DUTs will travel past the LMR base station toward the LMR subscriber unit until they detect the subscriber's emissions and cease transmitting on the LMR frequencies. Any impairment to the LMR system's link quality will be recorded at the LMR base station receiver. The DUT transceivers will be returned to their starting positions, a reliable link between them reestablished if necessary, and the test run repeated.

For DUTs with fixed stations, the procedure will be modified as illustrated in Figure 8. The DUTs will travel past the LMR base station in a leapfrog pattern. The benchmark numbering indicates the stopping position after repositioning of a fixed station. The DUT fixed stations will be stationary during data collection.



**Figure 8: Topology for LMR system uplink test for DUTs with fixed base stations**

### **3.2.2 Scenario pre-conditions**

The test system will be configured as described in Section 3.1.2 with the following exceptions. The LMR transmitter will be located at the subscriber unit site. The LMR receivers will be located at the base station site. A VSA monitoring system will be installed at the base station site, which will allow the test observers to correlate impairments to a voice transmission with DUT system emissions.

### **3.2.3 Scenario Assumptions**

Same as those for Section 3.1.3.

### **3.2.4 Test Procedure**

The test procedures are the same as those in Section 3.1.4 with the following exceptions. The two DUTs and LMR subscriber unit will be on opposite sides of the LMR base station as illustrated in Figure 7 or Figure 8. The DUTs will be positioned so that the LMR receiver receives no discernible interference from them. The DUTs will travel toward the LMR subscriber unit.

### **3.2.5 Performance Metrics**

Same as those for Section 3.1.5.

### **3.2.6 Data Analysis and Interpretation**

Same as those for Section 3.1.6.



## **4 PHASE III: DUT SHARING WITH CONVENTIONAL LMR SYSTEM**

### **4.1 Downlink Test**

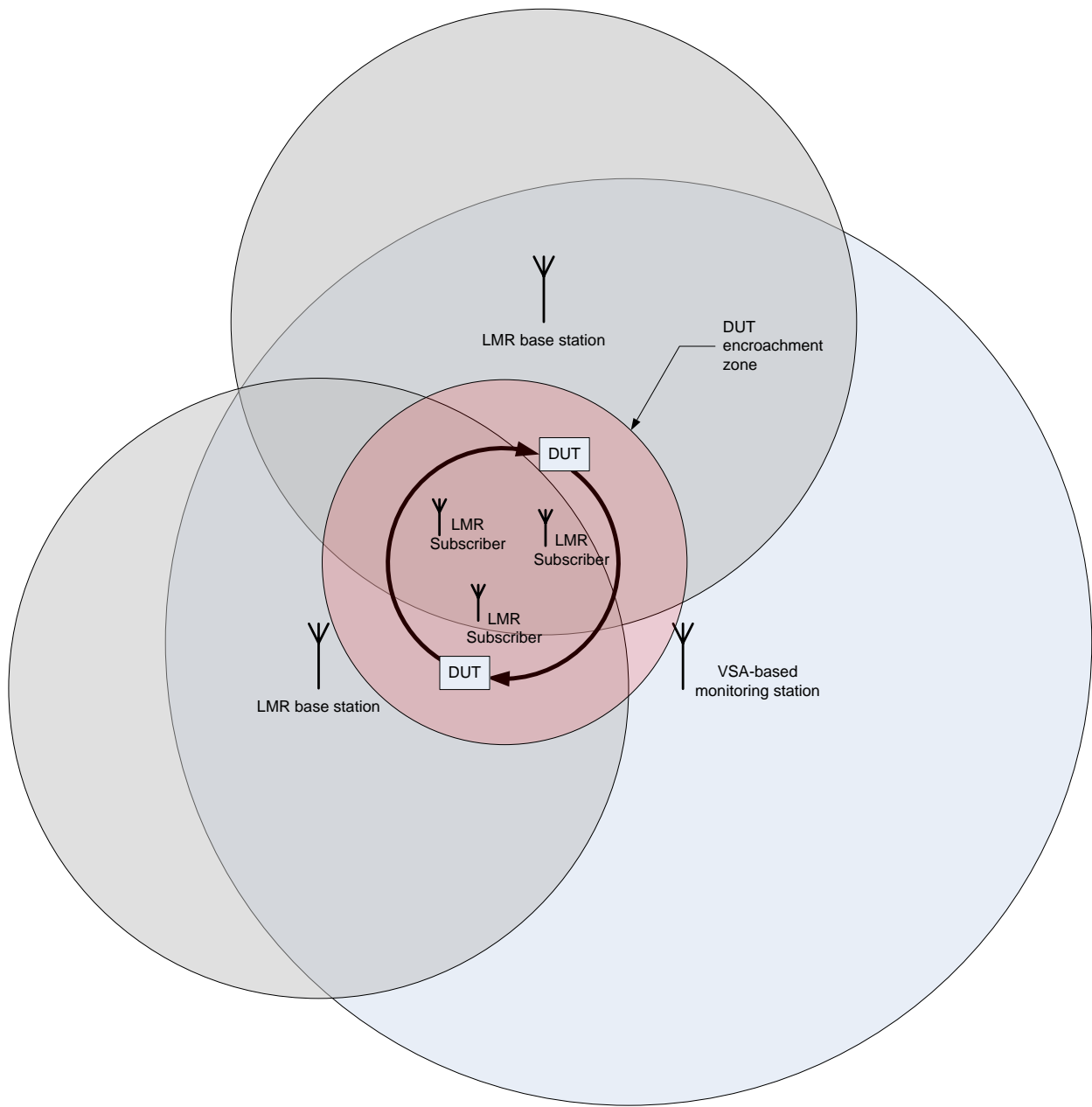
#### **4.1.1 Background**

This test is intended to answer the question: What is the effect of in-band emissions from DUTs on conventional mode LMR systems' downlink transmissions during routine voice operations? Due to its more free form nature, this stage of testing presents a number of logistical challenges. First, digital Project 25 LMRs, unlike analog FM LMRs, will simply mute their audio when subject to excessive interference. Consequently, during routine voice communications, a digital LMR user may not recognize that a message has been lost. For example, an isolated dispatch message sent from a base station could be lost in its entirety without any indication at the subscriber unit.

During these tests if a truncated or impaired message is received, co-channel interference cannot necessarily be attributed to a DUT. Other possible causes might include interference, man-made noise, and fading due to multipath or terrain obstructions. Monitoring data that correlates LMR channel impairments with coincident DUT activity may support a more definitive assertion of interference, especially if the LMRs are known to be within the DUT interference range. However, this criterion imposes additional restrictions on the topology of the test environment to satisfy dynamic range requirements of the spectrum monitoring system. Simultaneous observation of LMR and DUT emissions within the test range must be constrained to the observable range of the spectrum monitor. While this monitor will be equipped with a pre-selector, its coverage will still only be comparable to that of a typical LMR base station. At the other end of the monitoring system's input range, front-end overload is a concern, so transmitters will be restricted from approaching it too closely.

#### **4.1.2 Scenario Preconditions**

The test range for the conventional LMR network test will contain a DUT encroachment zone. The DUT encroachment zone is an area where two or more DUTs can maintain reliable communications links with each other within which primary radio systems are most susceptible to interference. The size of this zone will be determined using the results of the Section 3 interference range tests. Within this zone the likelihood of DUTs causing impairments to LMR communications is maximized, thus providing a greater possibility of observable interference events. Preferably this zone will encompass overlapping coverage from the periphery of two or more LMR base stations. Refer to Figure 9 for an idealized depiction of the topology. DUTs that use fixed base stations will remain stationary during data collection. The DUT base station will have an antenna that is approximately 10 m AGL. The fixed DUT subscriber unit will have an antenna mounted approximately 2 m AGL. The fixed station DUTs may be repositioned between data collection events at various opposing positions along the circular path indicated in Figure 9, such as two and eight o'clock, four and ten o'clock.



**Figure 9: Topology for LMR system downlink test**

A spectrum monitoring station using a VSA will record both LMR base station and DUT transceiver emissions in spectrogram format. Its location will be chosen based on the following criteria. The spectrum monitoring station will be located on a hill to maximize its coverage and insure a substantial signal to noise ratio on the VSA, so automated spectrogram post-processing algorithms can readily identify base station emissions.

The drive route for the DUTs will be chosen based on the following criteria. It must provide a closed loop route which is large enough to create an appreciable encroachment zone for LMR receivers to transit through. On the other hand, the breadth of this zone will be limited by the

reliable transmission range of the DUTs and must accommodate the worst case condition where the DUTs are located on opposite sides of the loop. Also, while circumnavigating the drive loop the DUT emissions must be consistently observable at the spectrum monitoring station, again, with a significant enough signal to noise ratio to facilitate spectrogram post-processing and interpretation.

To minimize the reporting of non-DUT related voice quality impairments during the test, LMR subscriber units will confirm the quality of the base stations' coverage by conducting a sequence of baseline drive tests over pre-defined routes through the encroachment zone with the DUTs turned off. Routes or locations that exhibit voice quality impairments as described in Section 4.1.5 will be excluded from further use and from subsequent interference reports.

Location and time data will be collected on both DUT and LMR vehicles. This will facilitate further analysis of suspected interference events. Measurement data will be time stamped and synchronized in the following manner. The computer which hosts the VSA software will be synchronized to GPS time. Each DUT vehicle will be equipped with a GPS tracking system which records the absolute time, location, and speed at one second intervals. Message transmissions will be scheduled at fixed intervals synchronized to GPS time. To assist in data analysis, each message will be pre-scripted and unique.

### **4.1.3 Scenario Assumptions**

General assumptions of this scenario are as follows:

- a) All transceivers will operate in the 410-420 MHz frequency range.
- b) The nature of possible *interference events* is described in Section 4.1.5.
- c) All measurements will be conducted outdoors on roadways. Vehicle speeds will range from 0-45 miles per hour.
- d) Testing will begin with co-channel frequency relationships. Should testing show significant co-channel interference, the procedures may be repeated to further assess the impact of other DUT emissions interactions as described in Section 1.5.
- e) All antennas will be omnidirectional.

Assumptions particular to the LMR system are as follows:

- f) The LMR system will be use the Project 25 Common Air Interface.
- g) All LMR subscriber units will be commercial off the shelf equipment operated in digital Project 25 mode.
- h) The LMR base station will be fixed in location.
- i) The subscriber units will generally be in motion though they may remain stationary if desired.
- j) The LMR transmitter frequencies will each be co-channel with a unique DUT system channel or subcarrier.
- k) The LMRs will be programmed to operate in half duplex mode.

- l) The LMR system is assumed to be a mobile-only system, which does not provide for in-building coverage. No margin is provided in the scenario design to account for building penetration losses.
- m) The LMR subscriber units will be vehicle mounted mobiles. Mobile transmit power levels may be adjusted to provide a uplink and downlink path balance.
- n) Simulcast LMR systems will not be investigated.
- o) Testing will be restricted to LMR voice channel operation. LMR data performance will not be assessed.

Assumptions particular to the DUT system are as follows:

- p) The DUT channel will be loaded using an IP traffic generator. The packet rate will be the one determined during Phase I testing.
- q) The DUTs will be configured to transmit at their maximum power.

#### 4.1.4 Test Procedure

The DUTs will establish reliable communications and travel along the predefined drive route around the encroachment zone. Starting outside the defined DUT encroachment zone LMR subscriber units will transit through the DUT encroachment zone following one of the predefined drive test routes. Subscriber units may loiter in the encroachment zone or transition across it. The only restriction is that they remain on pre-qualified routes.

#### 4.1.5 Performance Metrics

Each base station transmission shall constitute a measurement event. An *interference event* shall be defined as any impairment to intelligibility or fidelity of LMR voice communications which can be correlated to simultaneous DUT transmissions within a plausible interference range.

Operators of subscriber units will report the nature of any observed channel impairments to the system dispatch center. Engineers at the dispatch center will document the severity and nature of interference by categorizing interference events using one or more of the following descriptions:

- a) *Loss of fidelity*—the message is understood but the voice was distorted and unnatural sounding.
- b) *Partly unintelligible*—the message was received in its entirety, but parts of the message, such as syllables or perhaps shorter words, were severely distorted and unintelligible.
- c) *Mostly unintelligible*—the message was received, but most of it was distorted and unintelligible. Only certain syllables or words were discernible.
- d) *Completely unintelligible*—the transmission was received, but the voice is completely distorted and none of the words were discernible.
- e) *Message truncated*—the beginning or end of the message is not received, but the message was otherwise intelligible.
- f) *Message lost*—the entire message is not received. This would be indicated by the context of the base to subscriber conversation.

#### **4.1.6 Data Analysis and Interpretation**

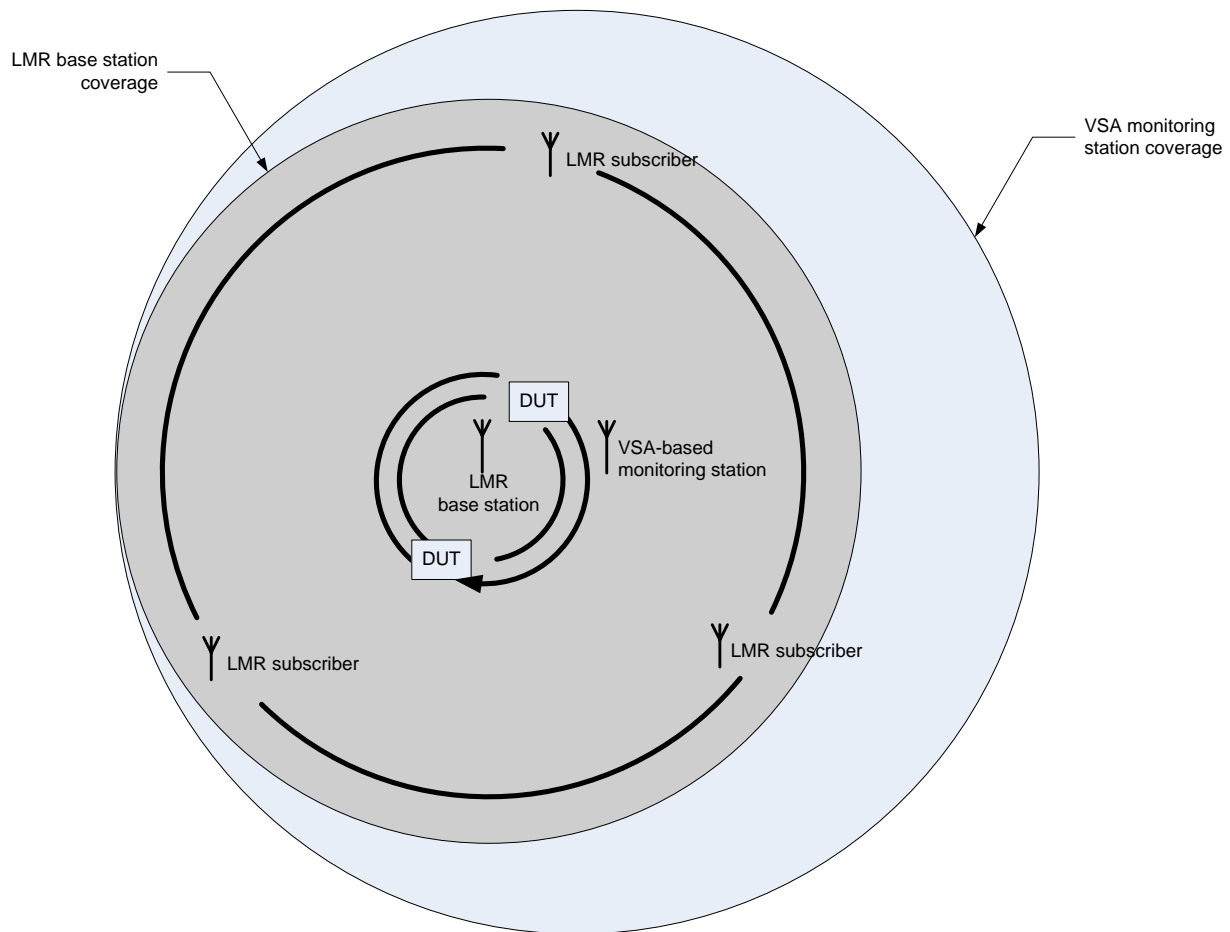
Reported interference events will be tabulated. For each reported event test engineers will examine the VSA spectrogram for indications of co-channel DUT and LMR transmissions. As needed, engineers will further examine location data for both DUT and LMR vehicles to ascertain the DUT to LMR separation distance and the probability of the DUT being the source of the channel impairment.

### **4.2 Uplink Test**

#### **4.2.1 Background**

This test is intended to answer the question: What is the effect of in-band emissions from DUTs on conventional mode LMR systems' uplink transmissions during routine voice operations? This test presents similar logistical challenges as the downlink case. The predominant limitation in this scenario is that the separation distance between DUTs and LMR subscribers, which in this case now transmit regularly, needs to be maximized to isolate testing to the corner case in which received power at the LMR base station is minimized. This suggests that testing should be restricted to a single LMR base station, since the spectrum monitoring station is now required to observe LMR subscriber transmissions at greater distances. Figure 10 depicts an idealized illustration of the proposed test topology.

Note that DUTs that use fixed base stations will remain stationary during data collection. The DUT base station will have an antenna that is approximately 10 m AGL. The fixed DUT subscriber unit will have an antenna mounted approximately 2 m AGL. The fixed station DUTs may be repositioned between data collection events at various opposing positions along the circular path indicated in Figure 10, such as two and eight o'clock, four and ten o'clock.



**Figure 10: Topology for LMR system uplink test**

#### **4.2.2 Scenario Preconditions**

As with the downlink case this test has a DUT encroachment zone. In this case it encompasses the LMR base station. In practice DUTs could come into close proximity to LMR base stations, so this test will examine a range of separation distances by reducing the DUT drive routes to a series of concentric loops around the base station. The range will vary from one to several city blocks. Within this zone the likelihood of DUT transmissions causing impairments to LMR communications is maximized increasing the probability of observable interference events.

A spectrum monitoring station using a VSA will record both LMR base station and DUT emissions in spectrogram format. It will be located to maximize its visibility of the LMR base station's coverage area. Some minimum separation from the LMR base station (which will transmit periodically) may be required to prevent front-end overload of the VSA.

To minimize the reporting of non-DUT related voice quality impairments during the test the dispatch operator at the LMR base station will confirm the quality of the system's uplink coverage as the subscriber units drive pre-defined routes around the perimeter of the base station.

Routes or locations with reduced coverage and impaired voice quality will either be excluded from further use or from subsequent interference reports.

Location and time data will be collected on both DUT and LMR vehicles. This will facilitate further analysis of suspected interference events.

#### **4.2.3 Scenario Assumptions**

Same as Section 4.1.3.

#### **4.2.4 Test Procedure**

The DUTs will establish reliable communications and travel along the predefined route around the LMR base station. Concurrently, LMR subscriber units will transmit a regular sequence of transmissions on the uplink while following their predefined drive test routes around the perimeter of the base station.

#### **4.2.5 Performance Metrics**

Same as Section 4.1.5.

#### **4.2.6 Data Analysis and Interpretation**

Same as Section 4.1.6.

## 5 PHASE III: DUT SHARING WITH TRUNKED LMR SYSTEM

### 5.1 Downlink Test

#### 5.1.1 Background

This test is intended to answer the question: What is the effect of in-band emissions from DUTs on trunked mode LMR systems' downlink transmissions during routine voice communications? The effect of DUT transmissions on conventional voice LMR communications is assessed in Section 4, so this test will focus on the functional effects of DUT transmissions on trunked digital Project 25 LMR control channel signaling. Project 25 control channel messages can be as brief as 32.9 ms in duration, so they will stress DUTs' detect and avoid capabilities.<sup>9</sup> The control channel uplink and downlink present unique challenges to DUTs.

The control channel downlink is the simplest of the two cases, since the downlink transmission is steady state and the transmit antenna is elevated to maximize coverage, and thus DUT detectability. The pertinent use case, similar to the Section 3 test, is the condition where the DUT may be outside the detection range of the base station but within the interference range of an LMR subscriber unit. Unlike the Section 3 test the subscriber unit will transmit in this scenario, and assuming the trunked system is on a standardized channel plan, it will do so on control and voice channel frequencies that are offset +9 MHz from the base station transmit frequencies.<sup>10</sup>

#### 5.1.2 Scenario Preconditions

The Project 25 trunking protocol is a complex, feature rich standard supporting a variety of call types such as unit-to-unit, talk group, broadcast, and announcement talk group. The signaling used to establish all of these connections is a consistent set of single or multi-block messages. All call types begin with some variation of a voice channel request message. Therefore, a simple talk group call will be examined.

Two LMR subscriber units will be positioned where the BER is 1.5-2.0% using the method described in Section 3. Both LMRs will be configured to communicate on the same talk group. The DUTs will be positioned adjacent to the LMRs. All LMRs and DUTs will be stationary. Note that DUTs that use fixed base stations will have a transmitter with an antenna that is elevated to approximately 10 m AGL. A group call will be initiated by asserting push to talk on the originating LMR; the receiving LMR should receive the message. Call setup is initiated via a "group voice channel request" message on the control channel uplink at  $f_1 + 9$  MHz (where  $f_1$  is the control channel downlink frequency) followed by a "group voice channel grant" downlink message on  $f_1$ . The DUTs will be configured to transmit co-channel with the control channel downlink. The originating LMR will, upon receipt of a channel grant message, retune to a voice channel transmit frequency,  $f_2 + 9$  MHz (where  $f_2$  is the voice channel downlink frequency), and begin transmitting. The receiving LMR subscriber unit should retune to  $f_2$  and receive the voice communication.

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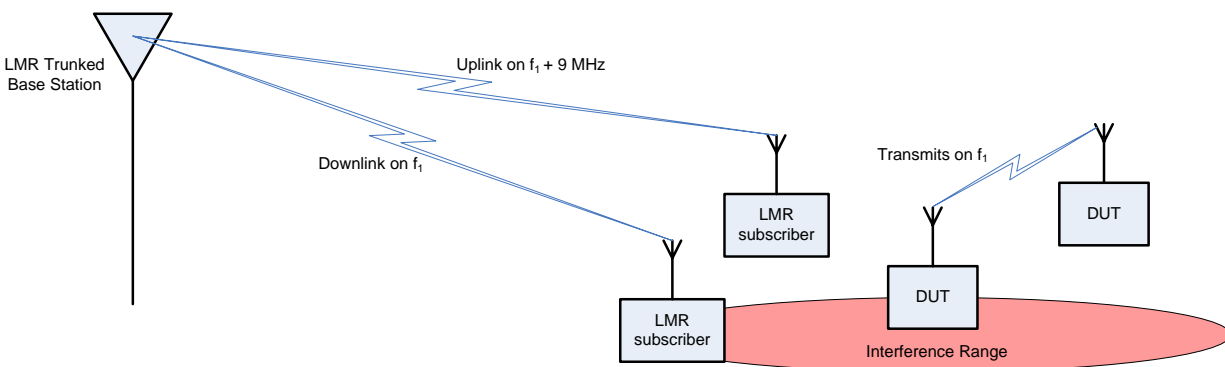
<sup>9</sup> TIA/EIA-102.AABB, Section 5.

<sup>10</sup> NTIA Red Book Section 4.3.9.



If a DUT transmission obscures the “group voice channel grant” message, the Project 25 base station may repeat the message multiple times within a certain time interval, so DUT interference would be manifested as either an unsuccessful or delayed group call.<sup>11</sup>

A spectrum monitoring station using a VSA will record both LMR base station and DUT transceiver emissions in spectrogram format. Its location will be chosen to ensure that it can simultaneously monitor LMR base station and DUT transmissions. Refer to Figure 11 for a depiction of the topology.



**Figure 11: Topology for trunked LMR system downlink test**

### 5.1.3 Scenario Assumptions

General assumptions of this scenario are as follows:

- a) All transceivers will operate in the frequency range of 406-420 MHz.<sup>12</sup>
- b) All assessments of channel impairments that might constitute *interference events* will be subjective.
- c) All measurements will be conducted outdoors on roadways.
- d) All LMRs and DUTs will be stationary.
- e) The first test trials will evaluate the DUT performance when co-channel with the LMR receiver. Should testing show significant co-channel interference the procedures may be repeated to further assess the impact of other DUT emissions interactions as described in Section 1.4.
- f) All antennas will be omnidirectional.

Assumptions particular to the LMR system are as follows:

<sup>11</sup> TIA/EIA-102.AABB, Section 3.6.

<sup>12</sup> Depending on the configuration of the operational LMR trunked system that will be used for the test DUT sensors may be configured to *sense* LMR transmissions in the 406-410 MHz range; however, DUT *transmissions* will be restricted to 410-420 MHz.

- g) The LMR system will use the Project 25 Common Air Interface.
- h) All LMR subscriber units will be commercial off-the-shelf equipment operated in digital Project 25 mode.
- i) The LMR base station downlink frequency will be co-channel with a unique DUT channel or subcarrier.
- j) Simulcast LMR systems will not be investigated.
- k) Testing will be restricted to LMR trunked control channel signaling functionality using talk group calls. LMR data performance will not be assessed.

#### **5.1.4 Test Procedure**

The LMRs and DUTs will be positioned as described in Section 5.1.2. The originating LMR subscriber unit will initiate group calls while the other LMR subscriber will receive them. With the DUTs disabled a control test will be conducted. A sequence of talk group voice calls will be transmitted through the trunked LMR system. A VSA will capture LMR control channel message transmissions and call setup times. (For the purposes of this test the call setup time shall be defined as the duration of time between the “group voice channel request” transmission on the control channel uplink and the beginning of the voice channel transmission.) The average call setup time will be determined. Next, the DUTs will be configured to transmit co-channel with the LMR control channel downlink frequency,  $f_l$ . The DUTs will be enabled and reliable communications established between them. A series of group calls will be initiated by the originating LMR subscriber unit. The call setup time will be recorded. Any failed group calls will be recorded. A minimum of 30 of each of the control and experimental trials will be performed.

#### **5.1.5 Performance Metrics**

Each base station transmission shall constitute a measurement event. An *interference event* shall be defined as a failure of the group voice call or a statistically significant delay in voice channel setup time with respect to the mean setup time measured in the absence of DUT activity.

#### **5.1.6 Data Analysis and Interpretation**

Reported interference events will be tabulated and mean call setup times for the control and experimental conditions compared. If necessary, test engineers will examine the VSA spectrogram for indications of co-channel DUT and LMR transmissions.

### **5.2 Uplink Test**

#### **5.2.1 Background**

This test is intended to answer the question: What is the effect of in-band emissions from DUTs on trunked mode LMR systems’ uplink transmissions during routine voice communications? The control channel uplink is more difficult for a DUT to detect. The uplink transmissions are short in duration, the LMR transmitter sources are geographically dispersed, and they transmit at lower elevations through greater ground clutter at lower power levels. Furthermore, the uplink transmissions occur on different frequencies than the downlink ones, so DUT systems that do not exploit knowledge of trunked system channel plans will not explicitly protect control channel

uplink frequencies based on detection of a paired downlink transmission. The loss of control channel uplink messages due to DUT interference could either prolong or interrupt call setup for trunked LMRs.

### 5.2.2 Scenario Preconditions

This test is constructed in a manner similar to that of the downlink case. Figure 12 depicts an illustration of the proposed test topology. All LMRs and DUTs will be stationary. Note that DUTs that use fixed base stations will have a transmitter with an antenna that is elevated to approximately 10 m AGL.

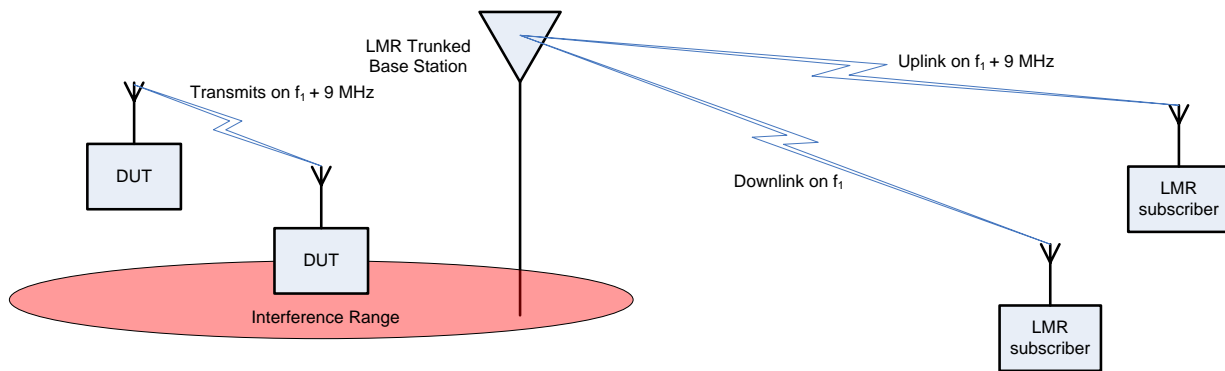


Figure 12: Topology for trunked LMR system uplink test

### 5.2.3 Scenario Assumptions

Same as Section 5.1.3, except that the DUTs will be located adjacent to the LMR trunked base station and will operate on the control channel uplink frequency,  $f_l + 9$  MHz.

### 5.2.4 Test Procedure

Same as Section 5.1.4.

### 5.2.5 Performance Metrics

Same as Section 5.1.5.

### 5.2.6 Data Analysis and Interpretation

Same as Section 5.1.6.

## 6 PHASE III: DUT GEO-LOCATION CHARACTERISTICS

### 6.1 Background

This test assesses whether a pair of DUTs with geo-location-based policy loads will avoid transmissions on frequencies assigned to operational trunked and conventional mode LMR base stations within the base stations' exclusion zones. An exclusion zone is a geographic area surrounding an LMR base station within which a DUT may not use an associated set of paired uplink and downlink frequencies. The exclusion zone is defined as the sum of the range of operation of the LMR subscriber and the interference range of the DUT.

### 6.2 Pre-conditions

The ability of the geo-location policy to enforce a predefined minimum separation distance between a DUT and a hidden node receiver will be measured using a receive-only LMR subscriber unit positioned within each base station's coverage area. The subscriber unit's location will be selected using the method described in Section 3 in which a 1.5-2.0% BER is obtained. The LMR will be stationary. While maintaining a tethered link the DUTs will enter the base station's coverage area, transit past the LMR receiver, and exit the coverage area as illustrated in Figure 13. Any impairment to the LMR system's link quality will be recorded at the LMR subscriber receiver using the monitoring system illustrated in Figure 6.

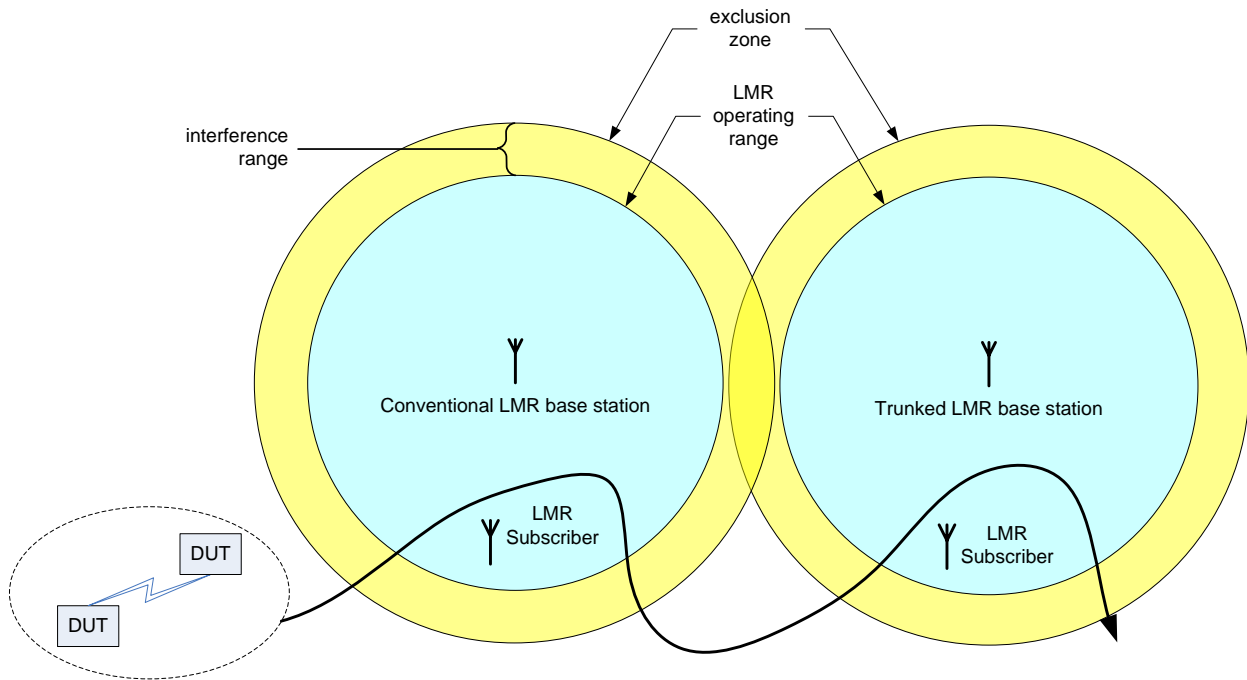


Figure 13: Topology for DUT geo-location test

### **6.3 Scenario Assumptions**

- a) The LMR system will use the Project 25 Common Air Interface.
- b) All LMR subscriber units will be commercial off the shelf equipment operated in digital Project 25 mode. They will operate in receive only mode.
- c) The LMR transmitter will be an operational commercial LMR base station operating in either trunked or conventional mode.
- d) The LMR transmitters and subscriber units will be stationary.
- e) The conventional mode base station will have one or more pairs of downlink and uplink frequencies.
- f) The trunked mode base station will have a pair of downlink and uplink control channel frequencies and one or more pairs of downlink and uplink voice channel frequencies.
- g) Testing will be restricted to LMR voice channel operation. LMR data performance will not be assessed.
- h) The coverage areas for both base stations will be estimated using a propagation modeling tool. Adjustments to the predicted coverage areas will be made based on the field experience of the system operator.

Assumptions particular to the DUT system are as follows:

- i) The DUT channel will be loaded using an Internet Protocol traffic generator. The packet rate will be the one determined during Phase I testing.
- j) The DUTs will be configured to transmit at their maximum power.

### **6.4 Test Procedure**

To assess the possible interference avoidance improvement afforded by a geo-location policy, the test will be conducted in two stages. In the first stage, the DUTs will traverse a predefined route with their geo-location policies disabled, i.e., the DUTs will operate in a sensing-only mode. In the second stage, the DUTs' will traverse the same predefined route with their geo-location policies enabled.

#### **6.4.1 Performance Metrics**

Audio quality of the voice transmissions will be assessed in accordance with the performance metrics defined in Section 4.1.5.

#### **6.4.2 Data Analysis and Interpretation**

Measurement events will be interpreted in accordance with the method defined in Section 4.1.6.

## 7 GENERAL INFORMATION

### 7.1 Acronyms and abbreviations

AGL: Above Ground Level

BER: Bit Error Rate

DSA: Dynamic Spectrum Access

DUT: Device Under Test

EIRP: Equivalent Isotropically Radiated Power

ENBW: Equivalent Noise Bandwidth

FM: Frequency Modulation

GPS: Global Positioning System

ITS: Institute for Telecommunication Sciences

LMR: Land Mobile Radio

LNA: Low Noise Amplifier

OOBE: Out of band emissions

P25: Project 25<sup>13</sup>

RF: Radio Frequency

RSMS: Radio Spectrum Measurement System

RSSI: Received Signal Strength Indication

TIA: Telecommunications Industry Association

VSA: Vector Signal Analyzer

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<sup>13</sup> The Project 25 standards apply to conventional and trunked base, mobile, and portable systems. The standards are published in the Telecommunications Industry Association/Electronics Industries Alliance, an American National Standards Institute accredited process. *See, e.g.,* <http://www.ANSI.org>.

## 7.2 Definitions

**1011 Hz Pattern:** A specific bit sequence defined in TIA-102.CAAA Section 1.3.3.6 that when demodulated by a Project 25 receiver causes it to emit an audible 1 kHz tone. This known bit sequence is often used by LMR receiver to compute BER over a channel.

**Available LMR Channels:** LMR channels unoccupied by LMR signals and are not Locked-Out LMR Channels.

**Channel Availability Check:** A process by which a DUT senses the band for LMR signals before opportunistically sharing spectrum in the band.

**Conventional Mode LMR:** An LMR system in which voice channel resources are manually selected by the operator.

**Detection Range:** The range at which the DUT system or device can reliably detect LMR transmissions.

**Detection Threshold:** The level at which a receiver can detect the presence of a transmitted LMR signal within the LMR Channel bandwidth.

**Downlink:** The transmission path from a LMR system base station to a LMR subscriber unit.

**DUT encroachment zone:** An area where two or more DUTs can maintain reliable communications links with each other within which radio systems are most susceptible to interference.

**DUT base station:** The master terminal in a DUT system.

**DUT subscriber:** The slave terminal in a DUT system.

**DUT Operating Channel:** A collection of one or more LMR channels which are not necessarily contiguous which span a given frequency range by which a DUT constructs an information bearing radio channel. Some DUTs require a minimum bandwidth to operate which is greater than the sum of LMR channels occupied.

**DUT:** Device Under Test.

**Exclusion range:** The sum of the LMR system operating range and the DUT system interference range. DUTs operating outside the exclusion range should not cause any harmful interference to LMR receivers.

**Exclusion zone:** A geographic area surrounding an LMR base station within which a DUT may not use an associated set of paired uplink and downlink frequencies.

**Guard Channels:** Unoccupied channels that provide frequency separation in order to avoid mutual interference.

**Hidden Node:** An LMR transceiver which is capable of communicating with other LMR transceivers at a remote location, but which cannot be detected by a DUT collocated at the remote location either because it is in receive-only mode or is outside the detection range of the DUT.

**Interference Range:** The interference range represents the minimum separation distance between the DUT and LMR receiver to prevent harmful interference to the LMR based on criteria specified in TIA TSB-88.1-C.

**In-Service Monitoring:** A process by which a DUT interrupts its communications to test for LMR activity within its occupied spectrum.

**Locked-Out LMR Channels:** Pre-determined LMR channels within the 410-420 MHz band for which DUT transmissions are not permitted.

**LMR Channel:** A segment of spectrum that is either 12.5 kHz or 25 kHz in width with center frequencies as specified within the NTIA channelization plan in the 410-420 MHz band or in Part 90, Subpart L of the FCC Rules for the 470-512 MHz band.

**LMR base station:** A fixed LMR transceiver.

**LMR subscriber:** A portable handheld or vehicular mounted LMR transceiver.

**LMR Operating Channels:** A collection of LMR channels that are in use.

**LMR Operating Range:** The maximum distance from which a quality link between LMR transceivers can be maintained for a given percentage of time. Reliability criteria are specified in accordance with TIA TSB-88.1-C.

**Sensor Bandwidth:** A portion of the 410-420 MHz or 470-512 MHz bands, which encompasses multiple LMR Channels that the DUT monitors at any given instant in time.

**Subscriber Unit:** An LMR mobile or portable radio.

**Tethered Link:** A communications link established between two DUT transceivers which has consistently reliable data transfer rates that are guaranteed by limiting the pathloss between devices by restricting the separation between them while they are in transit.

**Trunked Mode LMR:** An LMR system in which voice channel resources are shared and channel assignment is automatically accomplished via a control channel.

**Uplink:** The transmission path from a LMR subscriber unit to a LMR base station.



### 7.3 References

- [1] Wireless Communications Systems Performance in Noise and Interference Limited Situations Part1: Recommended Methods for Technology Independent Performance Modeling, TIA TSB-88.1-C, February 2008.
- [2] IEEE Recommended Practice for the Analysis of In-Band and Adjacent Band Interference and Coexistence Between Radio Systems, IEEE 1900.2-2008, 29 July 2008.
- [3] Comparison of Wideband Propagation in the 902-928 and 1850-1990 MHz Bands in Various Macrocellular Environments, NTIA Report 93-299, September 1993.