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# *TIA*

# *TELECOMMUNICATIONS SYSTEMS BULLETIN*

***WIRELESS COMMUNICATIONS SYSTEMS –***

***PERFORMANCE IN NOISE AND INTERFERENCE - LIMITED SITUATIONS***

***Part 3: PERFORMANCE VERIFICATION***

## PN3-4744.3-RV3
## To be published as TSB-88.3-C

***TELECOMMUNICATIONS INDUSTRY ASSOCIATION***

***Date January, 2008***

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# DOCUMENT REVISION HISTORY

| Version | Date | Description |
|---|---|---|
| TSB-88 Issue O | January 1998 | Original Release |
| TSB-88 Issue O-1 | December 1998 | Added Annex F |
| TSB-88 Issue A | June 1999 | Added Information and moved many tables from Annexes into the main body. |
| TSB-88 Issue A-1 | January 2002 | Added Annexes G & H and Corrigenda |
| TSB-88 Issue B | September 2004 | Consolidated Annexes F, G & H into document. Updated the ACCPR modulations and methodology, ACCPR tables moved to Annex A. Modified building loss section. Added new terrain data base information and new NLCD information. Numerous editing changes and examples added.<br>A CD with spreadsheets for each modulation is now included in a new Annex F. |
| TSB-88 Issue B | April 2005 | Clarify default ENBW for analog FM receivers that are deployed in the VHF and UHF bands. Corrected editorial errors. |
| TSB-88.3 Issue C | | Split TSB-88B into three documents<br>Updated determination of the Local Median.<br>Created three types of CATP, voice, data and measuring the local median value.<br>New application for measuring IM contributions and Annex C example.<br>New section on Intercept Point and impact on IM.<br>Corrected errors in TSB-88B on confidence level and interval. TSB-88A values were correct. |

# FOREWORD
# (This foreword is not part of this bulletin.)

Subcommittee TR-8.18 of TIA Committee TR-8 prepared and approved this document.

Changes in technology, refarming existing frequency bands, proposed 800 MHz band reorganizations and new allocations in the 700 MHz band, plus increased reporting of interference have recently occurred. These events support keeping this document current and that it provide the methodology of modeling the various interference mechanisms to support frequency coordinators in determining the best assignments to be made for the available pool of frequencies and mixtures of technology.

This document includes informative Annexes A through F.

This is Part 3 of Revision C of this Bulletin and supersedes TSB-88-B (including addendum TSB-88-B1). Other parts of this Bulletin are titled as follows:

- Part 1: Technology Independent Performance Modeling
- Part 2: Propagation Modeling, including Noise

| Source Subdivision in TSB-88-B | Superceded by[1] Subdivision in TSB-88.3C |
|---|---|
| 8 | 5 |
| | |
| Annex E | Annex A & B |
| [1] Note that much of the material in this document differs from that in the source document. | |

## Patent Identification

The reader's attention is called to the possibility that compliance with this document may require the use of one or more inventions covered by patent rights. By publication of this document no position is taken with respect to the validity of those claims or any patent rights in connection therewith. The patent holders so far identified have, we believe, filed statements of willingness to grant licenses under those rights on reasonable and nondiscriminatory terms and conditions to applicants desiring to obtain such licenses.

The following patent holders and patents have been identified in accordance with the TIA intellectual property rights policy:

- None identified

TIA is not be responsible for identifying patents for which licenses may be required by this document or for conducting inquiries into the legal validity or scope of those patents that are brought to its attention.

## INTRODUCTION

This document is intended to address the following issues:

- Accommodating the design and frequency coordination of bandwidth-efficient narrowband technologies likely to be deployed as a result of the Federal Communications Commission "Spectrum Refarming" efforts;

- Assessing and quantifying the impact of new narrowband/bandwidth efficient digital and analog technologies on existing analog and digital technologies;

- Assessing and quantifying the impact of existing analog and digital technologies on new narrowband/bandwidth efficient digital and analog technologies;

- Addressing migration and spectrum management issues involved in the transition to narrowband/bandwidth efficient digital and analog technologies. This includes developing solutions to the spectrum management and frequency coordination issues resulting from the narrow banding of existing spectrum considering channel spacing from 30 and 25 kHz to 15, 12.5, 7.5, and 6.25 kHz;

- Information on new and emerging Land Mobile bands such as the 700, 800 and 900 MHz bands;

- Preliminary information on narrowband and wideband data; 25, 50, 100 and 150 kHz channel bandwidths; and

- Address the methodology of minimizing intra system interference between current or proposed Noise Limited Systems in spectral and spatial proximity to Interference Limited Systems.

The TSB-88-C series of documents was prepared partially in response to specific requests from three particular user organizations: the Association of Public Safety Communications Officials, International (APCO), the Land Mobile Communications Council (LMCC) and the National Coordination Committee (NCC).[1]

This document, TSB-88.3-C is intended to address verification within the context described above.

[1] The National Public Safety Telecommunications Council (NPSTC) has assumed the responsibilities of the NCC which has been disbanded.

# Wireless Communications Systems – Performance in Noise and Interference-Limited Situations

# Part 3: Recommended Methods for Technology-Independent Performance Verification

## 1. SCOPE

### 1.1. The TSB-88-C Series

The TSB-88.X-C series of bulletins provides guidance on the following areas:

- Establishment of standardized methodology for modeling and simulating various and different bandwidth efficient technologies operating in a post "Refarming" environment or in new frequency band allocations;
- Recommended databases and propagation models that are available for improved results from modeling and simulation;
- Establishment of a standardized methodology for empirically confirming the performance of various and different bandwidth efficient systems operating in a post "Refarming" environment or in new frequency band allocations, and;
- Combining the modeling, simulation and empirical performance verification methods into a unified family of data sets or procedures which can be employed by frequency coordinators, systems engineers, system operators or software developers;

The purpose of these documents is to define and advance a standardized methodology to analyze compatibility of different technologies from a technology neutral viewpoint. They provide recommended technical parameters and procedures from which automated design and spectrum management tools can be developed to analyze proposed configurations that can temporarily exist during a “rebanding” migration process as well as for longer term solutions involving different technologies.

As wireless communications systems evolve, it becomes increasingly complex to determine compatibility between different types of modulation, different channel bandwidths, different operational protocols, different operational geographic areas, and application usage.

Thus, spectrum managers, system designers and system maintainers have a common interest in utilizing the most accurate and repeatable modeling and simulation capabilities to determine likely system performance. With increasing spectrum allocation complexity, both in terms of modulation techniques offered, channel bandwidths available and in the number of entities involved in wireless communications systems, a standardized approach and methodology is needed for the modeling and simulation of these systems, in all frequency bands of interest.

In addition, after deployment, validation or acceptance testing is often an issue subject to much debate and uncertainty. Long after a system is in place and optimized, future interference dispute resolution demands application of an industry accepted and standardized methodology for assessing system performance and interference.

These documents contain recommendations for both public safety and non-public safety performance that ought to be used in the modeling and simulation of these systems. These documents also satisfy the desire for a standardized empirical measurement methodology that is useful for routine proof-of-performance and acceptance testing and in dispute resolution of interference cases that are likely to emerge in the future.

To provide this utility necessitates that specific manufacturers define various performance criteria for the different capabilities and their specific implementations. Furthermore, sufficient reference information is provided so that software applications can be developed and employed to determine if the desired system performance has been realized.

Wireless system performance can be modeled and simulated with the effects of single or multiple potential distortion sources taken into account as well as the defined performance parameters and verification testing. These include:

- Performance parameters
- Co-channel users
- Off-channel users
- Internal noise sources
- External noise sources
- Equipment non-linearity
- Transmission path geometry and transmission loss modeling
- Delay spread and differential signal phase
- Over the air and network protocols
- Performance verification

Predictions of system performance can then be evaluated based on the desired RF carrier versus the combined effects of single or multiple performance degrading sources. Performance is then based on a faded environment to more accurately simulate actual usage considering all the identified parameters and potential degradation sources.

It is anticipated that these documents will serve as a recommended best practices reference for developers and suppliers of land mobile communications system design, modeling, simulation and spectrum management software and automated tools.

### 1.2. TSB-88.3-C

This document, Part 3 of TSB-88-C, addresses recommended system verification testing and identification of interference sources within the context described in §1.1, limited to frequencies below 1 GHz, within the context described in §1.1.

## 2. REFERENCES

This Telecommunications System Bulletin contains only informative information. There may be references to other TIA standards which contain normative elements. These references are primarily to indicate the methods of measurement contained in those documents. At the time of publication, the edition indication was valid. All standards are subject to revision, and parties to agreements based on this document are encouraged to investigate the possibility of applying the most recent edition of the standard indicated in Section 3. ANSI and TIA maintain registers of currently valid national standards published by them.

# 3. DEFINITIONS AND ABBREVIATIONS

There is a comprehensive Glossary of Terms, Acronyms, and Abbreviations listed in Annex-A of TIA TSB-102. In spite of its size, numerous unforeseen terms still may have to be defined for the Compatibility aspects. The new independent sections of TSB-88.1-C and TSB-88.2-C are referenced. Additional TIA/EIA references include; TIA 603-C, Land Mobile FM or PM Communications Equipment Measurement and Performance Standards; 102.CAAA Digital C4FM/CQPSK Transceiver Measurement Methods; 102.CAAB, Digital C4FM/CQPSK Transceiver Performance Recommendations; 902.BAAB-A ,SAM Wide Band Data; 902.CBAB ,IOTA Wide Band Data; TSB-902, TIA-905.CAAB, 2 Slot TDMA Transceiver Performance Recommendations and TIA 905. Some newer documents may not have been released when this document was approved for publication. ANSI/IEEE Std 100-1996. IEEE Standard Dictionary of Electrical and Electronic Terms will also be included as applicable. Items being specifically defined for the purpose of this document are indicated as (New). All others will be referenced to their source as follows:

| | |
|---|---|
| ANSI/IEEE 100-1996 Standard Dictionary | [IEEE] |
| TIA-603-C | [603] |
| TSB-102- A | [102/A] |
| TIA/EIA-102.CAAA-B | [102.CAAA] |
| TIA/EIA-102.CAAB-B | [102.CAAB] |
| Recommendation ITU-R P.1407 | [ITU3] |
| Report ITU-R M.2014 | [ITU8] |
| TIA/EIA-845 | [845] |
| TSB-902 | [902] |
| TIA-902-CAAB-A | [902.CAAB] |
| TIA-902-CBAB | [902.CBAB] |
| TSB-905 | [905] |
| TIA-905-CAAA | [902.CAAA] |
| TIA-905-CAAB | [902.CAAB] |
| TIA-905-CBAA | [902.CBAA] |
| TIA-905-CBAB | [902.CBAB] |
| TSB-88.1-C | [88.1] |
| TSB-88.2-C | [88.2] |

The preceding documents are referenced in this bulletin. At the time of publication, the editions indicated were valid. All such documents are subject to revision, and parties to agreements based on this document are encouraged to investigate the possibility of applying the most recent editions of the standards indicated above:

### 3.1. Definitions

For the purposes of this document, the following definitions apply:

**ACIPR Adjacent Channel Interference Protection Ratio** Same as Offset Channel Selectivity [603]

**ACP Adjacent Channel Power:** The energy from an adjacent channel transmitter that is intercepted by prescribed bandwith, relative to the power of the emitter. Regulatory rules determine the measurement bandwidth and offset for the adjacent channel. ACP = 1/ ACPR

**ACPR Adjacent Channel Power Ratio**: The ratio of the total power of a transmitter under prescribed conditions and modulation, within its maximum authorized bandwidth to that part of the output power which falls within a prescribed bandwidth centered on the nominal offset frequency of the adjacent channel. ACPR = 1/ACP

**Adjacent Channel:** The RF channel assigned adjacent to the licensed channel. The difference in frequency is determined by the channel bandwidth.

**Adjacent Channel Rejection [102.CAAA][ 603]:** The adjacent channel rejection is the ratio of the level of an unwanted input signal to the reference sensitivity. The unwanted signal is of an amplitude that causes the BER (or SINAD for analog) produced by a wanted signal 3 $dB$ in excess of the reference sensitivity to be reduced to the standard BER. The analog adjacent channel rejection is a measure of the rejection of an unwanted signal that has an analog modulation. The digital adjacent channel rejection is a measure of rejection of an unwanted signal that has a digital modulation.

Cross analog to digital or digital to analog, necessitates that the adjacent channel be modulated with its appropriate standard Interference Test Pattern modulation and that the test receiver use its reference sensitivity method.

Because it is a ratio is is commonly referred to as the Adjacent Channel Rejection Ratio (ACRR) as well.

**Advanced Multi-Band Excitation Vocoder:** Newer vocoder technology requiring a lower number of bits. There are various configurations offered and performance varies based on the number of bits and the error correction coding applied.

**Boltzmann's Constant (k):** A value 1.3805x $10^{-23}$ J/K (Joules per Kelvin). Room temperature is 290 K.

**C4FM [102/A]:** A 4-ary FM modulation technique that produces the same phase shift as a compatible CQPSK modulation technique. Consequently, the same receiver can receive either modulation.

**Channel Performance Criterion [New]:** The maximum BER at a specified vehicular Doppler rate necessary to deliver a specific DAQ for the specific modulation. The recommended CPC form is $C_f/N$ or $C_f/(I+N)$ @ X Hz Doppler.

**Co-Channel:** Another licensee, potential interferer, on the same center frequency.

**Confidence Interval:** A statistical term where a confidence level is stated for the probability of the true value of something being within a given range which is the interval.

**Confidence Level:** also called Confidence Coefficient or Degree of Confidence, the probability that the true value lies within the Confidence Interval.

**DAQ [New]:** The acronym for Delivered Audio Quality, a reference similar to Circuit Merit with additional definitions for digitized voice and a static SINAD equivalent intelligibility when subjected to multipath fading.

**Dipole:** A half wave dipole is the standard reference for fixed station antennas. The gain is relative to a half wave dipole and is expressed in *dBd*.

**Directional Height Above Average Terrain (DHAAT):** The Height Above Average Terrain within a defined angular boundary. Used for determining co-channel site separations by the FCC

**Effective Multicoupler Gain (EMG):** The effective improvement in reference sensitivity between the input of the first amplifier stage and the reference sensitivity of the base receiver alone.

**Error Function (*erf*):** The normal error integral. It is used to determine the probability of values in a Normal distribution (Gaussian distribution). Many statistical calculators can perform this calculation. Many spreadsheet programs have this as a function, although enabling statistical add-ins is necessary for this function to be available. Its compliment is the *erfc*. When added together they equal 1 $(erf + erfc = 1)$.

**Equivalent Noise Bandwidth (ENBW):** The frequency span of an ideal filter whose area equals the area under the actual power transfer function curve and whose gain equals the peak gain of the actual power transfer function. In many cases, this value can be close to the 3-*dB* bandwidth. However, there exist situations where the use of the 3- *dB* bandwidth can lead to erroneous results.

**Height Above Average Terrain (HAAT):** The height of the radiating antenna center above the average terrain that is determined by averaging equally spaced data points along radials from the site or the tile equivalents. Average only that portion of the radial between 3 and 16 km inclusive.

**IMBE [102/A]:** The acronym for Improved Multi Band Excitation, the project 25 standard vocoder per ANSI/TIA/EIA-102.BABA. “A voice coding technique based on Sinusoidal Transform Coding (analog to digital voice conversion).”

**Inferred Noise Floor [New]:** The noise floor of a receiver calculated when the Reference Sensitivity is reduced by the static $C_s/N$ necessary for the Reference Sensitivity. This is equivalent to kTb + Noise Figure of the receiver.

**Interference Limited:** The case where the CPC is dominated by the Interference component of $C/(I+N)$.

**Isotropic:** An isotropic radiator is an idealized model where its energy is uniformly distributed over a sphere. Microwave point-to-point antennas are normally referenced to *dBi*.

**Linear Modulation:** Phase linear and amplitude linear frequency translation of baseband to passband and radio frequency

**Lee’s Method:[12]** The method of determining the number subsamples of signal power to be taken over a given number of wavelengths for a specified confidence that the overall sample is representative of the actual signal within a given number of decibels.

**Local Mean:** The mean power level measured when a specific number of samples are taken over a specified number of wavelengths. Except at frequencies less than 300 MHz, the recommended values are 50 samples and 40$\lambda$. Note that for a lognormal distribution (typical for land mobile local shadowing), the local mean ought to result in the same value as the local median. However, the local mean calculation can produce false results if the instantaneous signal strength falls significantly below the measurement threshold of the measuring receiver.

**Local Median:** The median value of measured values obtained while following Lee’s method to measure the Local Mean. Note that for a lognormal distribution (typical for land mobile local shadowing) the local median ought to result in the same value as the local mean. However, the local mean calculation can produce false results if the instantaneous signal strength falls significantly below the measurement threshold of the measuring receiver.

**Location Variability:** The standard deviation of measured power levels that exist due to the variations in the local environment such as terrain and environmental clutter density variations.

**Macro Diversity:** Commonly used as "voting", where sites separated by large distances are compared and the best is "voted" to be the one selected for further use by the system.

**Mean Opinion Score:** The opinion of a grading body that has evaluated test scripts under varying channel conditions and given them a MOS.

**Measurement Error:** The variability of measurements due to the measuring equipment's accuracy and stability.

**Micro Diversity:** Diversity reception accomplished through the placement, of receivers at the same site operating on separate antennas. These receivers are selected among or combined to enhance the overall quality of signal used by the system after this process.

**Noise Gain Offset (NGO) [NEW]:** The difference between the overall gain preceding the base receiver (Surplus Gain) and the improvement in reference sensitivity (EMG).

**Noise Limited:** The case where the CPC is dominated by the Noise component of $C/(I+N)$.

**Number of Test Grids:** The number of uniformly distributed but randomly selected test locations used to measure the CPC. It is calculated using the Estimate of Proportions equation and the specified Area Reliability, Confidence Interval and Sampling Error.

**Out of Band Emissions (OOBE) [ITU8]:** Emission on a frequency or frequencies immediately outside the necessary bandwidth, which results from the modulation process, *but excluding spurious emissions.* This definition is restrictive for the purpose of this document. See Beyond Necessary Bandwidth Emissions (BNBE).

**Protected Service Area (PSA) [New]:** That portion of a licensee's service area or zone that is to be afforded protection to a given reliability level from co-channel and off-channel interference and is based on predetermined service contours.

**Reference Sensitivity [102.CAAA]:** An arbitrary signal strength value used in receiver $C/N$ calculations. A given value of Reference Sensitivity doesn' tspecifically relate to a defined audio quality or other measurement value. If its corresponding value of $C_s/N$ is known, an inferred noise floor can be determined.

**Sampling Error:** The percentage of error, caused by not being able to measure the "true value" obtained by sampling the entire population.

**Service Area:** The user's specific geographic bounded area of concern. Usually a political boundary such as a city line, county limit or similar definition for the users business. Can be defined relative to site coordinates or an irregular polygon where points are defined by latitude and longitude. In some Public Safety systems the Service Area may be greater than their Jurisdictional Area. This is done to facilitate interference mitigation or allow simulcasting without violating regulatory contour requirements.

**SINAD:** SINAD is a test bench measurement used to compare analog receiver performance specifications, normally at very low signal power levels, e.g 12 $dB$ SINAD for reference sensitivity. It is defined as:

$$SINAD(dB) = 20\log_{10}[\frac{Signal + Noise + Distortion}{Noise + Distortion}]$$

where: Signal = Wanted audio frequency signal voltage due to standard test modulation. Noise = Noise voltage with standard test modulation. Distortion = Distortion voltage with standard test modulation.

**Site Isolation:** The antenna port to antenna port loss in $dB$ for receivers close to a given site. It includes the propagation loss as well as the losses due to the specific antenna gains and patterns involved.

**Standard BER [102.CAAA]:** Bit Error Rate (BER) is the percentage of the received bit errors to the total number of bits transmitted. The value of the standard bit error rate (BER) is 5%.

**Standard Deviate Unit (SDU):** Also “Standard Normal Deviate.” That upper limit of a truncated normal (Gaussian) curve with zero mean and infinite lower limit which produces a given area under the curve (e.g., $Z$ = +1.645 for Area =0.95).

**Standard SINAD [603]:** The value of the standard signal-to-noise ratio is 12 $dB$. The standard signal-to-noise ratio (SINAD) allows comparison between different equipment when the standard test modulation is used.

**Subsample:** A single measured value. Part of a Test Sample.

**Surplus Gain:** The sum of all gains and losses from the input of the first amplified stage until the input to the base receiver.

**Symbol Rate:** The rate of change of symbols, symbols/sec, where each symbol represents multiple bits of binary information. Each symbol can have multiple states which correspond to the binary value represented by the symbol. The symbol rate is the bit rate divided by the number of bits per symbol.

**Talk Out:** From the fixed equipment outward to the "mobile" units. Also referred to as a forward link or down link.

**Talk In:** From the "mobile equipment" inbound to the fixed equipment. Also referred to as a reverse link or up link.

**Test Grid:** The overall network of tiles where random samples of the CPC are taken.

**Test Location:** The beginning of the Test Sample in a Test Tile.

**Test Sample:** A group of subsamples which are measured at a Test Tile.

**Test Tile:** The location where the random subsamples for CPC are to be taken.

**Uncertainty Margin**: An additional margin necessary due to measurement error.

**Validated Service Area Reliability [New]**: The number of test locations successfully measured with the desired parametric value divided by the total number of locations tested.

**Voting:** The process of comparing received signals and selecting the instantaneous best value and incorporating it into the system. [See also macro diversity.]

### 3.2. Abbreviations

| | |
|---|---|
| ANSI | American National Standards Institute |
| APCO | Association of Public Safety Communications Officials International, Inc. |
| ATP | Acceptance Test Plan |
| BER | Bit Error Rate |
| BDA | Bi-Directional Amplifier |
| C4FM | 4-ary FM QPSK-C; Compatible Four Level Frequency Modulation |
| CMRS | Commercial Mobile Radio Service |
| CPC | Channel Performance Criterion |
| $C_f/(I+N)$ | Faded Carrier to Interference plus Noise ratio |
| $C_f/N$ | Faded Carrier to Noise ratio |
| $C/I$ | Carrier to Interference signal ratio |
| CQPSK | AM QPSK-C; Compatible Quadrature Phase Shift Keying |
| $C_s/N$ | Static Carrier to Noise ratio |
| DAQ | Delivered Audio Quality |
| *dBd* | Decibels relative to a half wave dipole |
| *dBqw* | Decibels relative to a quarter wave antenna |
| *dBi* | Decibels relative to an isotropic radiator |
| *dBm* | Power in decibels referenced to 1 milliWatt |
| $dB\mu$ | Decibels referenced to 1 microvolt per meter (1 $\mu$V/m) |
| *dBS* | SINAD value expressed in decibels |
| $\frac{E_b}{N_0}$ | Energy per bit divided by the noise power in one Hertz bandwidth |
| EMG | Effective Multicoupler Gain |
| ENBW | Equivalent Noise Bandwidth |
| *erf* | Error Function |
| *erfc* | Complementary Error Function $(erfc\ x = 1 - erf\ x)$ |
| $ERP_d$ | Effective Radiated Power, relative to a $\lambda/2$ dipole |
| FPT | Faded Performance Threshold |
| FM | Frequency Modulation |

| | |
|---|---|
| HAGL | Height Above Ground Level |
| IF | Intermediate Frequency |
| $IIP^3$ | Input Third Order Intercept |
| $IP^3$ | Third Order Intercept |
| MOS | Mean Opinion Score |
| N/A | Not Applicable |
| NF | Noise Factor |
| $NF_{db}$ | Noise Figure |
| $OIP^3$ | Output Third Order Intercept |
| OOBE | Out of Band Emissions |
| PSA | Protected Service Area |
| RF | Radio Frequency |
| RRC | Root Raised Cosine |
| RSSI | Receiver Signal Strength Indication |
| SINAD | Signal plus Noise plus Distortion -to-Noise plus Distortion Ratio |
| UHF | Ultra High Frequency |
| VHF | Very High Frequency |
| $Z$ | Standard Deviate Unit |

## 4. TEST METHODS

Test methods listed in this section are either specific to the referenced normative TIA documents or informative recommendations.

Recommended test methods are defined in the following subsections:

§ 5.7.1 Voice Coverage Acceptance Testing

§ 5.7.2 Data Coverage Acceptance Testion

§ 5.7.3 Local Conformance Measurements

## 5. Performance Confirmation

This section addresses the issues associated with the empirical validation and quantification of wireless communications system performance. This process is integral to a proof-of-performance or acceptance test or to quantify the actual interference environment versus simulated predictions in interference-limited systems.

Conformance testing validates a user's expectation of obtaining the design reliability over the service area by collecting data at a statistically significant number of random test locations, uniformly distributed throughout the service area. The entire concept of conformance testing rests on statistics.

While it is impractical to measure every one of the infinite number of points within a given coverage area, one can measure a sufficient number to arrive at a value that is within an arbitrarily small interval of the actual reliability, with a specified high statistical confidence. The measurements become simple pass or fail tests and do not represent the reliability of the tile that was sampled. The process is based on statistical spot sampling to verify if the predicted value was achieved. The number of spot measurements and their locations are selected such that the pass to (pass + fail) quotient is, to a given statistical confidence, within a given interval of the actual area reliability.

The semantics of some of the terms used is critical for a proper understanding of this methodology. The **service area** is divided by a grid pattern to produce a large number of uniformly sized **tiles**, or test tiles. In one method of vehicular outdoor performance confirmation, within each test tile one **test location** is randomly selected. Starting at each of these test locations, a series of sequential mobile measurements (**sub-samples**) is made over a requisite distance. This test location measurement, containing a number of sub-samples, constitutes the **test sample** for this test tile. See §5.7.1.4 for voice CATPs.

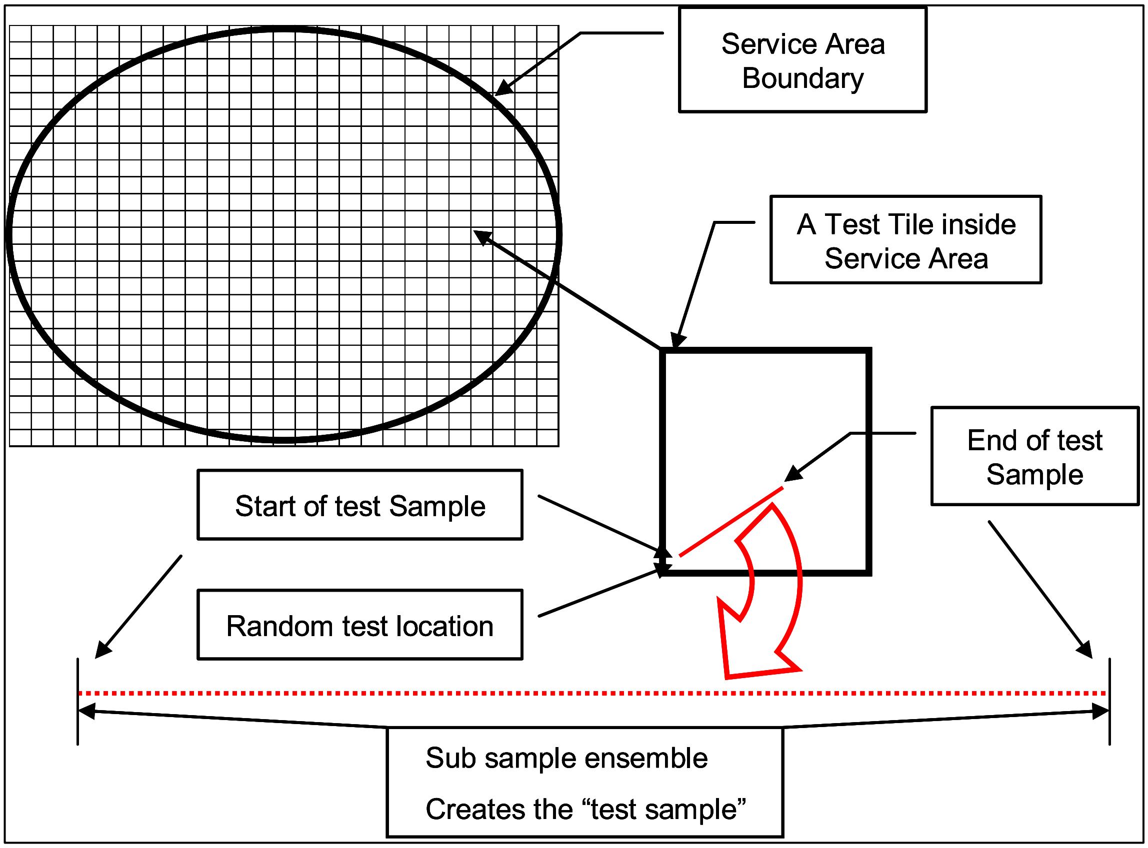


**Figure 1 - Sample Definitions**

Alternatively, the grid pattern is used to develop a test route that is uniformly distributed throughout the service area with an approximately equal distance traveled in each grid. This test route ought to pass once through each test tile while collecting data. Thus, a large number of test samples is collected and evenly distributed throughout the service area.

Randomly select the actual test location within each Test Tile when the test vehicle crosses into the tile at an arbitrary point. Overlay the Service Area with a test grid, without consideration for roads or accessibility[2]. The drive pattern compliments this random approach through the nature of the driver finding the closest way to the next test tile. Upon entering an untested Test Tile, have the coverage testing equipment indicate that this is a new, untested Test Tile. Conduct stationary tests by stopping at the nearest safe sampling point within that tile. Avoid viewing or using RSSI or any other parameter in determining the stopping point for the test. Develop a full description and procedure for test point selection during the pretest planning

[2] Adjust user requirements that are restricted to known routes, such as a transit district, to their specific routes or needs.

For a vehicular outdoor service area consisting of an underground tunnel, the route is fixed and the width of the service area is relatively small. The signal is sampled as above with the vehicle in motion. If the desired percentage of the samples passes, the service area is considered to be covered.

For performance confirmation in indoor service areas where the majority of users are on foot, including loading platforms and stations associated with underground tunnels, a different approach is recommended: The signal ensamble is collected and evaluated over as great an area as is practical.

Note: Separately state the desired service area reliability for mobile vs. portable situations and the results ought never to be combined. That is, portable indoor requirements are stated and tested separately from portable outdoor requirements, which can, in turn, be stated and tested separately from vehicular outdoor requirements.

### 5.1. Validated Service/Covered Area Reliability

The validated service or covered area reliability is determined by the requisite percentage of the tiles tested[3] that meet or exceed the CPC.

$$\text{Validated Service/Covered Area Reliability (\%)} = \frac{T_p}{T_t}(100) \qquad (1)$$

Where:

$T_p$ = Total of tests passed

$T_t$ = Total number of tests

### 5.2. Determination of Number of Test Tiles (Outdoor only)

The “estimate of proportions” is a method to determine with a high degree of confidence that sufficient test tiles have been developed to accurately validate the Outdoor Service or Covered Area Reliability.

### 5.2.1. Estimate of Proportions

$$T_\ell = \frac{Z^2 pq}{e^2} \qquad (2)$$

Where:

$T_\ell$ = Number of Test Tiles
$Z$ = Standard Deviate Unit (Corresponding to the confidence level)
$p$ = Target Service/Covered Area Reliability (decimal)(i.e. 95% = 0.95)
$q = 1 - p$
$e$ = Sampling error allowance (decimal)

[3] For service area reliability, all tested tiles are included. For covered area reliability, only those tiles predicted to meet or exceed the criterion are tested. Location information obtained during testing allows tiles tested in error or by automated means to be eliminated.

This is subject to a limit such that:

$$T_l \geq 100 \qquad (3)$$

The requirement is that $T_\ell$ be the larger of the two values calculated in equations (2) and (3).

Values for the standard deviate are available in most statistics books. Some typical values for one-sided (tail) tests [$Z_\alpha$] and two sided (tails) tests [$Z_{\alpha/2}$] are shown in Table 1 and Figure 2.

**Table 1 Values for Standard Deviate Unit**

| Percentage (%) | $Z_\alpha$ | $Z_{\alpha/2}$ |
|---|---|---|
| *50* | *0* | *0* |
| *70* | *0.524* | *1.036* |
| *80* | *0.841* | *1.281* |
| *85* | *1.036* | *1.439* |
| *90* | *1.281* | *1.645* |
| *95* | *1.645* | *1.960* |
| *97* | *1.881* | *2.170* |
| 99 | 2.326 | 2.579 |

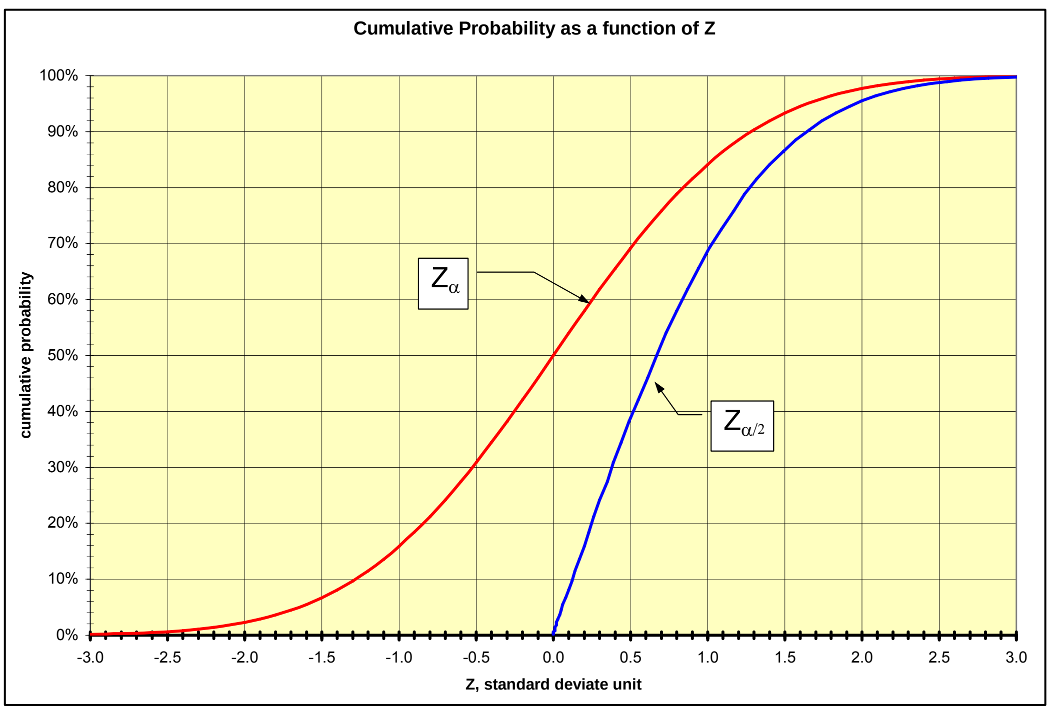


**Figure 2 - Cumulative Probability as a Function of $Z_\alpha$ and $Z_{\alpha/2}$**

The local median power is measured with a receiver calibrated at its antenna port, §5.7.3.5. Other distributions can be captured and used for additional analysis of fading.

## 5.3. Pass/Fail Test Criteria

The following pass/fail criteria are possible:

- The “Greater Than” Test
- The “Acceptance Window” Test.

### 5.3.1. The “Greater Than” Test

The “Greater Than” Test is defined such that the percentage of test locations that meet the CPC equal or exceed the service area reliability target. This necessitates a slight “overdesign” of the system by $e$ to provide the statistical margins for passing the conformance test as defined. For this test configuration, $Z$ has one-tail [$Z_\alpha$] and $e$ is the amount of overdesign, expressed as a decimal fraction.

### 5.3.2. The “Acceptance Window” Test

The “Acceptance Window” test allows the percentage of test locations that meet the CPC to fall within an error window, $\pm e$, which is centered on the service area target reliability to consider the acceptance test a pass. This eliminates the necessity for “over design”, but necessitates a two tail $Z$ [$Z_{\alpha/2}$] that increases the number of test samples to be evaluated.

## 5.4. Confidence

### 5.4.1. Confidence Level

The greater the number of test tiles, the higher the confidence level. The confidence level reflect a high confidence that the measured values indicate what the true value is. A confidence level of 99% is recommended unless this choice reduces the test tile size such that the requisite sample distance cannot be achieved.

### 5.4.2. Confidence Interval

This defines the limits within which the true value ought to fall. Using the preceding example of an acceptance window test with a 99% confidence level and 2% sampling error allowance and a target service area reliability of 95%, the statement would be, “I am 99% confident that the true value lies between 93 and 97% if the number of test tiles, $T_l = [(2.579^2)(0.95)(0.05)]/0.02^2 = 790$ tiles”.

## 5.5. Size Constraints & Accessibility

### 5.5.1. Outdoor

Recommended outdoor test tiles be ≥ 100λ by 100λ, but less than 2 km by 2 km. All test tiles to be of equivalent shape and area. A reasonable aspect ratio of 3:2 through 2:3 is considered to be square for the purpose of sizing test tiles of that shape. A tile created using other shapes, such as triangles and hexagons of equivalent areas is an acceptable alternative to a rectangularly shaped tile. Tiles need to be contiguous.

### 5.5.2. Tunnel

Tunnel test grid "tiles" are normally thin rectangular areas delineated by length. Tile lengths are dependant upon the system architecture. Considerations include the lengths of tunnel segments, locations of curves in either the horizontal or vertical plane(s) and placement of bi-directional amplifiers (BDA's) and antennas. For example, a leaky-feeder system with BDA's (or base stations) exhibits the best coverage near the output of the "upstream" BDA and the coverage will fall to a minimum value near the end of its feeder and the beginning of the adjacent BDA's feeder. In this case it is recommended that the tile boundaries coincide with BDA boundaries. If antennas are used in the system, tile boundaries can be adjusted or split to make sure that the effect of the antennas can be documented.

### 5.5.3. Indoor

For indoor service areas where the majority of users are on foot, including loading platforms and stations associated with underground tunnels, tiles are not used. Instead, the signal is sampled over as great an area as is practical. If individual buiding testing is necessary refer to §5.6.3.

### 5.5.4. Accessibility

Prior to testing, locations with inaccessible test tiles ought to be specified and treated per one of the following options:

- Eliminated from the calculation [Preferred]
- Estimated based on adjacent tiles (single tiles only)
- Considered a pass

If groups of inaccessible test tiles are encountered during a CATP it is recommended:

- Re-model the Coverage with these inaccessible locations removed from the prediction as their inability to be tested changes the predicted value.
- If removal of these groups of inaccessible test tiles causes the predicted reliability to fall below the original criterion, then change the coverage criterion to reflect this.

### 5.5.5. Treating Anomalous Tiles

If the coverage test results do not meet the specified Acceptance Criteria, secondary coverage testing can be performed for analysis and re-configuration. These areas can then be re-tested per the specification.

Only perform the Coverage Test procedure once per test tile. If any portion of the test is determined to be unreliable because of proven equipment malfunctions or failures, repeat the portion of the test affected by the equipment malfunction or failure.

If a test, or a portion thereof, is suspected to have failed due to external interference, those test tiles suspected of being affected by an interferer ought to be re-tested. If the test tiles re-tested fail and interference is found, those test tiles ought to be excluded from the acceptance calculations and potential solutions identified.

It could be possible to have multiple teams performing a Data-CATP simultaneously. However, the drive routes need to be carefully constructed and timed such that the probability of two test measurements using the same RF nodes is extremely remote. The goal of the test is to measure and verify the coverage of the communications “pipe.” This is best accomplished when only one device is presenting traffic to the portion of the wireless network under test. Traffic from more than one unit using the same RF nodes and backhaul could skew the results of the test, preventing a true measurement from being obtained. Should one or more test tiles fail the acceptance test, and there is a high probability that more than one device was using the nodes under test retest those tiles after ensuring that no other traffic is present on the associated nodes.

## 5.6. In-Building Recommendations

There are numerous ways to define indoor coverage and the associated building penetration loss[4]. There are trade-offs between thoroughness and practicality. Increased thoroughness and accuracy necessitates considerable additional costs in time and resources.

Different types of performance requirements can be defined by:

- Defining a penetration loss based on a class of buildings and providing that loss as a margin of additional field strength at the base of the building at street level.

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[4] The scenarios given are assumed that coverage is being provided by an external site or bi-directional amplifier system to provide coverage inside a building. If a dedicated micro-cell is being provided for coverage unique to a specific building, more comprehensive testing would be appropriate.

- Defining a penetration loss based on a class of buildings, with an associated standard deviation for that class of building, and providing that loss as a margin of additional field strength at the base of the building at street level to provide a calculated probability of achieving the desired signal level inside the building at ground level.
- Testing individual buildings from a list of specific buildings.

Tests can include multiple floors or be limited to the normally worst-case penetration loss of the ground level floor. Additional specifications for specific worst case locations ought to be evaluated against cost for providing coverage directly from a site or via in-building coverage enhancements such as bi-directional amplifiers. Some typical worst-case locations include:

- Elevators
- Stairwells
- Basements and below ground levels such as parking garages
- Bank vaults
- Jails
- X-ray rooms
- Nuclear facilities
- Shielded computer rooms
- Tempest Test facilities
- Tunnels, other than subways or vehicle tunnels with dedicated facilities

In general these locations have additional penetration losses due to shielding and lack of windows or facilities that support signal penetration.

### 5.6.1. Defined penetration loss

This is the simplest method as the necessary additional losses can be agreed upon prior to system design. Tables of measured building penetration losses for various classes of buildings are available in technical reference material [16] through [40]. Note however that these have a wide range of values and actual results vary in different geographic locations due to the size and type of glass used in windows and amount of steel in the structure, §5.6.4.4. Before determining a value, it is recommended that a sub-sample of the building(s) be physically measured to ensure confidence in any value specified.

### 5.6.2. Defined penetration loss plus standard deviation

In this case an additional margin is necessary, the root sum squares of the standard deviations for location and building penetration. The implication is that this provides a probability of achieving a desired DAQ in some percentage of each class of building. However, testing of this option is complicated by the additional statistical margin. Measuring field strength outside the building is not valid as only one variable is included and assumes that the building loss and standard deviation are true values. Individual building tests are therefore necessary, §5.6.3. Because conducting the requisite test for this methodology includes high cost and limited accuracy, this type of design criterion is not recommended.

### 5.6.3. Individual building tests

This provides the greatest confidence to the end users, but is the most costly in terms of complexity, time and resources. To simplify this type of test, it is recommended that individual tests be made very simple with limited individual test locations. For example:

- Residential building (single/2 story family) Single test in center of ground floor.
- Small commercial building (single story, open floor plan). Five test locations, one in each corner and one in center.
- Medium building (small school, light industrial, medical office), 20 test locations, uniformly distributed on the ground floor.
- Large building (Shopping malls, factories, buildings over 5 stories). Multiple test points uniformly distributed on the ground floor.

Because the design needs to include margins for probability, the agreed to percentage of passed test locations in the building ought to be determined prior to the design. When no building penetration standard deviation is included, 50% of the test locations passing confirm that the building passed. To achieve a higher percentage of successfully passed test locations would necessitate additional margins.

When a given building penetration loss is agreed to and a building fails to meet the agreed to percentage of passed test locations within the building, the actual penetration loss of that building ought to be measured if that building's failure has an affect on the overall CATP results. If the measured penetration loss exceeds the agreed to value, the test result representing that building is deemed invalid and is not included in any of the calculations for determining any CATP success or failure percentages that have been agreed to prior to testing.

#### 5.6.3.1. Physical in-building test

Conduct a moving test by walking in a circle, approximately 1 meter in diameter, while conducting a subjective test or capturing sufficient data for an objective test, §5.6.4.4. Alternatively a non-moving (static) test could be conducted. Agreement on the type of test needs to be obtained prior to system design.

A random selection of buildings is recommended. One building of the appropriate class, nearest the center of a CATP grid is recommended.

#### 5.6.3.2. Moving versus static testing

A moving test is preferred to a static test because it properly accounts for the statistical variations in the signal. If a static test is employed, and a given location test fails to meet the specification, it is recommended that the test team move 1-2 meters from the original location and repeat the test. Passing the second test constitutes passing that test location.

### 5.6.4. Exterior Wall Penetration (Indoor Systems)

System design specifications often necessitate a determination of RF loss through exterior walls of buildings to determine whether indoor signal enhancement is necessary. These measurements can be made by use of existing signals or by use of a low-power test transmitter/receiver system designed for building obstruction measurements. The accuracy of the existing signal method depends upon a line-of-sight path to the signal source and the absence of any strong reflections or multipath. A well-calibrated test transmitter/receiver system is recommended for these measurements, §5.7.3.5.

#### 5.6.4.1. Test Transmitter Method

A low-power test transmitter is used with an associated calibrated receiver to measure the penetration loss through the exterior walls. It is recommended that measurements be taken at regular intervals throughout the entire floor of interest for one test transmitter position corresponding to (and perpendicular to) each side of the structure. The results are then averaged for signals entering via each side of the structure, §5.6.4.3. A standard deviation can be calculated from the individual data pairs.

#### 5.6.4.2. Existing Signals Method

While it is not practical to measure building penetration loss (including the effects of interior walls and partitions) using the existing signals method, it is possible to measure exterior wall loss. If the test transmitter method cannot be used, a possible alternative could be to use strong, existing signals from a nearby transmitter site to estimate exterior wall loss. Use a calibrated portable measuring device to take readings while walking around the exterior of the building. Samples are taken at regular intervals and averaged for each side of the structure. Samples are then taken while walking around the inside of exterior walls. These readings can be more difficult to obtain, depending upon building construction, but the number of readings ought to correspond to the number taken out-of-doors. These readings can then be averaged for each exterior wall. The average propagation loss or blockage for each exterior wall is then the difference in *dB* between the average outdoor signal (in *dBm*) and the average indoor signal (in *dBm*). A standard deviation of the difference can be calculated using individual correlated data pairs. Building penetration loss can be estimated by adding a suitable value to the measured exterior wall loss.

#### 5.6.4.3. Building Loss

The building loss is calculated by linearly averaging the loss of each face.

$$\text{Bldg Loss (dB)} = 10\log\left[\left(\frac{10^{\left(Face1_{(dB)}/10\right)} + 10^{\left(Face2_{(dB)}/10\right)} + 10^{\left(Face3_{(dB)}/10\right)} + 10^{\left(Face4_{(dB)}/10\right)}}{4}\right)\right] \quad (4)$$

If the following face values are linearly averaged the resultant value would be 8.9 dB.

| | |
|---|---|
| Face 1 | 10 dB |
| Face 2 | 7.5 dB |
| Face 3 | 9.0 dB |
| Face 4 | 8.6 dB |

#### 5.6.4.4. Building Loss Examples

The following is the same information as provided in [88.2]. It is provided here to facilitate acceptance testing where buildings are involved.

Building loss is a function of many variables. In general, the loss decreases with increasing frequency due to the mechanisms involved. The materials commonly used in building constructions consist of steel, copper mesh, reinforcing steel mesh and metallic sheets. These are highly lossy and cause the windows to become the main method of penetration. At low frequencies, windows act as waveguides below cutoff, or small slots. Because the wavelength decreases with increasing frequency, the efficiency of coupling improves as more energy can pass through the same aperature. Many new buildings utilize metalized glass which can dramatically increase the penetration loss.

The penetration loss in wooden frame buildings works in the opposite direction. Materials commonly used include glass, brick and mortar, drywall, plywood, wood, and cinder blocks. In this case, the penetration is primarily via the walls and the loss normally increases with frequency [13]. Stucco buildings use wire mesh and therefore trend more toward industrial building losses. Many new residential structures employ metalized roofing materials which makes the penetration loss more reliant on window coupling.

Building loss generally decreases with height. As the number of stories increases, the loss on the higher floors decreases. Lower floor losses typically increase due to the increased amount of structual steel used. Buildings in earthquake prone areas generally have higher steel content.

Floor to floor losses are considerably higher than penetration loss. This is especially important in high rise buildings where a unit on the main floor can be limited in how many floors higher a desired unit can be and still communicate. In fire ground situations, an external unit is more desireable as it can relay communications and illuminate more of the building.

The following figures provide generalized medium building loss [13][37] and standard deviation [39]] . They are provided as a general reference as they are an amalgamation of many different studies and measurements. Local conditions can change these values. Use the methods in §5.6.4.1 and §5.6.4.2 to determine if the indicated values are applicable.

In general, applying one building loss value across an entire service area is not recommended. It is recommended that specific criteria be applied to defined areas appropriate to the current or envisioned type of construction. The specification can be applied within a geographically specified polygon.

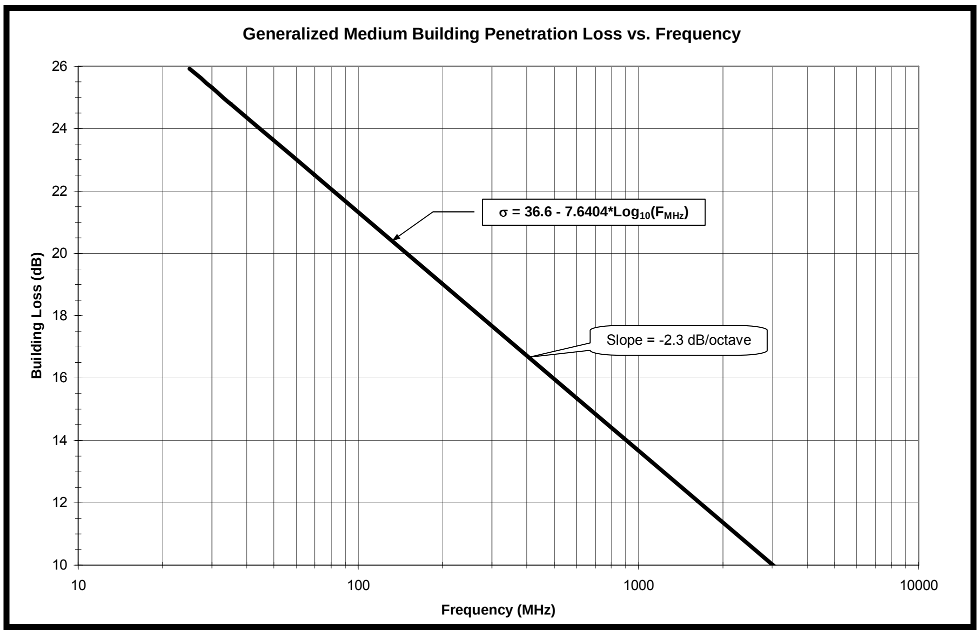



**Figure 3 - Generalized Medium Building Penetration Loss**

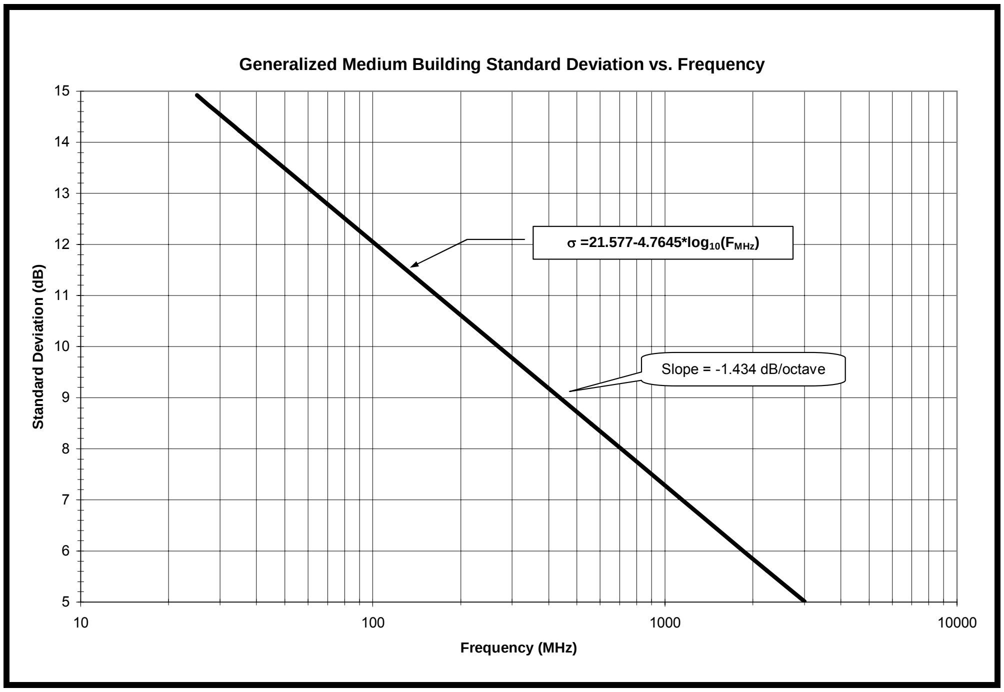



**Figure 4 - Standard Deviation, Generalized Medium Buildings**

## 5.7. Coverage Acceptance Testing

The objective of the Coverage Acceptance Test Plan (CATP) is to demonstrate that the System achieves or exceeds the specified minimum coverage criterion for the designated Service Area. The Radio coverage areas are defined within the Service Area Boundary.

Acceptance tests differ between voice and data systems although there are many common processes. A third type of test is described for the special case where meausuring the local signal power level is desired in interference disputes which occurred in the 800 MHz band prior to rebanding. This test is discussed separately in §5.7.3. For the voice and data CATPs, divide the predicted coverage area into a grid of uniform sized test tiles per §5.2.

### 5.7.1. Voice Coverage Acceptance Testing

Use the method of measuring signal power or BER% as discussed in §5.7.1.3 to perform the V-CATP. Use Annex A to determine the appropriate methods to use in the V-CATP.

#### 5.7.1.1. Carrier Power

The local median power is measured with a receiver calibrated at its antenna port. See §5.7.3.5. Other distributions can be captured and used for additional analysis of fading.

Note that the mean can present a distorted picture of the actual signal characteristics in cases where some of the sub-samples fall outside the dynamic range of the receiver used to measure signal strength. The median is subject to this sort of distortion only in cases where more than half of the sub-samples fall outside the dynamic range. It is, therefore, a more robust statistic.

To avoid the degradation to measurements due to interference, it is recommended that carrier power measurements be made on frequencies not expected to receive interference or that the measurement channel be audibly monitored for signs of interference.

#### 5.7.1.2. Distance

The recommended distance (*D*) for outdoor test route measurements of the local median received signal power in a test tile is $28\lambda \leq D \leq 100\lambda$. The preferred distance is $40\lambda$ as it smoothes out Rayleigh fading [12][5]. Shorter distances have a large impact from the Rayleigh fading. Larger distances tend to include changes in the local value due to the location variability starting to change. At lower frequencies, less than $40\lambda$ could be necessary.

Bit Error Rate measurements might necessitate longer distances and/or time intervals to capture the necessary number of test subsamples. It is recommended that BER measurements be made over 1 second or $40\lambda$, whichever is greater.

#### 5.7.1.3. Bit Error Rate

Measure BER using a known suitable standard symbol pattern such as the Project 25 digital 1011 Hz tone test pattern or a pseudorandom test pattern, e.g., the ITU-T O.153 patterns. See also §5.7.1.7.

#### 5.7.1.4. Number of Subsamples per Test Sample

In outdoor testing, it is recommended that the number of subsamples taken for each test sample to measure the median power in each tile be greater than 50. When measured over a distance of $40\lambda$, multiples of 50 subsamples are preferred to obtain maximum decorrelation.[6] Fifty (50) subsamples produce a 90% confidence level that the measured value is $\pm 1\ dB$ of the actual value, confidence interval. Increasing the number of subsamples decreases the confidence interval. For example, for 50 subsamples the result would be stated, "There is a 90% confidence level that the true value is within 1 $dB$ when 50 subsamples are taken over 40 wavelengths." To calculate different confidence intervals, use the equation

[5] The reference recommends $20\lambda \leq D \leq 40\lambda$. The $28\lambda$ recommendation is determined by requiring a minimum of 50 samples for 90% confidence with an error of less than 1% and samples taken at $0.8\lambda$. The $100\lambda$ is the recommended maximum decorrelation distance for log normal fading.

[6] Maximum decorrelation occurs at $0.8\ \lambda$.

(6), where $T_s$ is the number of subsample data points taken and the appropriate value of $Z_{\alpha/2}$ from the Values for Standard Deviate Units in Table 1[7].

$$\text{True Mean Value}_{(dB)} = \pm 20 Log_{10}\left(1 + \frac{Z_{\alpha/2}\sqrt{\dfrac{4-\pi}{\pi}}}{\sqrt{T_s}}\right) \quad (5)$$

Where:

$Z_{\alpha/2}$ is the confidence level (%) desired.

**Table 2 True Value Accuracy vs. Number of Subsamples and Confidence Level**

| *Ts* | 90%. | 95% | 99% |
|---|---|---|---|
| 50 | ±1.00 dB | ±1.18 dB | ±1.52 dB |
| 100 | ±0.72 dB | ±0.85 dB | ±1.10 dB |
| 150 | ±0.59 dB | ±0.70 dB | ±0.91 dB |
| 200 | ±0.51 dB | ±0.61 dB | ±0.79 dB |
| 250 | ±0.46 dB | ±0.55 dB | ±0.71 dB |
| 300 | ±0.42 dB | ±0.50 dB | ±0.65 dB |
| 350 | ±0.39 dB | ±0.46 dB | ±0.60 dB |
| 400 | ±0.37 dB | ±0.43 dB | ±0.57 dB |
| 450 | ±0.35 dB | ±0.41 dB | ±0.54 dB |
| 500 | ±0.33 dB | ±0.39 dB | ±0.51 dB |

The number of test subsamples for a given True Value accuracy and confidence level is:

$$T_s = \left[\frac{Z_{\alpha/2}\sqrt{\dfrac{4-\pi}{\pi}}}{\left[10^{\frac{TV\pm_{dB}}{20}} - 1\right]}\right]^2 \quad (6)$$

Where:

TV is the confidence interval of the True Value, ± dB.

[7] $Z_{\alpha/2}$ is the argument of the unit normal distribution for a confidence level of 1-$\alpha$ Use Table 1 values for the calculation.

**Table 3 Number of Test Subsamples vs. True Value and Confidence Level.**

| True Value | 90%. | 95% | 99% |
|---|---|---|---|
| ±0.25 dB | 872 | 1231 | 2133 |
| ±0.50 dB | 212 | 299 | 518 |
| ±0.75 dB | 91 | 129 | 224 |
| ±1.00 dB | 50 | 71 | 122 |
| ±1.25 dB | 31 | 44 | 76 |
| ±1.50 dB | 21 | 30 | 51 |
| ±1.75 dB | 15 | 21 | 37 |
| ±2.00 dB | 11 | 16 | 27 |
| ±2.25 dB | 9 | 12 | 21 |
| ±2.50 dB | 7 | 9 | 16 |
| ±2.75 dB | 5 | 8 | 13 |
| ±3.00 dB | 4 | 6 | 11 |

If necessary, large indoor spaces ought to be tested and logged at a rate of approximately 125 samples per second while the test setup is moving at a reasonably constant walking speed and logging its location within the area, Unlike outdoor testing, the aim of indoor testing is to characterize the coverage for as much of the floor space as possible as compared to the method in §5.6.3.

### 5.7.1.5. Measurement Techniques [845]

Although calibration accuracy of the equipment used is important, consistency in the measurement technique is of equal importance. Measurements taken at different times with the same equipment ought to be repeatable, and measurements taken with different equipment ought to at least correlate within a calibration factor.

It is occasionally necessary to make both mobile and portable measurements for the same system. This can involve different measurement tile sizes for the mobile versus portable measurements. As it is not statistically sound to mix the results for the two types of measurements it is recommended that, in cases where this occurs, the mobile and portable criteria are evaluated separately.

#### 5.7.1.5.1. Outdoor

It is recommended that for outdoor measurements use automatic data collection equipment mounted in a vehicle similar to those used by the customer. This equipment is capable of mapping the data with GPS, dead-reckoning, or a combination of both techniques to accuracies such that any location measurement is accurate within no more than 20% of the tile size dimension or 100 meters, whichever is less. In some cases Differential GPS might be necessary.

#### 5.7.1.5.2. Tunnel

Roadway tunnel measurements can be taken with the same data collection equipment used for outdoor testing, above. Since GPS is not usable within the tunnel, dead-reckoning or some other manual technique can be used to ensure the data is properly posted.

It is recommended that measurements for subway and other tunnels where the design is primarily for hand-held portables be taken with portable data collection equipment that can be on a wheeled cart or worn as a backpack or shoulder pack. Since minimum RF design levels normally take portable antenna inefficiencies and body losses into account, the calibrate the test antenna to a half-wave dipole, keep it in a stationary position and clear of body obstructions. A tracking method needs to be used to document the location of the samples. This can be done by setting a marker where the subway or rail car enters the tunnel and another marker when it leaves. If the speed is kept relatively constant, location information can be calculated. This becomes easier if there are bi-directional amplifiers or discrete antennas within the tunnel, as their locations can be easily ascertained from the data.

#### 5.7.1.5.3. Indoor

Testing can be subjective or objective. Subjective testing is much easier for indoor testing and is therefore recommended using the equipment in the configuration being deployed. If objective testing is utilized, then signal levels can be captured using automated test packages over a four second period. Measurements can be taken with equipment mounted on a cart, backpack or shoulder pack. Handheld units can also be necessary for areas where there are many small rooms, stairs, etc. Since minimum RF design levels normally take portable antenna inefficiencies and body losses into account, calibrate the test antenna to a half-wave dipole and keep it clear of body obstructions.

Log the location of each test location on a drawing of the area where the test was conducted.

#### 5.7.1.5.4. Inbound vs. Outbound Measurements

Performing inbound tests is much more complicated and, therefore, much more costly to perform than outbound tests. Additionally the principal of reciprocity ties the inbound results to the outbound results in a mathematically predictable manner. It is, therefore, recommended that, except in the cases of simulcast systems, receiver voting systems, or systems with large height differences between the transmit and receive antennas, the results for inbound performance be inferred from the outbound tests and link budget differentials and that inbound tests not be performed.

**Table 4 VCATP Test Matrix**

| | | Objective Test | Subjective Test |
|---|---|---|---|
| **Talk-Out Test** | Digital (Single Site) | BER% & SSI 1) | OK |
| | Analog (Single Site) | SSI | OK |
| | Digital (Simulcast) | BER% & SSI 1) | OK |
| | Analog (Simulcast) | N/A (data for info only) | Recommended |
| **Talk-In Test** | Digital (Single Site) | BER% & SSI 2) | OK |
| | Analog (Single Site) | SSI 2) | OK |
| | Digital (Multi-Site) 3,4) | BER% & SSI 2) | OK |
| | Analog (Multi-Site) 3,4) | SSI 2) | OK |
| | Digital (Voting) | Undefined test 5) | Recommended |
| | Analog (Voting) | Undefined test 5) | Recommended |

1. Measured BER% is the preferred method. However, SSI provides additional information about identifying potential interference. See §5.11.
2. Failures due to interference ought to be agreed upon prior to testing as to whether they are counted or not.
3. Evaluate difference in link budget and use in conjunction with Talk-Out Testing as applicable, §5.7.3.4.
4. Individual tests per site.
5. Current test signals (Tables A-2 & 3 [88.1], O.153) cannot proceed past the base receiver. Therefore enhancements due to voting cannot be objectively determined until a more elaborate test is developed.

Talk-In macro diversity testing is not currently addressed. The subjective testing is recommended, as any testing using the O.153 test pattern doesn't contain the necessary interface to reach the comparator for processing the selection of the best information from multiple sources. As a result, current implementations would necessitate multiple test instrumentations, one at each site, recording the appropriate SSI and BER% (digital only) and time stamping the data for post processing to determine if at least one site met the criterion. This would be an expensive proposition and still not provide any indication as to improvements due to voting or any link degradation between the site and the comparator. Therefore subjective testing is recommended.

#### 5.7.1.6. Vehicular Antenna Considerations

Mount the vehicle antennas in accordance with [845]. Antenna ought to be mounted in the center of the vehicle's roof and placed clear of all other obstacles.

Specific performance tests might necessitate that the antenna be placed so as to simulate actual mobile operating conditions. This could result in the antenna being placed in such locations as behind light bars or on the trunk. Because true signal strength cannot be measured under such conditions, it is recommended that data obtained from antenna mounted in this manner not be used to simulate conditions of portable operation, whether by use of attenuators or post-processing losses.

#### 5.7.1.7. Digital Test Pattern Generation

The digital test patterns are based on the ITU-T O.153 (formerly V.52) pseudo-random sequence. The FORTRAN procedure given below generates this pattern for binary and four level signals.

```
function v52()
C Function produces the V.52 bit pattern called for in the digital FM
C interference measurement methodology.  Each time this function is
C called, it produces one bit of the V.52 pattern.

        integer v52        ! The returned V.52 bit.
        integer register    ! The shift register that holds the current
                          ! state of the LSFR.

        data register/511/  ! The initial state of the shift register.
        save register       ! Saving the shift register between calls.

C Returning the value in the LSB of the shift register.
        v52=and(register,1)

C Performing the EXOR and feedback function.
        if(and(register,17) .eq. 1 .or. and(register,17) .eq. 16) then
          register=register+512
        end if

C Shifting the LSFR by one bit.
        register=rshft(register,1)
        end
```

The data from the procedure above is binary, and can be used to drive binary data systems directly. Since many modulations utilize four level symbols, pair the binary symbols from the O.153 sequence into 4-level symbols. This can be done with this procedure:

```
function v52_symbol()

C Function produces a di-bit symbol based on the V.52 sequence and
C the Layer 1 translation table.


        integer v52           ! External V.52 function.
        integer bit_1,bit_0    ! The two bits of the di-bit pair.
        integer v52_symbol     ! Four level V.52 symbol.
        integer table(0:1,0:1) ! Translation table to map bits into 4-
                             ! level symbols.

C Setting up the translation table.
        data table  /+1,+3,-1,-3/

C Making the V.52 draws and translating them to a 4-level symbol level
C with the translation table.
        bit_1=v52()
        bit_0=v52()
        v52_symbol=table(bit_1,bit_0)
        end
```

### 5.7.2. Data Coverage Acceptance Testing

Take measurements for Throughput or Message Success Rate in each of these test tiles. It is recommended that test vehicles contain subscriber devices, such as a laptop computer or mobile data terminals (MDT) be used for testing. Simulate handhelds by adding an attenuator to the mobile device.

it is recommended that the test teams use an automated test tool for executing the D-CATP to reduce the time and the number of people required to perform a quantitative survey and also reduce human influence that could bias the results. It is recommended that the test package use the GPS (Global Positioning System) for determining location information. The GPS accuracy ought to be HDOP <1 so Wide Area Augmented System (WAAS) can be used to augment GPS accuracy. When conditions deny GPS access and WAAS access, manually select the location based on the map display.

During the test, the actual location sampled within a test tile will be selected by detection of entering an untested test tile. It is recommended to use a tool that provides a GPS driven map display with the coverage test grid as well as a direct interface to the data radio. The fixed end will receive inbound messages from the test data radio, initiate outbound messages to the data test radio and record the messages status of each to a file.

#### 5.7.2.1. Criterion Selection

There are two types of data coverage testing criteria for validating coverage for both moving and fixed wireless data systems. They are:

- Message Success Rate (MSR)[8]
- Data Throughput Rate (DTR)

Both the uplink (subscriber to network) and downlink (network to subscriber) communications paths can, and in most cases ought to be tested. Test systems in the environment that they have been designed for. Mobile systems are typically tested a velocities between 48 -105 kph (30 - 65 mph) while portable system are typically tested at pedestrian speeds.

MSR based testing confirms that a specific sized message (nominally 100 - 500 bytes) can be reliably delivered throughout a defined percentage of the defined service area, typically 90 - 95%.

DTR based testing confirms that a specific data throughput (at a defined protocol layer) can be reliably delivered throughout a defined percentage of the defined service area, typically 90 - 95%. While data throughput can be defined at any

[8] The rate term is frequently used in the industry. For the purpose of this document, rate only applies to the entire service area as exhaustive testing in each test location is not sufficient to determine rate for that location. It involves simple pass or fail testing

protocol layer, it is typically tested at the TCP/UDP or User layer. Quality of Service (QoS) performance metrics such as residual bit error rate (BER) / packet error rate (PER), delay and jitter could optionally be measured for informative purposes.

Narrowband data systems (<25 kHz channel bandwidth) ought to be tested using message success rate as the performance criterion. The limited capacity of a narrow radio channel precludes bandwidth intensive applications therefore usage is usually constrained to message based applications, such as basic database inquiry, dispatch, and text messaging. There are some advanced systems that support higher spectral efficiency that permit constrained file transfer and WEB browsing.

Wideband data systems (50 - 150 kHz channel bandwidth) can be tested using either message success rate or data throughput rate methodologies. Advanced radio technology such as [902] based systems are able to support file transfers, WEB browsing, and even constrained (< 200 kb/s) streaming video. The selected method depends on the users' choice of applications and radio technology deployed.

Broadband data systems[9] (>1 MHz channel bandwidth) are typically tested using the data throughput rate as the performance criterion. This is due to the high bandwidth and low delay of broadband radio technology. This permits "off the shelf" standard IP based applications (e.g. streaming video, WEB, and file transfers) to be deployed similarly to a normal office wire-line environment.

#### 5.7.2.2. Test Variations

In addition to the selection of MSR or DTR, numerous other applicable test options, based on the specific system, need to be specified. These include:

- Test Tile Criteria
  - Number of Test Tiles
  - Test point selection within Test Tile
  - Test Procedure at Test Point
- Stationary or Moving Test
- Mobile or Portable Test Equipment
- One Way or Round Trip
- Treatment of Inaccessible Test Tiles
- Treatment of Test Anomolies

Generic recommended acceptance criteria and test results reporting are also included.

[9] Broadband configurations are only partially discussed as TSB-88.4-C is specifically devoted to this type of system.

#### 5.7.2.3. Coverage Message Success Rate

The purpose of this test is to demonstrate that messages transmitted over the radio network demonstrate successful delivery of inbound and outbound messages in a specified percentage of the Service Area, e.g. 95%.

The MSR CATP is based upon verifying a coverage prediction that accurately represents the implemented infrastructure and parameters that are consistent with the specification. If the implemented system varies from the design parameters, prepare a revised coverage map. New test maps ought to reflect the measured losses and gains associated with the implemented infrastructure and subscribers. These can be used to define the test configuration and potential areas from which test locations might be included in the evaluation process.

The inbound coverage test is deemed passed if the number of passed, valid test points is equal to or greater than the specified percent of the service area, based on the total number of valid test points.

The outbound coverage test is deemed passed if the number of passed, valid test points is equal to or greater than the specified percent of the service area, based on the total number of valid test points.

##### 5.7.2.3.1. Test Procedure

Prior to testing verify that the data radio in the test vehicle:

- Is the same device type and configuration as used to predict coverage, including the antenna type and mounting location (i.e., at center of vehicle roof, with no nearby obstructions such as light bars)
- Is operating satisfactorily and within published specifications
- Is equipped with the computer, the application for testing, and proper connections at the fixed end

To verify coverage for portable data radios, add the appropriate attenuation to the mobile test receiver for the desired configuration, §5.6. [88.1][88.2]

- Outdoor coverage
- In-building coverage
- In-vehicle coverage

The attenuation value is the difference between the mobile test radio modem's antenna system and the additional loss used in the coverage prediction to account for portable antenna performance and the type of coverage testing.

The coverage test consists of inbound and outbound test transmissions initiated automatically by the test tool. The recommended range for vehicle speed (traffic conditions permitting) during a test transmission is between 75% and 125% of the speed used to predict coverage. For reference, these are approximately:

**Table 5 MSR Speed Range**

| Prediction | Speed (kph) | Range (kph) | Speed (mph) | Range (mph) |
|---|---|---|---|---|
| Walking | 3 | 2 to 4 | 2 | 1 to 3 |
| City | 50 | 38 to 63 | 30 | 23 to 38 |
| Highway | 100 | 75 to 125 | 60 | 45 to 75 |

Each test transmission consists of a short outbound message trigger (OMT), one outbound message and one inbound message of the exact "CATP Message Size" used to predict coverage. When its GPS receiver determines an unsampled test tile has been entered the test tool initiates the test sequence with the OMT. Wait for the outbound message from the fixed end. When the outbound message is received, initiate an inbound message. If the outbound message is not received in an expected time interval, automatically initiate an inbound message.

- If the outbound message is received by the data radio, record the outbound test as “tested”.
- If an outbound message or inbound message is not received after all protocol retries, record the inbound or outbound test as an unsuccessful test.
- The files from the appropriate mobile or portable test and the fixed network application can then be merged, post coverage test, to determine inbound and outbound message success.

### 5.7.2.3.2. Test Results

The coverage criterion allows the failure of up to 100% - Criterion % of all inbound test messages and up to 100% - Criterion % of all outbound test messages from the total number of valid test transmissions for all of the tested tiles. Separately sum the inbound link and outbound link message transmission successes and failures to determine the results of the test. If the inbound link failures represent less than 100% - Criterion % of the valid inbound link test point locations and the outbound link failures represent less than 100% - Criterion % of the valid outbound link test point locations, the test is deemed passed and completed.

If either the inbound or outbound coverage test failures amount to more than 100% - Criterion % of the total number of the valid test tiles, it is suggested that secondary coverage testing be performed to determine the extent of the problem.

### 5.7.2.3.3. Coverage Test Documentation

It is recommended that for each test tile, record test information at both the fixed location and at the test vehicle. Merge the fixed and test vehicle files to create an Inbound file and an Outbound file which contain:

- Test tile identifier (X,Y coordinate)
- Test Location (latitude and longitude)

- Inbound Success (1 for pass, 0 for fail)
- Inbound Sent Time, Inbound Receive Time at fixed end
- Outbound Success (1 for pass, 0 for fail)
- Outbound Receive Time, OMT Sent Time

### 5.7.2.4. Coverage Data Throughput Rate

The purpose of this test is to prove that the measured Average Application Throughput over the radio network should meet or exceed the specified criterion in a specified percentage of the Service Area, e.g. 95%,

During the D-CATP, take measurements uniformly distributed within coverage area. Perform all tests while the system is in an unloaded condition. Limit traffic during the D-CATP to the test radio and a test server that is located within the wired network. This ensures that the tests measure only the latency associated with the wireless network.

Use standard UDP packets of a specified number of bytes to measure the throughput performance in this test using UDP/IP. Store and record all lost packets and the statistics as a result of the coverage testing.

#### 5.7.2.4.1. Coverage Area and Test Point Selection

Divide the predicted coverage area into a grid of uniform sized test tiles per §5.2.1

Select the actual location sampled within a test tile by detection of entering an untested test tile. It is recommended to use a tool that provides a GPS driven map display with the coverage test grid as well as a direct interface to the test radio.

If an area is too small geographically to feasibly be divided into tiles of uniform size, uniformly distributed, determine a smaller number of uniformly sized tiles that is a sub-multiple of the original total. Obtain the total test samples by taking samples in each Test Tile, testing all accessible tiles, and then repeating the test as necessary to obtain the necessary number of samples for the area. Ensure each repetition contains the same number of samples, and tests all accessible tiles.

#### 5.7.2.4.2. Test Procedure

It is recommended that the following be completed before commencing the coverge throughput test:

- The core network equipment is installed and operational. Include gateway(s) between wireless/core networks, test servers, wireless network control and management equipment as appropriate.
- Required backhaul equipment/services have been installed and are operational.

- Wireless network devices have been installed and tested.
- Pre-testing is complete and mutually acceptable to all parties
- Test client configuration has been tested and deemed ready for coverage test
- General drive route(s) have been determined and scheduled
- Test time frames during low vehicular traffic periods have been determined and scheduled
- Internal communications between test teams/test coordinator have been set up
- Any relevant security agencies have been notified

An IP performance measurement tool is recommended for testing (based on an industry accepted tool). The tool should measure throughput in a single direction.

Accomplish the coverage testing using a vehicle utilizing the unit under test, traveling on streets as defined in the D-CATP "Service Area". Upon entering an untested tile in the area under test stop the vehicle at the first safe/feasible physical location and manually initiate the measurement process. Using the IP performance tool first perform a downlink transfer for the specified throughput session (from the test server to test radio) avergaging the downlink application throughput over the sample period. Store the throughput for the sample. Next perform a similar transfer session for the uplink direction (from a test radio to the test server) avergaging the uplink application throughput over the sample period. Store the throughput for the sample. Use the stored uplink and downlink average application throughput measurements for for the acceptance test calculations. Store the GPS location for later analysis in the test tool. Upon completing and storing the throughput measurement, move to the next test tile. Consider failure to establish a connection a failed tile.

#### 5.7.2.4.3. Test Results

Summarize the test results:

- Uplink: The Application Throughput Coverage Percentage meets or exceeds the uplink throughput specification.

- Downlink: The Application Throughput Coverage Percentage meets or exceeds the downlink throughput specification.

Adjust the coverage area's specific acceptance criterion based on the statistical margin of error. For example, if the system's passing criterion is 95%, and the error margin for the zone was ± 0.5%, the passing criterion for the zone would be ≥94.5%.

It is recommended that a Coverage Test Log be completed on a daily basis by each test team. In the event a test tile is inaccessible, document the x, y test tile coordinate and document the reason for not testing (e.g. no road, fence blocking road, washed out road). [§5.5.4]

Using the Test tool, capture the received signal strength (RSSI) from the test radio once every second. The subscriber RSSI values can then be averaged based on the length of the sample time. The RSSI value is the signal strength which is received by the subscriber, regardless of whether the measurement is for uplink or downlink.

Calculate the error rate of the radio channel via the IP performance tool. An application can count the number of lost packets in the transfer, and provide this number as well as expresses the number as a percentage of all packets during the transfer period. Capture the metric using the Test tool and store for later analysis. Use Equation (7) for BER and Equation (8)  for PER.

$$BER = \frac{\sum_{t=start\,time}^{stop\,time} bit\,errors}{8 \times \sum_{t=start\,time}^{stop\,time} byte\,count} \tag{7}$$

$$PER = \frac{\sum_{t=start\,time}^{stop\,time} packet\,errors}{\sum_{t=start\,time}^{stop\,time} packet\,count} \tag{8}$$

Immediate location values can be captured by the Test configuration tool during the measurement. Based on GPS or Dead Reckoning information or both, the current geographical position can be determined. Correlate each coverage/throughput measurement to a geographical location.

Additionally, separate test results maps can be useful in depicting the following:

- Mean uplink throughput for each test location
- Mean downlink throughput for each test location
- Mean round trip latency measurement for each test location
- Median downlink RSSI for each test location

#### 5.7.2.4.4. Test Documentation

Include the configuration of the test devices as part of the D-CATP results documentation.

- Radio Node Settings
- Test configuration UDP settings
- Mobile/portable test configuration nominal power level

Provide the results of each test in a database file to include:

- Immediate location of each test point (latitude/longitude in decimal degrees)
- Mean uplink throughput at each tested location
- Mean downlink throughput at each tested location
- Median RSSI reading at each tested location
- Number of lost datagrams at each test location (error rate)
- A calculation of the Application Throughput Coverage Percentage

### 5.7.2.5. Motion Throughput Test

The motion throughput test is to demonstrate that the defined application meets the throughput requirements for a single vehicle in motion at specific speed ranges, over the service area.

Take application throughput measurements while in motion, with test points uniformly distributed within the service area. Perform all tests while the system is in an unloaded condition. Limit only test devices in the area during the time of acceptance testing.

Accomplish the motion testing in a vehicle utilizing the subscriber, traveling on streets as defined in the Acceptance Test Plan Definition “Service Area”. Perform the motion throughput test as conditions and traffic laws permit. When the test vehicle enters a tile in the area under test, automatically initiate the measurement process. Each measured throughput sample ought to correlate to a beginning and ending location, tile ID, and median speed. Store this data for later analysis.

#### 5.7.2.5.1. Results, Post-Processing

Sort the measurements and median speeds into multiple speed ranges as indicated in Table 6. Review the number of samples per tile per speed range to ensure that the correct number of samples has been taken. If so, the tile can be marked as complete for that speed range. Update the Test configuration tool(s) to reflect all completed tiles for each test range. A separate mobile and Test configuration test kit might be required to test each speed range.

Test results are considered valid when the appropriate number of tiles has been sampled, and the appropriate number of subsamples within each tile has been taken.

Include in the test data:

- UDP Settings
- Application throughput for each speed range
- Percent of lost datagrams for each speed range

Capture and log location valuesbased on GPS and/or Dead Reckoning information in order to determine the current geographical position. For motion testing, log the beginning and ending geographical location, to allow the establishment of a location segment. Each throughput measurement ought to be correlated to a geographical location segment.

Capture the speed during the throughput sample and the median speed at the end of each sample period. This can be used to sort the throughput measurements by speed range.

The error rate of the radio channel can now be calculated by counting the number of lost packets in the transfer, expressed as a percentage of all packets during the transfer period. Once calculated, log these metrics for later analysis.

Since variability in speed is to be expected during the sample periods, calculate the median speed over the sample period and store it for post analysis. Sort each sample by speed range. Average together all uplink samples and downlink samples within each speed range to produce a single application throughput for each speed range.

**Table 6 *DTR Sample Speed Ranges***

| Range | Speed (km/hr) | Speed (mph) |
|---|---|---|
| 1 | 8-32 | 5-20 |
| 2 | 32-56 | 20-35 |
| 3 | 56-80 | 35-50 |

Calculate and tabulate the average application throughput per speed range. For example, if the system is designed for a coverage reliability of 95%, it is possible that 5% of the locations exhibit throughput that are less then the passing acceptance criteria. Therefore, in each speed range, exclude the samples exhibiting the lowest 5% application throughput values from any further calculations. Average the highest 95% of the measurements to determine an Average Application Throughput result for each speed range.

### 5.7.3. Local Conformance Measurements

#### 5.7.3.1. Local Median/Local Mean

Because of the possibility of limited dynamic range the local median of a signal is preferred to the local mean as the statistical measure of the signal strength. Where dynamic range is not a concern, the local mean can be used. The upper and lower deciles and standard deviation of the samples can also provide useful information as to the character of the signal distribution. Characterization of these parameters is not usually necessary at each test sample location. Subsampling to perform these measurements ought to use a receiver calibrated at its antenna port. The use of a mean power value generally needs a detection system possessing either a linear or logarithmic transfer function. Alternately, if the transfer function of the detection system is known, but is non-linear, a suitable set of correction factors can be developed and applied to correct the non-linear ranges of the transfer function.

#### 5.7.3.2. Determination of the Local Median

A simple method of measurement to determine the value of a desired signal median value over a prescribed area is provided, to determine if a victim system (system receiving interference) has a prescribed median signal level sufficient to be guaranteed resolution by the local interferers without any additional system changes on the victim system's part in a post rebanding environment.

Recommendations include:

- Simple tests increase the probability that it will be used.
- Tests ought to have a scientific basis.
- Results ought to be repeatable (although they can change over longer periods of time)
- After measured data collection is completed the benchmark values can be determined by software evaluation of the measured data.
- Testing ought to cause minimal disruption of services and be conducted during periods of normal to high traffic conditions.

To minimize the number of tests, a first test to determine if additional tests will even be necessary can be conducted. It will measure the RSSI $(C+I+N)$. If a victim system's radio will operate (unmutes) in the local area being tested, then it can be concluded that the value of $C$ is greater than $(I+N)$. It is recommended that a test tone or some modulation be provided so that a receiver unmute can be audibly verified[10]. Since the maximum difference between $C$ and $(I+N)$ has to be large enough to allow the radio to unmute, then the error in measuring the criterion has been met. However, if the results do not meet the target, then conduct a second test of $(I+N)$ to permit a more accurate determination of the local median value of the desired signal. If the computed median value of $C$ is within 2 $dB$ of the

[10] Prior to any testing the unmuting capability verify the C/N threshold.

target, optioinally perform a second *(I+N)* test to determine that the value of *(I+N)* hasn't changed during the testing.

It is possible that the value of *C* cannot be computed due to high *(I+N)*. If this is the case, then a third test is necessary. For the third test turn off all potential interference sources. This test is more disruptive which is why it is left as the last alternative. Figure 5 shows a flowchart of the potential tests. The values listed represent the recommended values after the rebanding of the 800 MHz band.

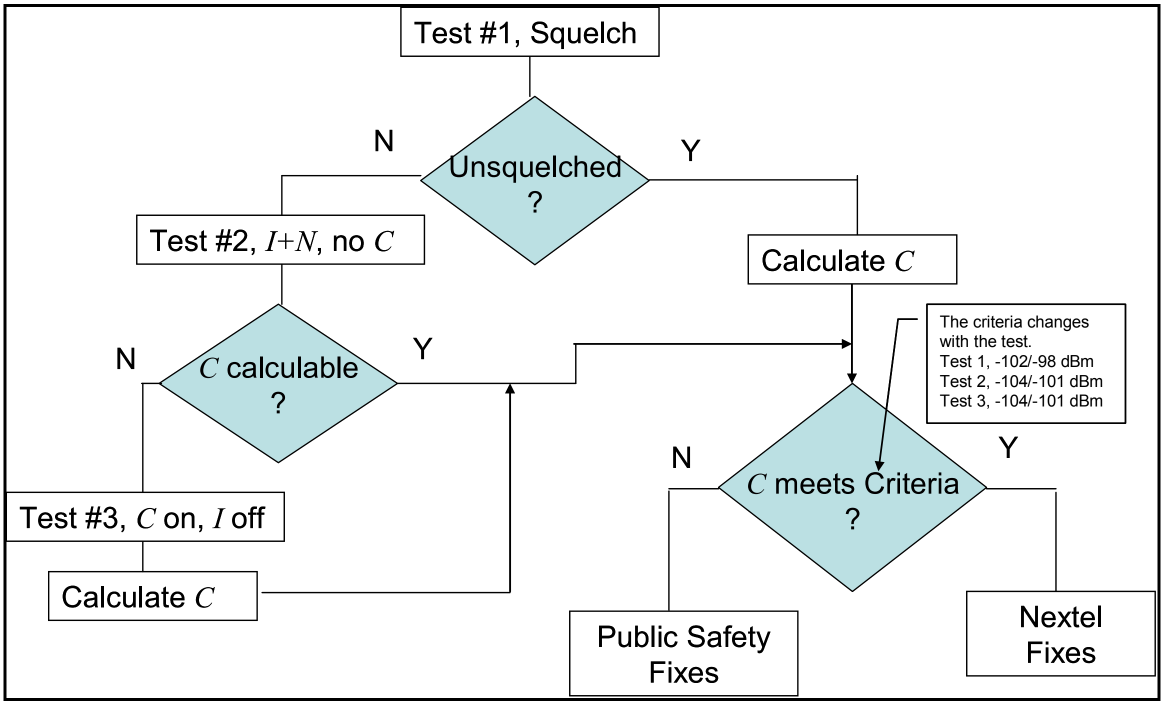



**Figure 5 - Local Median Testing Flowchart**

The sequence of tests allows a preliminary determination of the median desired signal level without requiring that base transmit frequencies be taken out of service. More exhaustive troubleshooting testing might necessitate that the interfering emitters be turned off. This normally requires late night testing which might not be appropriate if the interfering emitters are not active due to reduced traffic loading during late night testing. The *(I+N)* testing can be done during normal business hours, as only one channel at a time needs to be taken out of service on the victim's system.

#### 5.7.3.2.1. Test Receiver Calibration.

1) Calibrate the test receiver's RSSI.

2) The receiver test setup can be configured including a band-pass or low pass filter. A band pass or low pass filter is necessary to minimize the potential of receiver intermodulation that could occur. The filter ensures

that only signals from the desired system and the Carrier's OOBE are measured.

3) Configure the test receiver with the appropriate filter. Using a signal generator accurate to ± 0.5 *dB* prepare a calibration table of RSSI vs. actual signal strength, (as measured at the output of the antenna[11]) every 5 *dB* from the minimum detectable signal up to at least -70 *dBm*. This table will be utilized to convert the RSSI readings into actual received signal levels at the output of the test half wave dipole antenna.

4) Verify that the receiver unmutes with a properly modulated signal approximately 5 *dB* above the receiver's inferred noise floor, (5 *dB* $C_s/N$). This will normally be the case with digital (P-25) receivers. Analog receivers ought to have their squelch adjusted to open at 5 *dB* $C_s/N$. This will be slightly better than 12 *dB* SINAD in the non NPSPAC portion of the band and 12 *dB* SINAD in the NPSPAC portion.

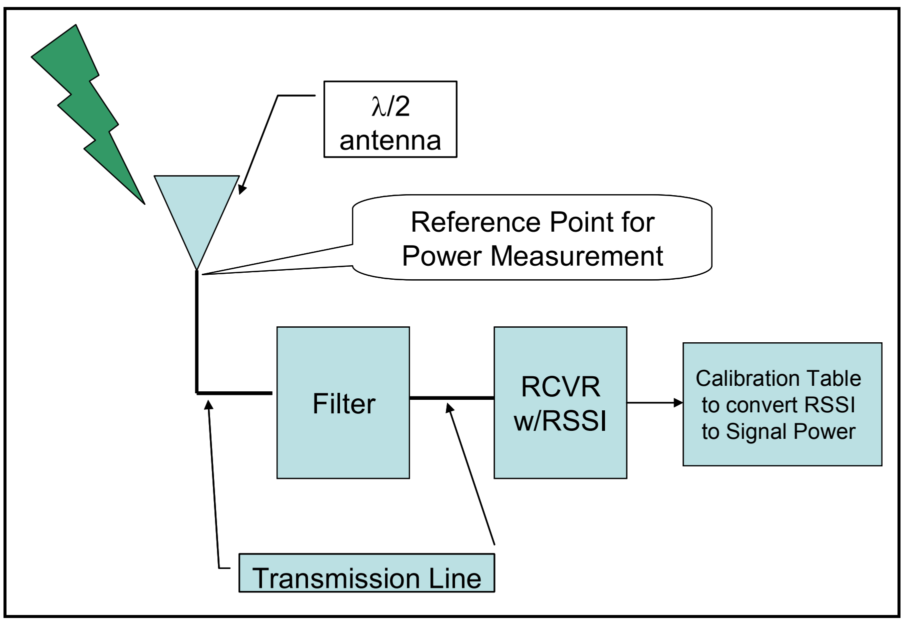



**Figure 6 - RSSI Calibration**

#### 5.7.3.2.2. Define Test Area

1) Determine the size of area to be tested. A minimum area of 3 arc seconds by 3 arc seconds[12] is recommended, centered on a known problem location. Local obstructions can determine the size, as well as how large

[11] Use a half wave dipole antenna.
[12] Three arc seconds is equal to 303.6 feet in the North-South dimension and 303.6*Cosine (Latitude) in the East-West dimension, 200 to 276 feet in the conterminous USA. A 100 m by 100 m area is recommended.

the reported affected area is. If the affected area is quite large, a location of reported problems ought to be selected near the center of the affected area.

2) It ought to be large enough to be consistent with coverage predictions and regulatory field strength ($dB\mu$) contour limitations.

3) The data points ought to be relatively uniformly distributed across the area being tested.

4) To the extent practical, maintain a constant velocity along the route to prevent over- sampling in any given location. Alternatively, means can be incorporated into software to address this issue.

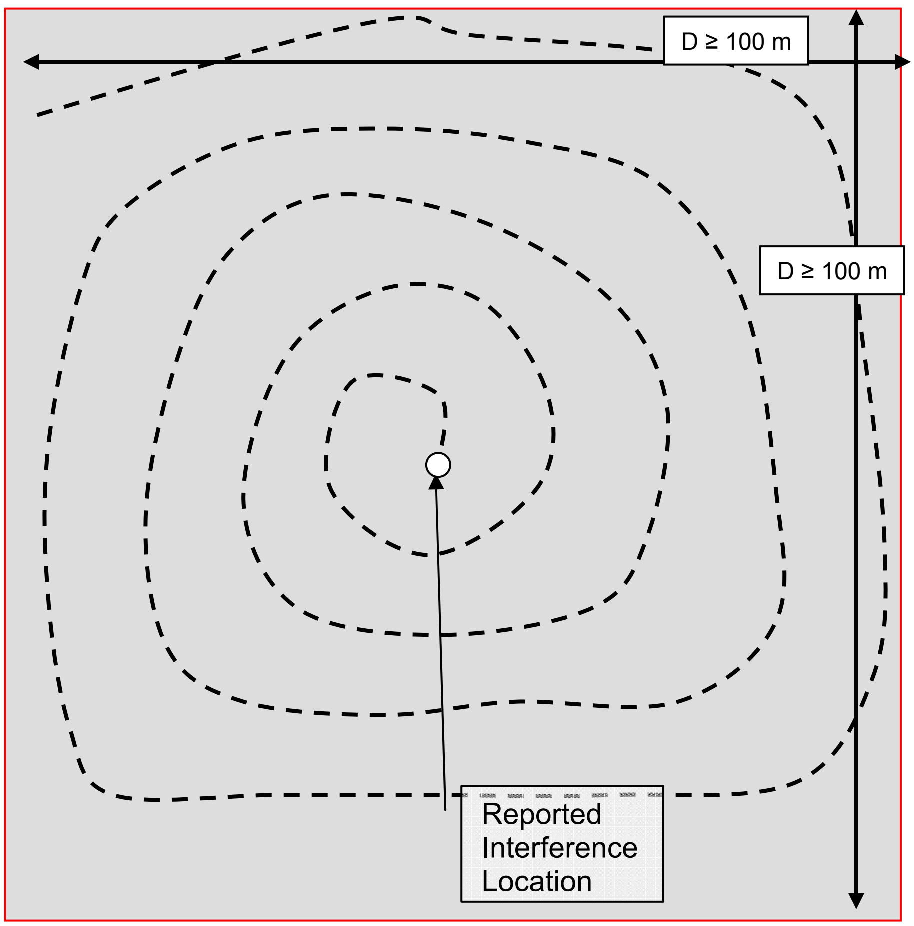



**Figure 7 - Example Measurement Route**

Figure 7 is an example of a simplified route. Local obstructions and access can limit the route. It is important to develop the route so that no one portion is overly represented in the measured data.

#### 5.7.3.2.3. Test 1, (C+I+N)

1) Modulate the desired channel with a test signal to audibly verify that if the radio is unmuted.

2) Determine the specific value for the victim radio type.

a) For digital radios this is approximately 5 *dB C/(I+N).*

b) Analog radios ought to have their manual squelch set for a *C/(I+N)* of 5 *dB*.

3) With all appropriate channels transmitting constantly, gather "continuous" data over a route that covers the prescribed area[13]. This is measuring *(C+I+N)*

4) Gather data points at a relatively constant speed[14] following a route that covers the prescribed area. See Figure 7.

5) If the test receiver has AFC, disable it so it remains on the test frequency and is not "pulled" toward the interfering emitters signal.

6) From the data, determine the median *(C+I+N).*

a) If the median *(C+I+N)* is more than 2 *dB* greater than the median target value and the receiver was unmuted, then the "threshold test" is considered a pass and no additional testing is necessary.

b) If the median *(C+I+N)* is **not** more than 2 *dB* greater than the median target value, and the test receiver did not unmute or was intermittently unmuted, perform Test 2.

#### 5.7.3.2.4. Test 2, (I+N only)

This test is to determine the level of interference present so that it can be subtracted from the total signal level measured in the previous tests. Run this test under the same conditions as test 1

1) Utilize the same route through the test area as in the previous tests along with the same number of samples to the extent possible.

2) With the desired signal not transmitting but with the potential interfering carriers present, measure the signal level in the test area and determine the median signal level of (*I+N*).

3) Subtract the median level of this test's *(I+N)* from the median level of the *(C+I+N)* measured in Test 1. ((*C+I+N*) - (*I+N*)). This will yield the true

[13] Use a sampling rate frequent enough to capture multiple samples per wavelength

[14] To the extent practical, maintain a constant velocity along the route to prevent over-sampling in any given location. Alternatively, means can be incorporated into software to address this issue.

value of the signal level (*C*). If the resulting value is close to the criterion value, repeat the test 2 as necessary until a high confidence in the value is obtained. In certain cases, e.g. the (*I+N*) might be so strong that *C* cannot be determined. When this condition exists use test 3.

a) If the calculated median *C* is close to the target value, an additional test, repeating the *(I+N)* test can optionally be performed to ensure that the *(I+N)* has not changed. The route would be the same as used in step 4a) above.

b) If the two calculated values are within ± 3 *dB*, then combine the *(I+N)* data files to determine the median *C*.

c) If the two calculated values are different by ≥ ±3 *dB*, run test 2 a third time and combine the closest two *(I+N)* data files to determine the median *C*.

#### 5.7.3.2.5. Test 3, *(C only)*

This test will be necessary if the value of *C* could not be determined in Test 2.

1) Arrange for all the Carrier's transmitters in the vicinity to be shut down. Insure that the desired signal is present.

2) Retrace the previous route through the test area collecting, as practical, the same number of samples as in previous tests.

3) With only the desired signal present, measure the signal level in the test area and determine the median signal level. The receiver ought to remain unmuted throughout this test.

4) If the measured median power level is greater than, or equal to, the test criteria and the receiver is unmuted, the system has met the protection criteria and is eligible for interference mitigation.

#### 5.7.3.2.6. Example Calculations

- Median (*C+I+N*) = -98 *dBm* [1.585E-13 Watts]
- Median (*I+N*) = -110 *dBm* [1.0E-14 Watts]
- *N* is constant = -124 *dBm* [3.981E-16 Watts]

From this data, the value of *I* can be calculated:

- ***I+N*** = -110 *dBm* (1.0E-14)
- ***N*** = -124 *dBm* (3.981E-16)
- ***I*** = 100E-16 -3.981E-16) = 96.019E-16 (-110.18 *dBm*)[15].

- ***C*** = 1,585E-16 - 96.019E-16 = 1,488.981E-16 = **-98.27 *dBm***

[15] This step is optional but may provide additional information about the interfering emitter(s).

Comments:

- The *(I+N)* might not be constant due to interfering emitters being intermittently active. This is the reason for the short time difference between the (*C+I+N*) measurement and the *(I+N)* measurement.
- The purpose of an external test receiver filter is to minimize receiver IMR from being included in the measured data. This facilitated using various test receivers. A minimum receiver IMR specification of ≥ 70 *dB* is recommended. If a lower receiver IMR value is used, add additional attenuation of potential IM generating signals as necessary.
- The test antenna is a half wave dipole.
- Calibration is to the output of the test antenna. This compensates for the filter insertion loss and cable losses.
- AFC could have the undesired effect of locking onto the interferer and producing invalid measurements. If applicable, disable the AFC function.
- If the measured value of *C* is within 3 *dB* of the prescribed value, optionally rerun the (*I+N*) test over the same route to confirm that the measured median (*I+N*) is still valid (no significant change). See test 2, step 3 above.
- The median value rather than the mean value is used due to potential RSSI upper and lower limits. These limits would invalidate a mean value, §5.7.1.1.
- Receiver calibration methodology is, §5.7.3.5 -5.7.3.7. See also [845], § 4, “Signal Strength Measurement” and its associated sub clauses.

### 5.7.3.3. Alternative Local Median Determination by Measuring BER%

For a digital system, (*C+I+N*) RSSI and BER% can be measured simultaneously. This provides more precise information about the median *C/(I+N).* Different receivers of the same model and manufacturer could have slightly different characteristics. Individual receiver calibration is necessary to mitigate differences.

Measure the static BER% of the test receiver using normal test equipment. The reference sensitivity value allows the receiver’s noise floor to be calculated based on the static *C/N* in Table A -1. Add the $C_f/N$ to the calculated noise floor to determine the faded sensitivity for the receiver. For example, if the 5% BER is -120 *dBm* for a C4FM receiver then the noise floor of that receiver is -127.6 dBm (-120 *dBm* - 7.6 *dB*). From Table A -1, add the $C_f/N$ necessary for a C4FM receiver, 2% BER (DAQ 3.4), $C_f/N$ = 17.7 *dB*. Thus the *C* to achieve 17.7 dB $C_f/N$ is -109.9 *dBm* (-127.6 dBm + 17.7 *dB*).

If the criterion is a 20 *dB C/(I+N)*, use the 1% faded BER for C4FM.

The process of determining if 1% BER is achieved in the local area determines that the desired *C/(I+N)* is being achieved.

This test provides a better understanding of the root cause interference mechanism. If *(C+I+N)* is large, but the BER% increases, the *(I+N)* component is increasing, §5.11.

### 5.7.3.4. Talk-Out vs. Talk-In Testing

Conformance testing need only be done in the Talk Out (outbound) direction. Use a calculated offset correction value to evaluate talk in (inbound) performance when reciprocity is applicable. If there is a large difference in height between the site's transmit and receive antennas, the assumption of reciprocity probably is invalid. The additional expense and complexity of a talk in test might be justified in the following cases:

- Antenna distortions due to antenna support structure
- High ambient noise levels at site or in field
- Different Selectivity or Mode for Talk Out (down link) and Talk In (up link)
- Diversity
  - Macro (Voting)
  - Micro (On Site Receiver Combining)
- Different Horizontal Antenna Patterns
- Trunked Systems with adjacent channels assigned to other systems near the edge of the Service Area[16].

### 5.7.3.5. Calibration of a CPC Evaluation Receiver

Calibrate a CPC evaluation receiver to its antenna input port using a signal source whose absolute level accuracy is specified as within ± 0.5 $dB$. Compensate for coaxial cable losses in the calibration process. The calibration signal source ought to have been calibrated within the time interval recommended by its manufacturer, but in no event more than one year prior to calibrating the test receiver. Prior to calibrating the CPC evaluation receiver, warm up the calibration signal source according to its manufacturer's recommendation for guaranteed amplitude accuracy[17].

The available output RSSI can change on some test radios when their supply voltage approaches a critical value, e.g. 11.5 Volts. The RSSI value can vary over the test receiver's frequency band. The same radio's RSSI calibration can also vary at low RSSI values due to low signal levels providing random noise a greater influence of the reported value. It is recommended that the RSSI calibration be performed multiple times to average the noise's effect.

---

[16] **Caution:** While this may be acceptable for talk-out, talk-in may still be problematic unless additional measures to reduce adjacent channel coupled power (e.g. automatic subscriber output power management, reduced carrier deviation) or network design attributes (e.g. satellite receivers - macro diversity) are employed to mitigate potential interference. The potential for this to occur is raised for trunked systems as the control channel may be interference free while an assigned traffic channel may have an adjacent channel. The extension of the field strength restrictions to 3 or 5 miles (depending on the Regional Frequency Plan) and high ACPR values can create cases where the Near/Far problem in the talk-in direction is increased.

[17] *TIA/EIA-845, ""* provides comprehensive information on calibration, data gathering and data formats.

In summary, for each test radio:

- Vary the supply voltage to determine any critical minimum value that must be maintained.
- Calibrate the receiver for its specific test frequency.
- Perform multiple calibrations and average them.

When BER is the criterion, add attenuation to the CPC evaluation receiver so that its reference sensitivity is obtained at its specified power level. This is necessary to prevent a very sensitive receiver from biasing the test results. When received power is being measured, it is unnecessary to derate a receiver to its simulated test reference sensitivity.

#### 5.7.3.6. RSSI Mobile

Using a substitution method, the loss of the calibration coaxial cable can be measured and the receiver calibration table adjusted to represent the median signal strength necessary to produce RSSI (Received Signal Strength Indicator) indications over the dynamic range of the RSSI circuit. The recommended maximum step size is1 $dB$ from the RSSI threshold for 20 $dB$, then 2 $dB$ size steps for 20 $dB$, and 5 $dB$ steps thereafter. Local Mean Power is measured with a receiver calibrated at its antenna port. The use of a mean power value generally necessitates a detection system possessing a linear or logarithmic transfer function. Alternately, if the transfer function of the detection system is known but is non-linear, a suitable set of correction factors can be developed and applied to correct the non-linear ranges of the transfer function.

#### 5.7.3.7. RSSI Fixed End

Using a substitution method, the loss of the calibration coaxial cable can be measured and the receiver calibration table adjusted to represent the median signal strength to produce RSSI indications over the dynamic range of the RSSI circuit. The recommended maximum step size is 1 $dB$ from the RSSI threshold for 20 $dB$, then 2 $dB$ size steps for 20 $dB$, and 5 $dB$ steps thereafter. Local Mean Power is measured with a receiver calibrated at its antenna port. The use of a mean power value generally necessitates a detection system possessing a linear or logarithmic transfer function. Alternatively, if the transfer function of the detection system is known, but is non-linear, a suitable set of correction factors can be developed and applied to correct the non-linear ranges of the transfer function.

When a receiver multicoupler feeds a receiver or has a tower mounted preamplifier installed, create a calibration curve to compensate for the additional gain and the resultant amplified noise. This is a not practical procedure as injecting signals at the amplifier input can interrupt service for other receivers. A Noise Gain offset to calibrate the RSSI can be applied, but the weak signal region could necessitate a separate calibration.

The RSSI Noise offset consists of the Surplus Gain, the overall gain between the first amplifier input and the subsequent losses prior to the input of the test base receiver, less the Effective Multicoupler Gain (*EMG*). This is the effective improvement in reference sensitivity between the input of the first amplifier stage and the reference sensitivity of the base receiver alone.

RSSI Noise Gain Offset = Surplus Gain - *EMG* (9)

EMG = Reference sensitivity at first amplifier input - base reference sensitivity w/o amplifiers, but with amplifiers providing their noise contribution. This necessitates a directional coupler methodology for measuring the effect of the base receiver. Referring to Figure 8:

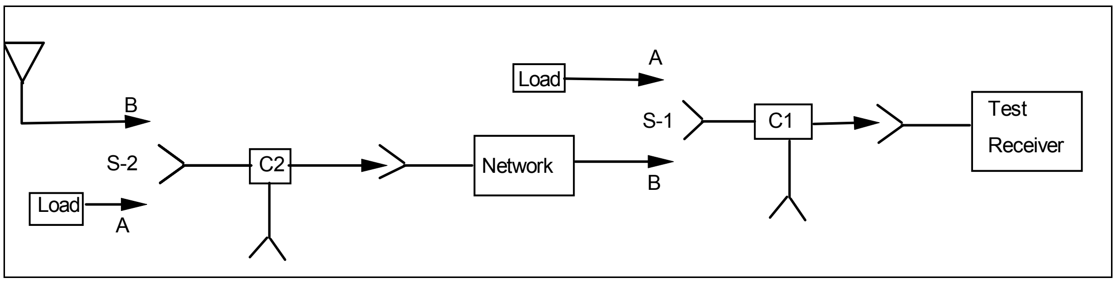



**Figure 8 - Multicoupler Calibration**

a) Measure and record the test receiver static reference sensitivity through a calibrated directional coupler, C1, with its input terminated in 50 Ω, S-1 to A. Record the insertion loss of the calibrated directional coupler C1.

b) Repeat and record the measurement through directional coupler C1 with its input port connected to the amplifier chain, S-1 to B and S-2 to A, terminated in 50 Ω .

c) Measure and record the test receiver static reference sensitivity through the calibrated directional coupler C2 with its input terminated in 50 Ω, S-1 to B, S-2 to A. Record the insertion loss of the calibrated directional coupler C2.

d) Calculate the *EMG*, Step (a) power minus Step (c) power, both corrected for coupler insertion losses.

e) Calculate the Total Gain, Step (b) power minus Step (c) power, both corrected for coupler insertion losses.

f) Calculate the RSSI Noise Gain Offset. Step *(*b) power minus Step (a) power, both corrected for coupler insertion losses. This ought to equal the difference calculated in step (d) and (e).

g) Calibrate the RSSI by normalizing the input power level at C1 to that of a receiver that isn't connected to a multicoupler scheme. This would necessitate that the "normalized" input power be Greater than the reference sensitivity by the RSSI Noise Gain Offset in *dB*.

For example, assume that the reference static sensitivity is -119 *dBm*, the *Cs/N* is 7 *dB* which infers that the noise floor of the receiver is -126 *dBm*. The corrected measurement a) would be -119 *dBm*. Corrected Measurement b) is -115.3 *dBm* and corrected measurement c) is -123.3 *dBm*. From this measurements, the *EMG* is (-119 -(-123.3)) = 4.3 *dB*. The Total Gain is (-115.3 - (-123.3)) = 8 *dB*. The RSSI Noise Gain Offset is (-115.3 - (-119)) = 3.7 *dB*. Thus the receiver needs a -115.3 *dBm* signal power to produce the same reference performance as a -123.3 *dBm* signal would at the input to the first amplifier. Thus by injecting the calibration signal at the input of the receiver at the RSSI Noise Gain Offset value, it is equivalent to injecting a signal at the input of the first amplifier which is *EMG dB* greater than the reference sensitivity of the receiver by itself, which isn't always practical when a system is in service.

## 5.8. Symbolic RF Noise Modeling and Simulation Methodology

### 5.8.1. Receiver/Multicoupler Interference

Receiver intermodulation effects are rarely considered in system interference. When a tower mounted amplifier or tower mounted amplifier and amplified receiver multicoupler are used they can dramatically increase the link margins, but increase potential intermodulation that can be detrimental.

The amount of gain provided has a direct impact on the overall noise figure of the cascaded combination of elements and on the intermodulation performance. As linear systems come into existence an increased awareness of the tradeoffs is necessary to more accurately calculate the effect. Adding gain without determining its overall effect on the system performance and interference potential is a practice to be avoided.

Some base stations specify the performance sensitivity at the input to the receiver multicoupler. Most base stations receiver noise figures fall between 9 and 12 *dB*, with a typical design noise figure of 10 *dB*. The overall receiver multicoupler scheme has a composite noise figure of between 5 and 7 *dB*, with 6 *dB* being a typical design value. With an amplifier noise figure of 4 *dB*, 25 *dB* of gain, 16 *dB* of splitting loss and one *dB* of cable loss, the resulting noise figure of the cascaded chain can be calculated using equation (10):

$$NF_C = NF_1 + [NF_2 -1]/G_1 + [NF_3 - 1]/[G_1 \bullet G_2] \tag{10}$$

Where:

$NF$ is the Noise Factor (*numeric*)

$G$ is the Gain of an Amplifier (*numeric*)

$NF_1$ = 4.0 *dB* = ***2.5***. $G_1$ = 25 *dB* = ***316***

$NF_2$ = 17 *dB* = ***50*** $G_2$ = -17 *dB* = ***0.02***

$NF_3$ = 10 *dB* = ***10***

$NF_C$ = 2.5 + [50 -1]/316 + [10 – 1]/[316 x 0.02] = 4.08 = 6.1 $dB$

The generalized form of Equation (10)[18] is:

$$NF_C = NF_1 + \sum_{i=2}^{n} \frac{NF_{i-1}}{\prod_{j=1}^{i-1} G_j} \qquad (11)$$

From this example, the overall noise figure of the combination is improved over the base station receiver by itself but degraded from the noise figure of the multicoupler amplifier. By increasing the gain of the amplifier, and reducing the loss in the splitter, the cascaded noise figure trends toward the noise figure of the multicoupler. However, all the excess gain tends to increase the level of intermodulation products for components down stream. With linear systems, a specification that limits the amount of “excess gain” that can be introduced prior to the base receiver could be necessary to keep the entire system operating within a linear region.

To determine the absolute power level of the intermodulation products makes the use of the Third Order Intercept point ($IP^3$) necessary. Considerable confusion exists around the $IP^3$ due to manufacturers’ specmanship. Most manufacturers use the Output Third Order Intercept Point ($OIP^3$) as it produces a higher number. Reducing the manufacturers $OIP^3$ by the gain of the amplifier calculates the Input Third Order Intercept Point ($IIP^3$). This is more useful as one can now determine the intermodulation products with respect to the desired carrier and design noise threshold, adjusting absolute levels by selecting gain and loss elements.

[18] Known as Friis Equation

## 5.9. Interference Effects

Interference power is included in measured data. For analog receivers, the power measured includes all sources of power. This can include undesired interference components as well as the desired signal level.

### 5.9.1. Intermodulation

A receiver with an 80 *dB* Intermodulation Rejection (IMR) has an $IIP^3$ in the 0 to +5 *dBm* range[19]. To measure the IMR[20], start with the static sensitivity criterion, such as 12 *dB* SINAD, $C_s/N$ = 5 *dB* for an analog FM radio with ±4 kHz deviation. The desired signal is increased by 3 *dB* and two interfering signals are injected. One, *Pa*, is the closest offset channel and the other, *Pb*, is the furthest offset channel. In this case, 2 times the closest channel, minus the furthest channel creates a product that falls back on the same frequency as the desired[21]. The two signals are increased at the same level until the 12 *dB* SINAD performance specification is again reached. The difference between the equal levels of the intermodulation signals and the original reference is the IMR of the receiver.

In Figure 9, if the IMR specification is 80 *dB*, and the 12 *dB* SINAD is -119 *dBm*, (0.25 μV); the following test would be conducted. Inject -119 *dBm* and measure 12 *dB* SINAD.

For this example, the inferred design noise threshold is -124 *dBm*. Increase the desired signal level to -116 *dBm*, a 3 *dB* boost. Inject the two IM producing channels; increasing them until 12 *dB* SINAD is once again obtained. With a receiver of 80 *dB* IMR, these IM source channels will be 80 *dB* above the 12 *dBS*, -39 *dBm*. This once again produces a $C_s/N$ of 5 *dB*, 12 *dBS*, comprised of the -124 *dBm* design thermal noise and another -124 *dBm* noise equivalent from the interference from the IMR. The combined noise sources equal -121 *dBm* versus the desired signal at -116 *dBm*. Figure 9 illustrates a graphical solution for the $IIP^3$ of +3.5 *dBm*. Two slopes are constructed, a 1:1 relationship from the design noise threshold and a 3:1 slope for the third order products offset by (80 + 5) 85 *dB* at the design noise threshold. The equation for this relationship is:

$$IMR = 2/3\,(IIP^3 - Sens) - 1/3\,(C_s/N \text{ @ Sens}) \qquad (12)$$

In this example, sensitivity for 12 *dB* SINAD was -119 *dBm* with a $C_s/N$ of 5 *dB*. If the *IMR* is 80 *dB*, the $IIP^3$ is = +3.5 *dBm*.

---

[19] The value depends upon the reference sensitivity and Cs/N at reference sensitivity.
[20] [603], §2.1.9.
[21] The narrow band offset channel spacings per [603], [102.CAAA], [905.CAAA] are 50 kHz/100 kHz. The wide band offset channel spacings per [902.CAAB] & [902.BBAB] are 600 kHz/1.2 MHz.

The preceding calculation was for a single receiver. The process becomes more complex when a receiver multicoupler is cascaded with the receiver. The $IIP^3$ of the receiver has to be known to determine the interaction with the parameters of the receiver multicoupler chain.

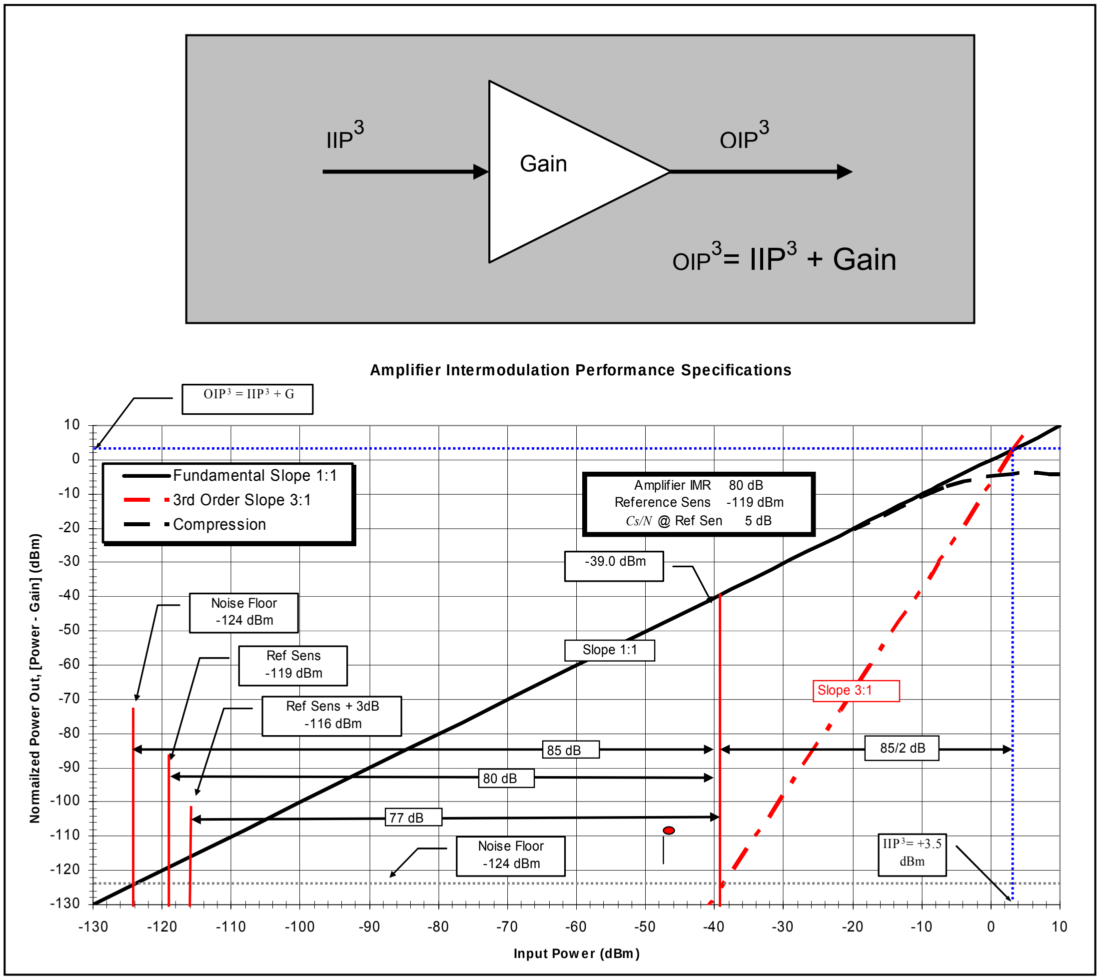
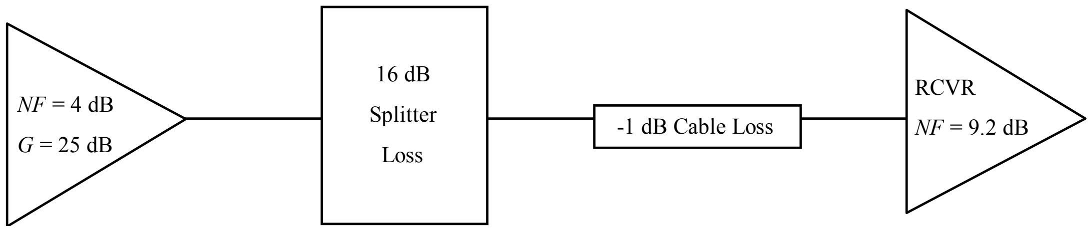



**Figure 9 - Amplifier Intermodulation Performance Specifications**

Receiver multicoupler manufacturers typically use the $OIP^3$ for their specification. Knowing the gain of the amplifier and the splitting losses one can calculate the impact on the desired and undesired portions. This also highlights the case of when there are more than one amplifier in the multicoupler chain and excessive gain inserted to lower the cascaded effective noise figure. This can greatly reduce IMR performance. Tower top amplifiers normally involve three stages, the tower top amplifier, a distribution amplifier and the actual receiver.

An example can illustrate the issues. Consider the previously described base station configuration with a receiver multicoupler. The parameters and lineup are shown in Figure 10. The base receiver noise figure is calculated to be 9.2 $dB$, based on 12 $dBS$ = -119 $dBm$, $C_s/N$ = 5 $dB$ and an *ENBW* = 12 kHz.

The receiver multicoupler has 25 *dB* of gain and 17 *dB* of losses prior to the receiver's antenna port. The amplifier's $OIP^3$ is given as +34 *dBm*. Subtracting the gain calculates an $IIP^3$ of +9 *dBm*.




$NF_1$ = 4 *dB* = 2.51     $G1$ = 25 *dB* = 316

$NF_2$ = 17 *dB* = 50     $G2$ = -17 *dB* = 0.02

$NF_3$ = 9.2 *dB* = 8.32

$$NFc = 2.51 + \frac{(50-1)}{316} + \frac{(8.32-1)}{(316)(0.02)}$$

$$NFc = 2.51 + 0.16 + 1.16 = 3.83 = 5.83 \ \ dB$$

$NF_{imp}$ = 9.2 - 5.83 = <u>3.37</u> *dB*

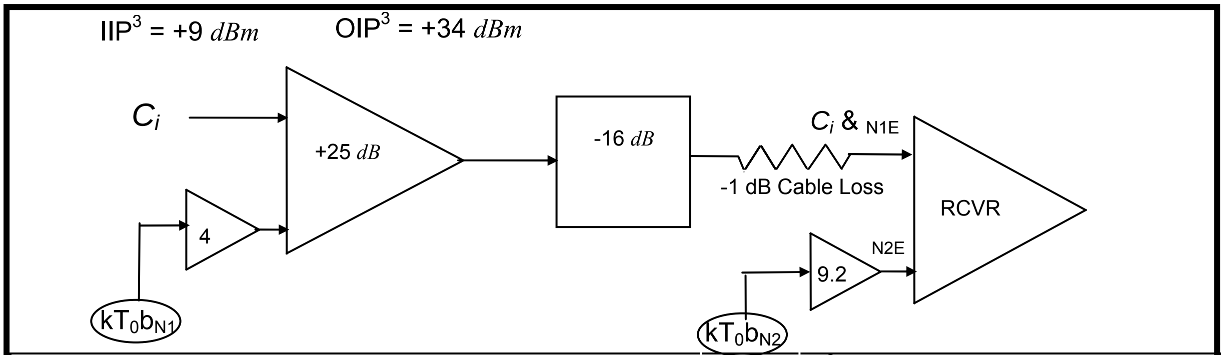
**Figure 10 - Noise Figure Calculation**

The traditional cascaded noise figure approach calculates an effective noise figure at the input of the multicoupler of 5.83 *dB*, producing a 3.37 *dB* improvement in the noise figure for the combination.

### 5.9.2. The Symbolic Method

Symbolically all active devices are shown, in Figure 11, as a single amplifier with some known amount of gain. Inputs to the amplifier include another amplifier which has the gain of the device's noise figure which is fed from a noise source equal to the $kT_0b$ value of the actual receiver. Following the flow from the first amplifier, the noise source is amplified and attenuated until it arrives at the input of the final receiver. In this case the accumulated noise power is -121.2 *dBm*. The receiver has its own noise source which is -124.0 *dBm*. The sum of these two noise sources is -119.37 *dBm*. To achieve a $C_s/N$ of 5 *dB* necessitates that $C$ be -114.37 *dBm*. To achieve that power with the given gain and losses would need a -122.37 *dBm* signal at the input to the first amplifier. The receiver's sensitivity, by tself, for a $C_s/N$ of 5 *dB* is -119 *dBm* so the improvement of the combination is

-119 - (-122.37) = 3.37 *dB*, the same as calculated by the cascaded noise figure equation (10). This method works best when attenuators are in the chain. A very small error can occur when this is not the case.




| | | |
|---|---|---|
| *N1E* = -133.2 | N2E = -133.2 | $IIP^3$ = +3.5 *dBm* |
| +4.0 | <u>+9.2</u> | 12 dBS = -119 *dBm* |
| +25.0 | **-124.0 *dBm*** | ENBW = 12 kHz (10.8 *dB*) |
| <u>-17.0</u> | | $C_s/N$ @ 12 dBS = 5 *dB* |
| **-121.2 *dBm*** | | $NF_{dB}$ = 9.2 *dB* |
| | | **$kT_0b$ = -133.2 *dBm*** |

$\Sigma(N1E + N2E)$ = -119.37 *dBm*

$C_i$= [-119.37 + 5] -25 +16 +1 = -122.37 *dBm*

Performance Improvement = -119.0 - (-122.37) = **<u>3.37</u> *dB***

**Figure 11 - Symbolic Method**

This approach allows evaluating the effect of system IMR noise power. Equations (15) and (16) can be used to calculate either a relative or absolute power level for the third order product. First calculate an equivalent signal power level to use in this evaluation. For the classic IMR case as measured by the TIA method, the equivalent signal power $C_i$[22], is:

$$C_i = \frac{2\left(P_a\ Channel\ Pwr\right)+\left(P_b\ Channel\ Pwr\right)}{3} \tag{13}$$

For the TIA test method, both IM offset channels are held at the same power level. However in the field, users frequently have to deal with IMR where the frequency offsets vary and unequal in power. In these cases the equivalent power to use for

[22] All powers are in the same units of *dB* with an absolute reference, typically *dBm*.

$C_i$ would be to consider only the specific case which would be where the two signals have different average powers and the effect of the actual mixing process where one frequency is doubled and the other not, so the resultant power falls into the victim's bandwidth. The example is for third order intermodulation. It is also assumed that the mixer remains constant and that no additional selectivity is available. In this case:

$$C_i = \frac{2(P_a) + P_b}{3} \qquad (14)$$

Where $P_a$ is the power in absolute $dB$ of the signal whose frequency is doubled and $P_b$ is the power in absolute $dB$ of the signal whose frequency is not doubled.

An application with specific frequencies, calculates the interfering carrier levels and the intermodulation power that results for a specific design or problem evaluation. At the input of an amplifier:

$$\text{Relative IM} = 2\ (IIP^3 - C_i) \qquad (15)$$

Where $C_i$ = Equivalent interferer.

$$\text{Absolute IM Level} = C_i - \text{Relative IM} \qquad (16)$$

Combining Equations (16) and (15) plus accounting for the Gains and Losses the result is:

$$\text{Absolute IM Level}_{\text{dBm}} = C_i - 2(IIP^3 - C_i) + (G - L) \qquad (17)$$

Where $C_i$ and $IIP^3$ are in $dBm$ and Gains ($G$) and Losses ($L$) are in $dB$.

In most cases system designers are interested in the level of the IM and can then follow it through the chain of amplifiers and loss elements until it arrives at the input of the last amplifier stage. At the final stage, the individual carriers also will be present and can once again produce IM. The total noise would then be the sum of the individual noise sources and the individual IM products, $C/(\Sigma N + \Sigma IM)$. Continuing with the example, consider the following case.

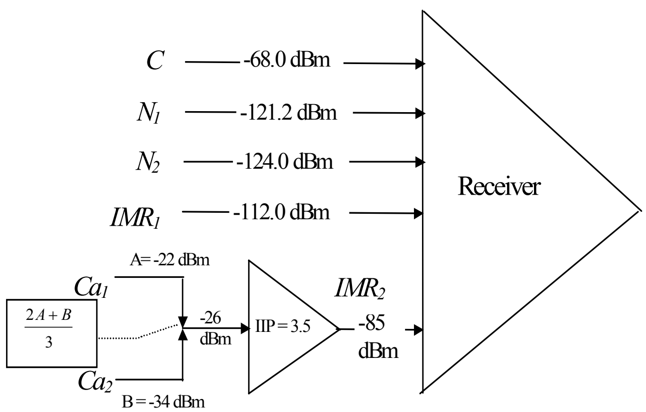
The Adjacent channel power, $C_{a1}$, at the input to our multicoupler amplifier is -30 $dBm$, and the Alternate channel, $C_{a2}$, is -42 $dBm$. This is the classic 2A-B IM case. From equation(14):

$$Ci = \frac{[2(-30) + (-42)]}{3} = -34\ dBm \qquad (18)$$

The $IIP^3$ of the first amplifier is +9 $dBm$. From equation(17), the absolute IM level at the input of the receiver is calculated to be -34 $dBm$ -2(9-(-34)) + 25 -17 = -112 *dBm*. The individual $C_{a1}$ and $C_{a2}$ would be amplified (25 -17) = 8 *dB* to -22 *dBm* and -34 *dBm* respectively. From equation(14), their $C_i$ is now -26 *dBm*.

Using the same 80 *dB* IMR receiver with an $IIP^3$ = +3.5 *dBm* that was previous described, the absolute IM level, using equation (17) calculates the IM noise introduced by the receiver itself to be -85 *dBm*, Figure 12.

There are now five different inputs to the final receiver that impact its performance; the desired $C$, and the four noise sources, $N_1 + N_2 + IMR_1 + IMR_2$. In this example, the IMR due to the high interfering power levels are controlling. In a 25 kHz analog FM system, to achieve a CPC with a DAQ = 3, A -1 [88.1] indicates that a $C_f/(I+N)$ = 17 *dB* is needed, therefore the necessary desired signal level at the input of the receiver is -68 *dBm* or greater. As shown from this example, additional amplifiers in the "gain chain" can amplify high interfering signals to such a high level that IMR in unavoidable. The addition of an attenuator (pad) is recommended to optimize the sensitivity versus IMR performance.




$$\Sigma Ns = N_1 + N_2 + IMR_1 + IMR_2 = -85dBm$$

$$\frac{C}{\Sigma(N + IMR)} \equiv 17dB, \therefore C = -68dBm$$

**Figure 12 - Multicoupler IMR Performance Example**

It is important to remember that there is a probability consideration that has to be included, and that the type of interference also needs to be considered. For example, if the interfering adjacent channel had the same sub-audible signaling, a receiver would unsquelch whenever the intermodulation interference was present even though no desired carrier was present. This would dramatically impact the users perception of the amount of interference.

### 5.9.3. Multicoupler Parametric Values

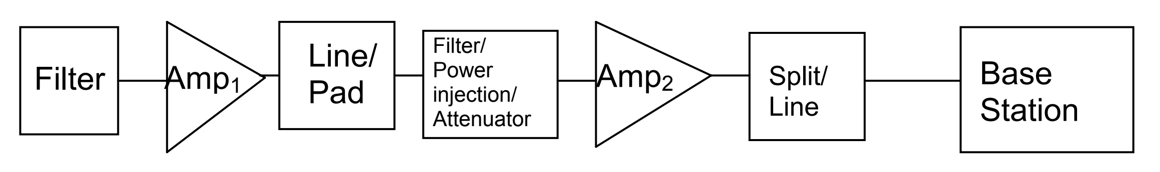
Using the listed parameters, the improvement of the receiver reference sensitivity used in the Noise Figure examples, Figure 10 and Figure 11 are: 2.6 $dB$ using a tower top amplifier; -0.24 $dB$ for a multicoupler only.

Therefore, a simple method for frequency coordination would be to assume the values indicated are typical and that a base sensitivity improvement of +3 $dB$ can be assumed for a tower top amplifier with all transmission line losses eliminated. This is equivalent to having the receiver input at the input to the tower top amplifier and adding 3 $dB$ of increased sensitivity. If the receiver sensitivity improves beyond -119 $dBm$ (0.25 $\mu$V), use the value of -119 $dBm$.

For the receiver multicoupler configuration, the assumption is that the receiver reference sensitivity can be referenced to the input of the receiver multicoupler. This is equivalent to eliminating the receiver line losses between the multicoupler and the receiver being evaluated.

More detailed evaluations could be undertaken if specific values of the parameters are made available by the applicant, or victim, when a proposed coordination is being challenged.

The values in Figure 13 represent common receiver multicoupler deployments to use if specific information is unavailable or the recommendation that the receiver reference sensitivity can be referenced to the input of the receiver multicoupler is unacceptable in a challenge.




| | | | | | |
|---|---|---|---|---|---|
| Filter | Bandwidth | Band of Interest | | | |
| | Insertion Loss | 1.0 *dB* | | | |
| $Amp_1$ | Noise Figure | 3.0 *dB* | | | |
| | $IIP^3$ | +10 *dBm* | | | |
| | 1-dB Compression | -2 *dBm* | | | |
| | Gain | 20.0 *dB* | | | |
| Line / Pad | Loss (dB) | Based on antenna HAGL | | | |
| Attenuator | Loss (dB) | Assume surplus gain limited to < 9 *dB* | | | |
| Filter / Power Inj | Insertion Loss (dB) | 0 *dB*, special case usage | | | |
| $Amp_2$ | Noise Figure | 4.5 *dB* | | | |
| | $IIP^3$ | +15 *dBm* | | | |
| | 1-dB Compression | -3 *dBm* | | | |
| | Gain | +20 *dB* | | | |
| Splitter (Bold is typical value) | N Ways | 8 | 16 | 32 | 64 |
| | Loss | 10 *dB* | 13 *dB* | **16 dB** | 19 *dB* |
| Line | Loss | 1 *dB* typical for local distribution | | | |

**Figure 13 - Receiver Multicoupler**

### 5.9.4. Non-Coherent Power Addition Discussion

When adding powers, the values need to be in some form of Watts before they are added. In microwave systems the picoWatt is commonly used. To add the powers, it is not necessary to convert them to a specific Watt level, milliWatt, microWatt, or picoWatt. As long as they all are at the same pseudoWatt level they can be added and converted back and forth to the nonlinear form of decibels.

The following simple method is used to combine powers in the decibel form. Take the *dB* difference of two powers and look up in Figure 14 or Table 7 the value to add to the higher power. For example, if a -113 *dBm* and -108 *dBm* are to be combined, the difference is 5 *dB*. The value from Table 7 indicates to add +1.2 *dB* to the -108 *dBm* for a composite -106.8 *dBm*. For cases with more than two power levels, the process can be repeated multiple times. $P1$ and $P2$ can be combined to $Pc$ which can then be combined with P3 for the average power of all three.

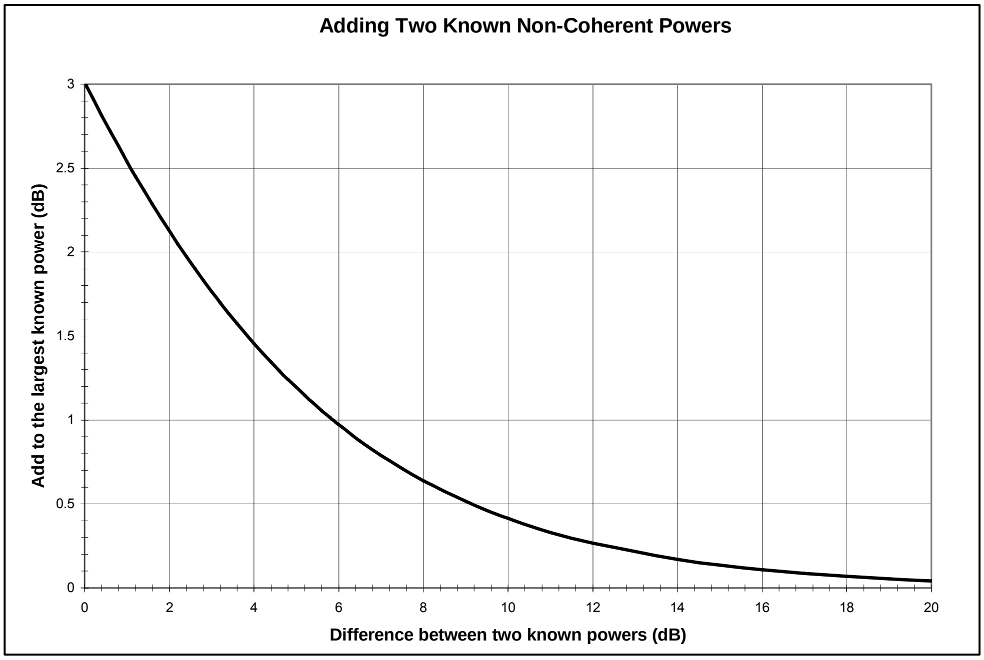



**Figure 14 - Adding Non-Coherent Powers**

**Table 7 Adding Non-Coherent Powers**

| dB Difference | Add To Largest | dB Difference | Add To Largest | dB Difference | Add To Largest | dB Difference | Add To Largest |
|---|---|---|---|---|---|---|---|
| 0.0 | 3.01 | 2.6 | 1.902 | 5.2 | 1.146 | 11 | 0.331 |
| 0.2 | 2.911 | 2.8 | 1.832 | 5.4 | 1.1 | 12 | 0.266 |
| 0.4 | 2.815 | 3.0 | 1.764 | 5.6 | 1.056 | 13 | 0.216 |
| 0.6 | 2.721 | 3.2 | 1.698 | 5.8 | 1.014 | 14 | 0.17 |
| 0.8 | 2.629 | 3.4 | 1.635 | 6.0 | 0.973 | 15 | 0.135 |
| 1.0 | 2.539 | 3.6 | 1.573 | 6.5 | 0.877 | 16 | 0.108 |
| 1.2 | 2.451 | 3.8 | 1.513 | 7.0 | 0.79 | 17 | 0.086 |
| 1.4 | 2.366 | 4.0 | 1.455 | 7.5 | 0.71 | 18 | 0.068 |
| 1.6 | 2.284 | 4.2 | 1.399 | 8.0 | 0.639 | 19 | 0.054 |
| 1.8 | 2.203 | 4.4 | 1.345 | 8.5 | 0.574 | 20 | 0.043 |
| 2.0 | 2.124 | 4.6 | 1.293 | 9.0 | 0.515 | 25 | 0.016 |
| 2.2 | 2.048 | 4.8 | 1.242 | 9.5 | 0.461 | 30 | 0.004 |
| 2.4 | 1.974 | 5.0 | 1.193 | 10.0 | 0.414 | | |

### 5.9.5. Determining Unknown Power from Sum and One Known Value

Can be used to identify the magnitude of an unknown when the total power (sum) and one specific value is known. For example, if the total power is measured to be -100 *dBm* and one contributor is known to be -106 *dBm* then the other contributors can be found to be -101.25 *dBm*, 1.25 *dB* below the total power. See §5.11.1 for using this method to identify interference sources.

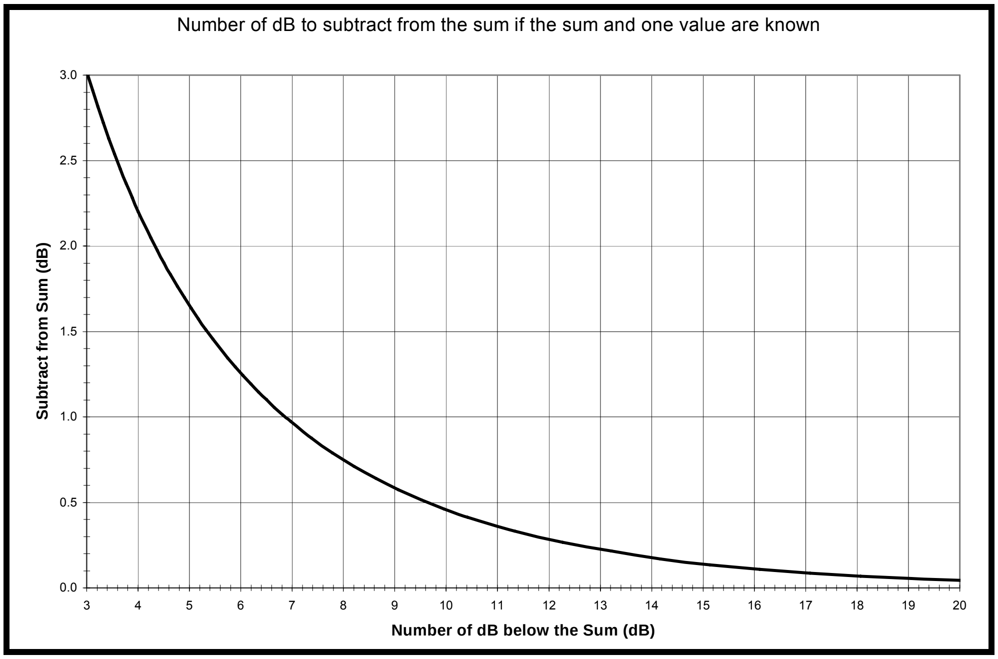



**Figure 15 - Determine Unknown Power from Sum and One Value**

| dB Difference | Subtract From Sum | dB Difference | Subtract From Sum | dB Difference | Subtract From Sum |
|---|---|---|---|---|---|
| 3 | 3.01 | 7 | 0.97 | 14 | 0.17 |
| 3.25 | 2.78 | 7.5 | 0.85 | 14.5 | 0.15 |
| 3.5 | 2.57 | 8 | 0.75 | 15 | 0.14 |
| 3.75 | 2.38 | 8.5 | 0.67 | 15.5 | 0.12 |
| 4 | 2.21 | 9 | 0.59 | 16 | 0.11 |
| 4.25 | 2.05 | 9.5 | 0.52 | 16.5 | 0.10 |
| 4.5 | 1.90 | 10 | 0.46 | 17 | 0.09 |
| 4.75 | 1.77 | 10.5 | 0.41 | 17.5 | 0.08 |
| 5 | 1.65 | 11 | 0.36 | 18 | 0.07 |
| 5.25 | 1.54 | 11.5 | 0.32 | 18.5 | 0.06 |
| 5.5 | 1.43 | 12 | 0.28 | 19 | 0.05 |
| 5.75 | 1.34 | 12.5 | 0.25 | 19.5 | 0.04 |
| 6 | 1.25 | 13 | 0.22 | 20 | 0.03 |
| 6.5 | 1.10 | 13.5 | 0.19 | | |

**Table 8 Determine Unknown Power from Sum and One Value**

## 5.10. Noise-Adjusted Faded Performance Threshold

Environmental noise causes a receiver's apparent Faded Performance Threshold to algebraically increase. This "Noise-Adjusted Faded Performance Threshold", $FPT_{Adj}$, is calculated as follows:

$$Adjustment = 10 \log_{10}(1 + N_r/NF) \quad (19)$$

$$FPT_{Adj} = FPT + Adjustment \quad (20)$$

Where,

$N_r \equiv$ The environmental noise (relative to $kT_0b$), expressed in linear (not $dB$) units. See "Environmental RF Noise Data" in [88.2].

$NF \equiv$ The receiver's Noise Factor, expressed in linear (not dB) units.

FPT $\equiv$ The receiver's Faded Performance Threshold, expressed in $dB$ units in Annex A of [88.1].

An example of this adjustment is contained in Annex C, of [88.1].

## 5.11. Identifying Interference

### 5.11.1. Separating Composite Signal Levels

Interfering carriers have the impact of affecting performance similar to an increase in noise. Since BER and RSSI can be measured, a reasonable calculation of interference can be made from evaluating these two related parameters.

An example is provided in Figure 16. BER can be mapped into $C_f/(I+N)$, e.g., a BER of 2% might, for example, correspond to a ratio of 17 *dB* (50). RSSI is essentially $(C+I+N)$. When calibrated this might indicate that when a particular test yielded a measured 2% BER, the total power was for example -100 *dBm* (1 x $10^{-10}$ mW). Thus the $C$ and $(I+N)$ components can be solved for. Bench measurements can determine the value of $N$ based on measured reference sensitivity and subtracting the $C_s/N$. The $C$ and $I$ values can be solved for. High BER measurements at normal RSSI indications would represent increased $I$ or $N$ contributions. If $N$ is -124 *dBm*, then $C$ = -100.1 *dBm* and there is interfering power at approximately -118.1 *dBm*.

The example can also be done using tables in §5.9.4 for a quick estimate. Since the difference is 17 *dB*, the difference between the sum $(C+I+N)$ and $(I+N)$, the unknown $C$ is approximately 0.1 *dB* below $(C+I+N)$. Thus $(I+N)$ is 17.1 *dB* below the $(C+I+N)$. Repeating this process, and knowing that $N$ = -124 *dBm* which is 6.9 *dB* below the $(I+N)$. Therefore the unknown is approximately 1 *dB* below the $(I+N)$.

A simple way to identify interference potential is to use a receiver monitoring an idle channel. If the RSSI indicates strong power levels, the measurement is $(I+N)$ as $C$ is not present.

This method can proactively determine potential trouble areas before they affect users. It is intended to proactively provide information concerning potential interference situations that could occur in the future or have not been previously reported.

Using a receiver with a calibrated RSSI, approach local areas of potential interference with the desired frequency not active. If the RSSI $(I+N)$ indicates a value that is “X” *dB* less than the local desired signal level, known from previous measurements, a determination of potential interference zones can be quickly determined. Note however that the $(I+N)$ can vary with time and activity of various emitters. Also the desired can be different due to hardware issues.

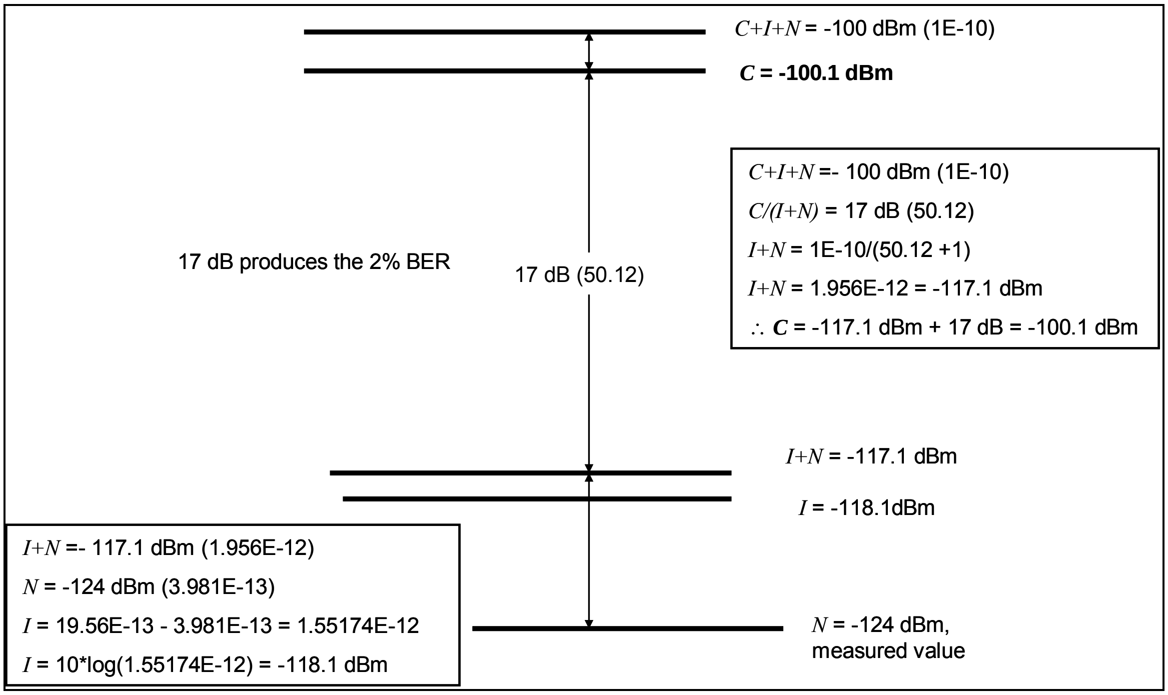



**Figure 16 - Determining an Interfering Level**

### 5.11.2. Receiver Intermodulation

Using attenuators to determine the effect on changes in power levels can identify receiver intermodulation as well as the order of the product. This is extremely useful in determining the actual mechanisms at work so that the root cause and solution can be determined.

The following cases represent a 3rd order intermodulation example. The power (*dB*) of each component adds to produce a resultant composite power. The absolute value of the resulting IM product can be quickly calculated by doubling the *dB* value between $IIP^3$ and *Ci* and subtracting it from *Ci*.

- If the powers of both carriers (*Pa* and *Pb*) are increased or decreased by 1 *dB* the resulting power (*Ci*) of the intermodulation product changes by the order of the product. (3 *dB* for third order). *Ci* changes by 1 *dB* while the doubled value changes by 2 *dB* resulting in a 3 *dB* change.
- If *Pa* is increased by 1 *dB* the resulting power (*Ci*) increases by 2 *dB*.
- If the *Pb* is increased by 1 *dB* the resulting power (*Ci*) increases by 1 *dB*.

These relationships assist in confirming intermodulation as well as identifying the components. Reducing the power, while monitoring the resulting change in degradation, allows determining the intermodulation order as well as its components.

When an attenuator is used to reduce the interfering signal level, the desired is also reduced. As a result, a 1 *dB* reduction by inserting an attenuator will result in a 2 *dB* decrease in the $C/(I+N)$ when receiver intermodulation is dominant.

The effect of changing the power of the victim's desired signal or reducing the power of the interfering source is quite different.

- If the individual interfering contributors are reduced by 1 *dB*, the $C/(I+N)$ improves by 3 *dB* for third order IM if $I >> N$[23]. (See [88.1]).
- If the desired is raised by 1 *dB*, the $C/(I+N)$ improves by 1 *dB*

External intermodulation products no longer follow the order that created them. Once generated outside the victim receiver, they follow a 1:1 reduction when attenuation is added.

The examples given use a high $IIP^3$ and the interfering values are relatively low compared to a near/far interference scenarios that can exist where the desired is weak and the interfering carriers are strong as a unit is far from its desired site and close to interfering sites.

[23] Generally if there is a 10 *dB* difference, the interference is dominant and the 3 *dB* will be seen. If they are relatively close in value, the effect will be much less.

Assume $P_a$ = -30 $dBm$
$P_b$ = -42 $dBm$
$IIP^3$ = +9 $dBm$

Reference $Ci = \frac{2(P_a) + P_b}{3}$ Equation(11) $= \frac{2(-30)+(-42)}{3} = -34.00\ dBm$

Increase $Pa$ by 1 $dB$ $= \frac{2(-29)+(-42)}{3} = -33.33\ dBm$

Increase $Pb$ by 1 $dB$ $= \frac{2(-30)+(-41)}{3} = -33.67\ dBm$

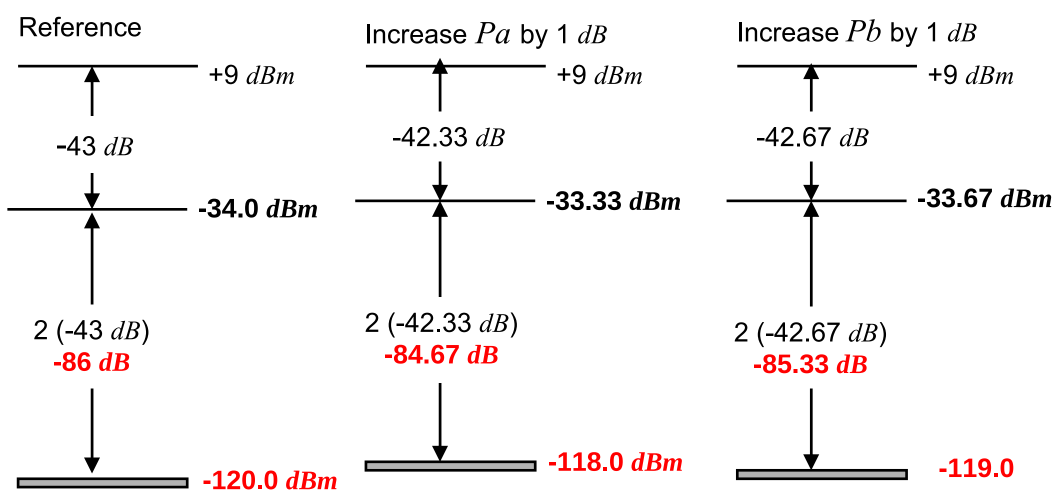



**Figure 17 - Receiver Intermodulation**

### 5.11.3. Measurement Application

Annex C describes a useful spreadsheet application where a series of measurements can determine the magniture of various intermodulation and OOBE contributors. This is quite useful in advanced troubleshooting.

### 5.11.4. Intercept Point

The use of intercept points is discussed in §5.9.1 with respect to intermodulation. With the introduction of wide band data, the intermodulation specifications are reduced due to the wider receiver ENBW which necessitates a higher signal power.

With the advent of wide band data, published receiver intermodulation rejection (IMR) specifications are lower than IMR levels seen in narrow band analog or digital voice systems. This is a direct result of wider receiver bandwidths, more complex modulations and different criteria for reference sensitivity. The concept of the intercept point is crucial to understanding why this occurs and how lower IMR specifications affect potential system interference.

The 3rd order intercept point ($IP^3$) is quite useful in determining the interfering effects of receiver intermodulation. It cannot be directly measured since that very high signal power levels would be necessary, strong enough to burn out the receiver's front end. As a result indirect measurements are used to determine a receiver's IMR performance and from that the $IP^3$ can be determined.

The indirect measurement involves injecting a desired signal into a receiver at its static sensitivity level (e.g., 12 $dB$ SINAD sensitivity), boosting the desired signal by 3 $dB$ and then injecting two equal signals that will produce a 3rd order IM product on the test receiver's desired frequency causing receiver sensitivity to degrade back to its static sensitivity reference (e.g., 12 $dB$ SINAD). The method of measurement is the same in all private land mobile standards: [603], [102.CAAA], [902.BAAA], [902.CAAA] and [905.CAAA]. However this method of measurement applies only to the 3rd order IM.

Receiver 3rd Order IMR values can be accurately determined by these measurements, but the higher order $IP^n$ values are more difficult to measure as the signal powers of two equal IM source signals are considerably higher. These high levels contribute phase noise from the signal generators that exceeds the receiver's internal thermal noise causing inaccurate measured values.

To eliminate this inaccuracy, it is recommended that the IMR test set up be modified so that the desired signal is set to 30 $dB$ above the reference sensitivity. In this case the phase noise from the signal generators that generate the IM source will have little effect. This allows the $IP^n$ to be calculated.

For the purpose of this discussion it is assumed that the $IP^3$ and $IP^5$ are the same. This is a reasonable assumption as they tend to be close in value with the $IP^5$ possibly being slightly higher. Assuming they are the same is a conservative approach.

With the advent of wide band systems, the specified IMR levels will be lower than narrow band systems due to the wider receiver ENBW producing a higher noise floor and the higher $C/N$ necessary for DCPC at a lower error rate. This discussion is provided to assist in an understanding of why this occurs. To facilitate this, a series of examples are provided to demonstrate that the $IP^n$ determines the IMR of a receiver

If an example receiver has an ENBW of 11 kHz, a reference sensitivity of -120.6 *dBm* for 5 *dB Cs/N*, and an IMR specification of 80 *dB*, then the following results would apply.

| | |
|---|---|
| ENBW | 11 kHz |
| Noise Figure | 8 *dB* |
| Thermal Noise floor | -125.6 *dBm* |
| *Cs/N* | 5 *dB* |
| Reference Sensitivity | -120.6 *dBm* |
| Reference Sensitivity + 30 *dB* | -90.6 *dBm* |

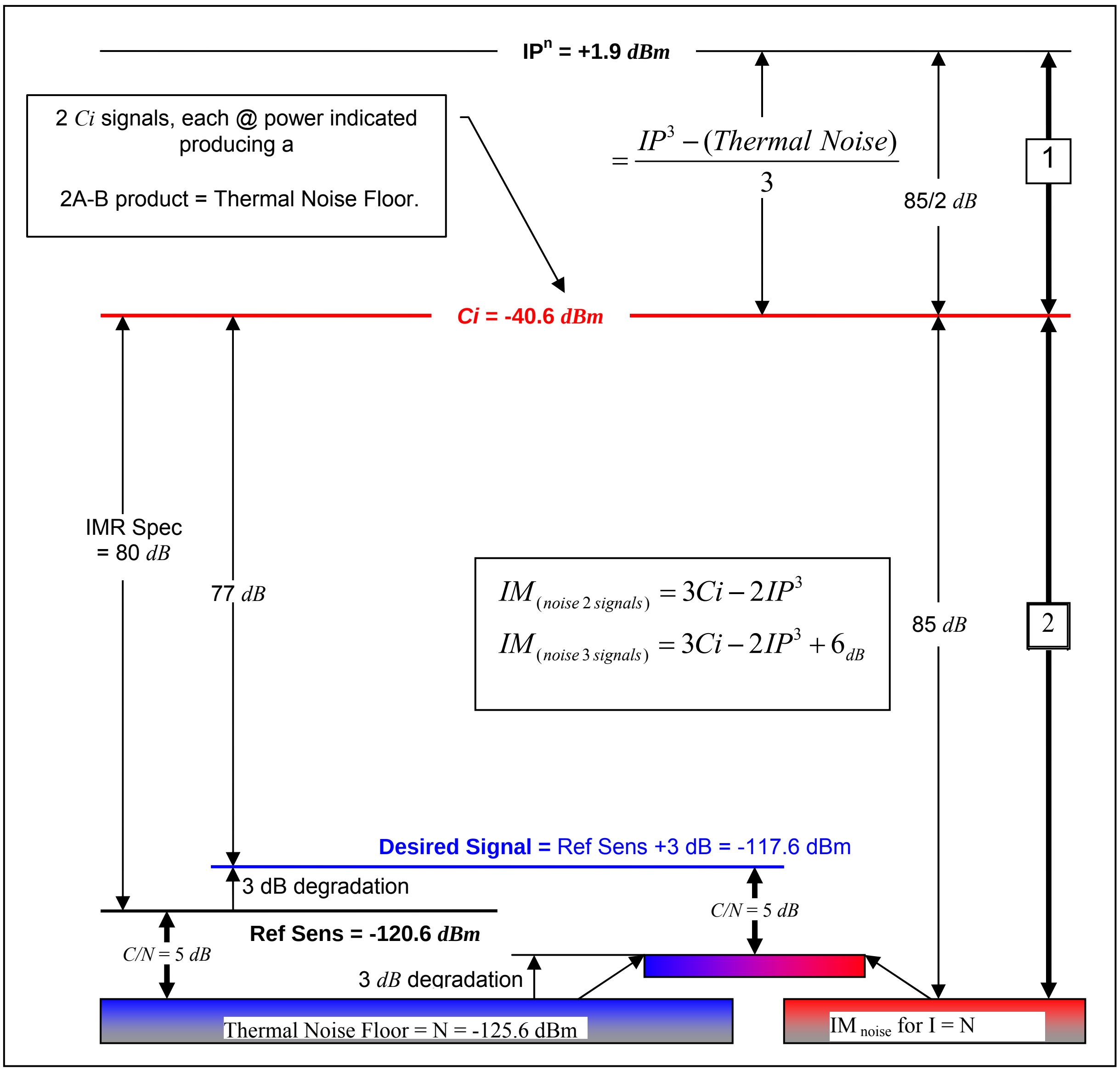



**Figure 18 - Third Order *IP* Determination**

Figure 18 shows the standard TIA IMR measurement. The desired is increased by 3 *dB* above reference sensitivity. Two interfering signals are provided so they produce an on-channel intermodulation signal. The signal furthest offset is modulated while the closer frequency is unmodulated. The two equal signals are increased until reference sensitivity is regained. This produces an IM power level that is equal to the thermal noise of the receiver. The IM power and thermal noise combine producing an equivalent noise level 3 *dB* greater than the thermal noise floor. The IMR is the difference between the original reference sensitivity and the level of the interfering signals, -40.6 *dBm*.

Note that the value of the box labeled 2 is twice the size of the box labeled 1. Box 1 is the difference between the interfering signals ($Ci$) and $IP^3$. Box 2 is the equivalent noise level that the IM signals ($Ci$) produce. There are several ways that the $IP^3$ can be calculated. The difference between $Ci$ and $IP^3$ is one third of the difference between the $IP^3$ and the receiver's thermal noise floor as that is the scenario the test was designed to create.

$$IP^3 - Ci = \frac{IP^3 - IM_{Noise\ Level}}{3} \tag{21}$$

Solving for $IM_{Noise\ Level}$ produces

$$IM_{Noise\ Level-2} = 3Ci - 2IP^3 \tag{22}$$

This is valid for the 2 equal signal test [for 2A-B 3rd order IM product].

The ratio of the $IMR^n$ Product and the $IP^n$ are related by their order. The $n^{th}$ order produces a difference between $IP^n$ and $Ci$ of one, while the difference between $Ci$ and the $IM_{noise}$ is (n-1) times the difference between $IP^n$ and $Ci$. This is represented in the various figures by the square boxes. This is the mechanism to compute the $IP^n$ from measurements at 30 *dB* above reference sensitivity.

If a three equal signal generator test is run [for A + B - C 3rd order IM product] then the $IM_{Noise\ Level}$ will be 6 *dB* greater resulting in a 2 *dB* reduction in the signal power of each $Ci$.[15].

$$IM_{Noise\ Level-3} = 3Ci - 2IP^3 + 6_{dB} \tag{23}$$

#### 5.11.4.1. Phase Noise Impact.

An ideal signal generator would produce a single frequency continuous wave (CW) output. Unfortunately this is not possible. Random noise is spread over a small range of frequencies, and is referred to as phase noise. Phase noise is specified as *dBc/Hz*: *dB* below the carrier in a 1 Hz bandwidth. For this discussion if it is assumed that the signal generators have a specification of -130 *dBc/Hz* at the offset frequencies we are using for the measurements, then for the 11 kHz bandwidth, the noise is 89.6 *dB* [-130 + 40.4 dB] [24] below the signal generator level. Thus the noise at a generated level of -40.6 *dBm* would be -130.2 *dBm*. Combined, these noise sources (2 generator sources at -130.2 *dBm* and the $IM_{noise}$ at -125.6 *dBm*) produce a composite noise of -123.3 *dBm* and distort the measurement, producing a lower IMR value than would be measured with pure sources. To offset this potential inaccuracy, it is recommended that the tests be run at a higher signal power level to minimize the phase noise impact or the higher specification signal generators be utilized.

[24] The worst case value of -130 *dBc/Hz* is used for this example. Generators with -140 *dBc/Hz* are available. Analog generators have better performance than digital generators.

### 5.11.4.2. Alternative Test

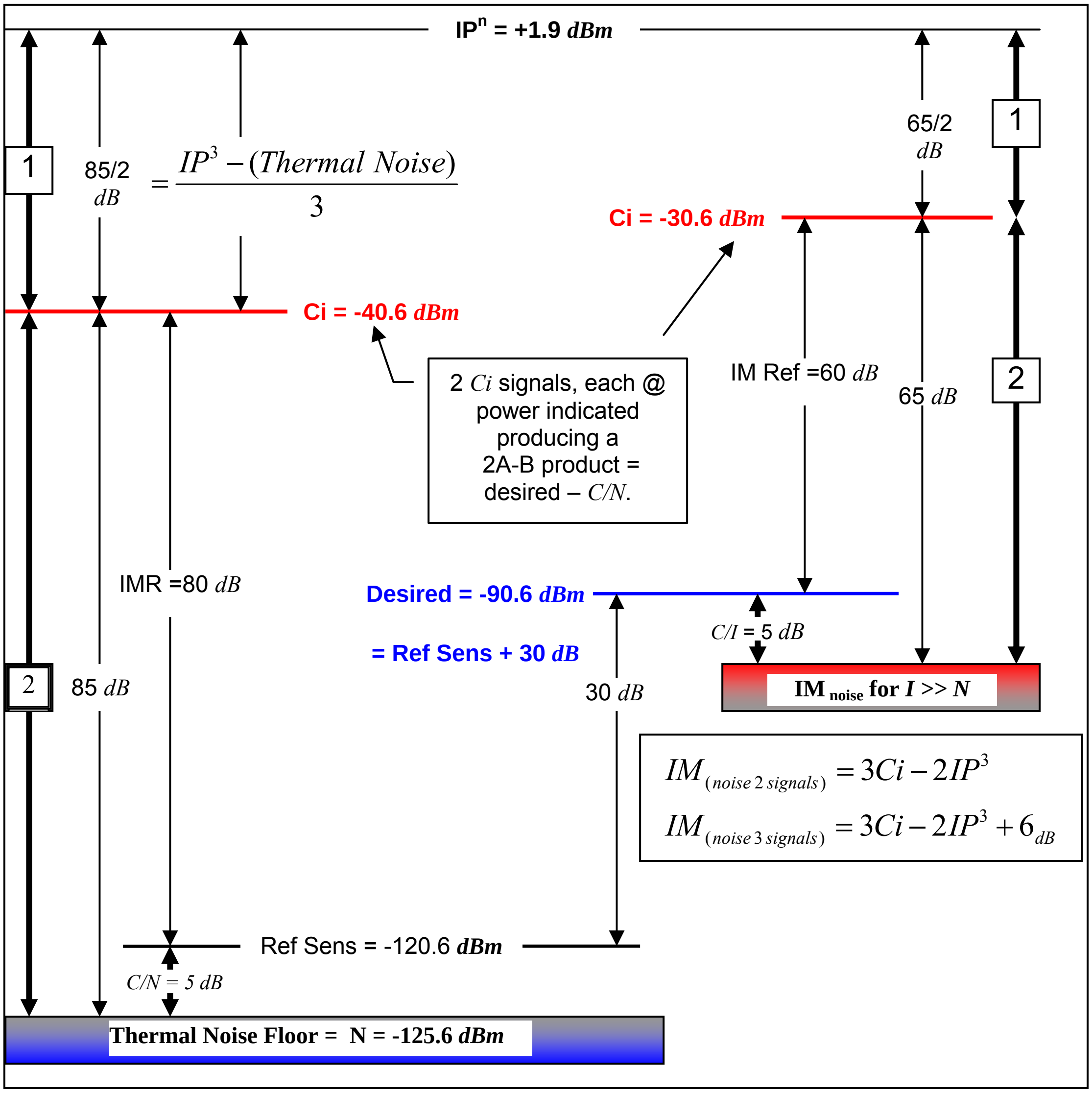



**Figure 19 - Alternative $IP^3$ Determination**

The right hand side of Figure 19 shows the same test run at 30 *dB* above reference sensitivity. In this case the internal thermal noise (-125.6 *dBm*) and phase noises (2 at -130.2 *dBm*) are insignificant and the -95.6 dBm $IM_{Noise}$ is controlling. Again, two interfering signals are provided so they produce an on-channel intermodulation signal. The signal furthest offset is modulated while the closer frequency is unmodulated. The two equal signals are increased until reference sensitivity (e.g., 12 *dB* SINAD) is regained. This produces an IM power level that is *Cs/N dB* below the desired signal reference level. Note that for the desired signal level 30 *dB* above normal reference sensitivity the IM source signal power only increases by 10 *dB* and the IMR measured is reduced by 20 *dB*. However, for this example, the $IP^3$ remains the same because the impact of phase noise was not included in these examples.

To convert the measured *IMR* to an equivalent $IMR^3$ specification necessitates that the measured value be corrected for the "*IMR Slope*".

$$IMR\ Slope\ Adjustment = \frac{(n-1)}{n}(dB) \tag{24}$$

The IMR slope adjustment occurs because the resulting IM noise increases at a rate proportional to the order of the IM product. If the interfering signals level are increased by 1 *dB*, the resulting product increases by the IM order. The measured change in IM is the difference between the original measured value and the new *Ci* and new $IM_{Noise}$. For the 3rd order case, a 1 *dB* increase in *Ci* causes the $IM_{Noise}$ to rise by 3 *dB* and the new measured IMR value to decrease by 2/3 *dB*.

For this example, since the increase is 30 *dB* above the normal reference sensitivity a correction of 20 *dB* then calculates the 80 *dB* IMR value originally defined

### 5.11.4.3. 5th Order *IP*

Figure 3 demonstrates that the IMR is considerably better for an $IP^5$ the same value as the $IP^3$, 73 *dB* verses 60 *dB*. This is due to the difference in the 5:1 vs. 3:1 ratio between the $IP^n$ and the *Ci*.

$$IM_{Noise\ Level-2} = 5Ci - 4IP^5 \tag{25}$$

The IMR value would be hard to measure directly as it would necessitate that *Ci* equal -23.6 *dBm* (Equation(5) and the example $IP^5$ = +1.9 *dBm*). In this case the signal generators would have an even higher phase noise contribution that the measurement would be extremely compromised. Even at 30 *dB* above reference sensitivity, the signal generator phase noise contribution is beginning to approach the $IM_{noise}$ contribution. In this case, an even greater desired signal ought to be considered.

To compute the actual 5th order *IMR*, use Equation(24) with n = 5. Add 4/5 *dB* for each *dB* above the normal reference sensitivity. This would produce an $IMR^5$ of 97 *dB*, 24 *dB* greater than the 73 *dB* measured.

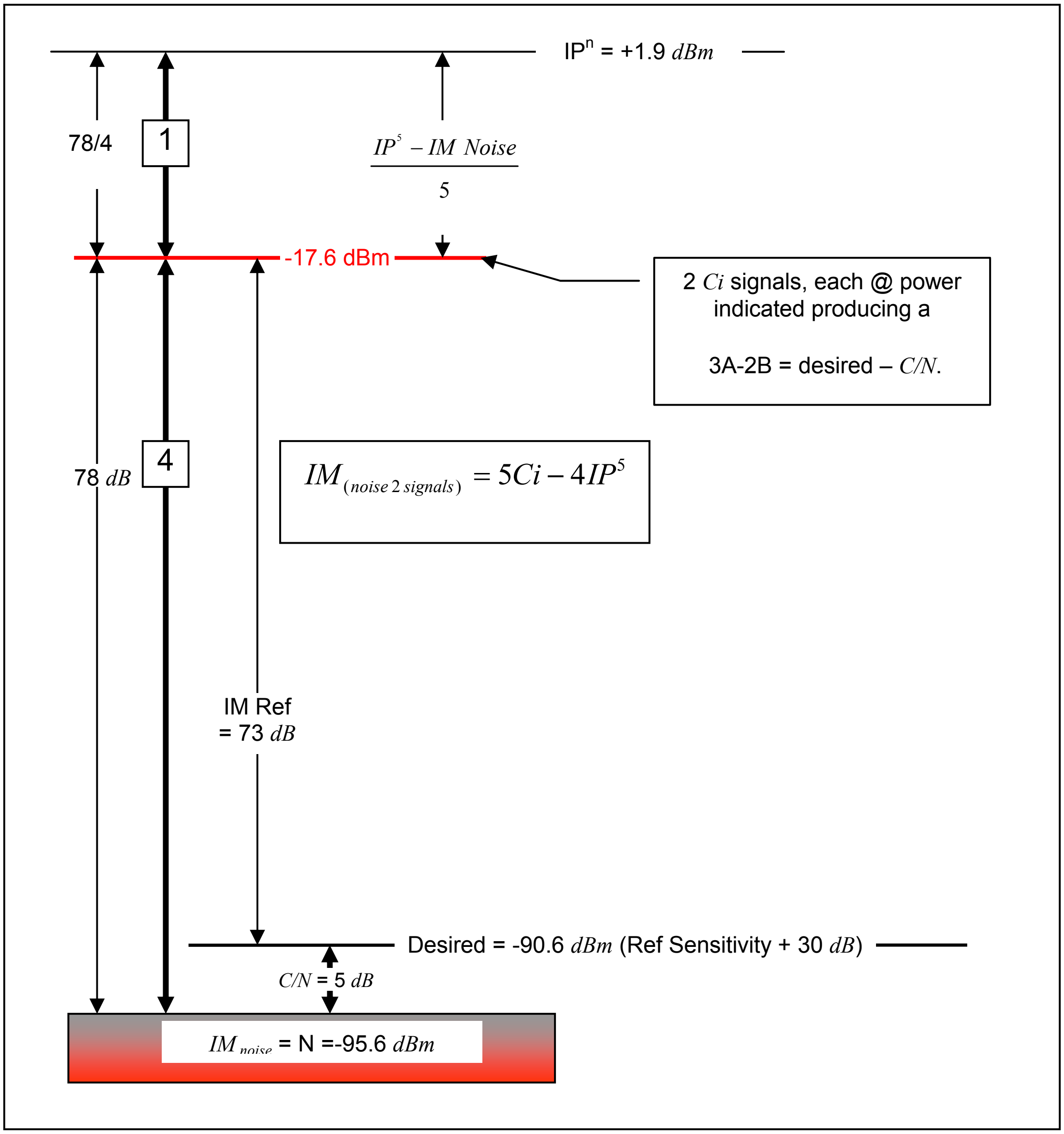



**Figure 20 - 5th Order IP Determination**

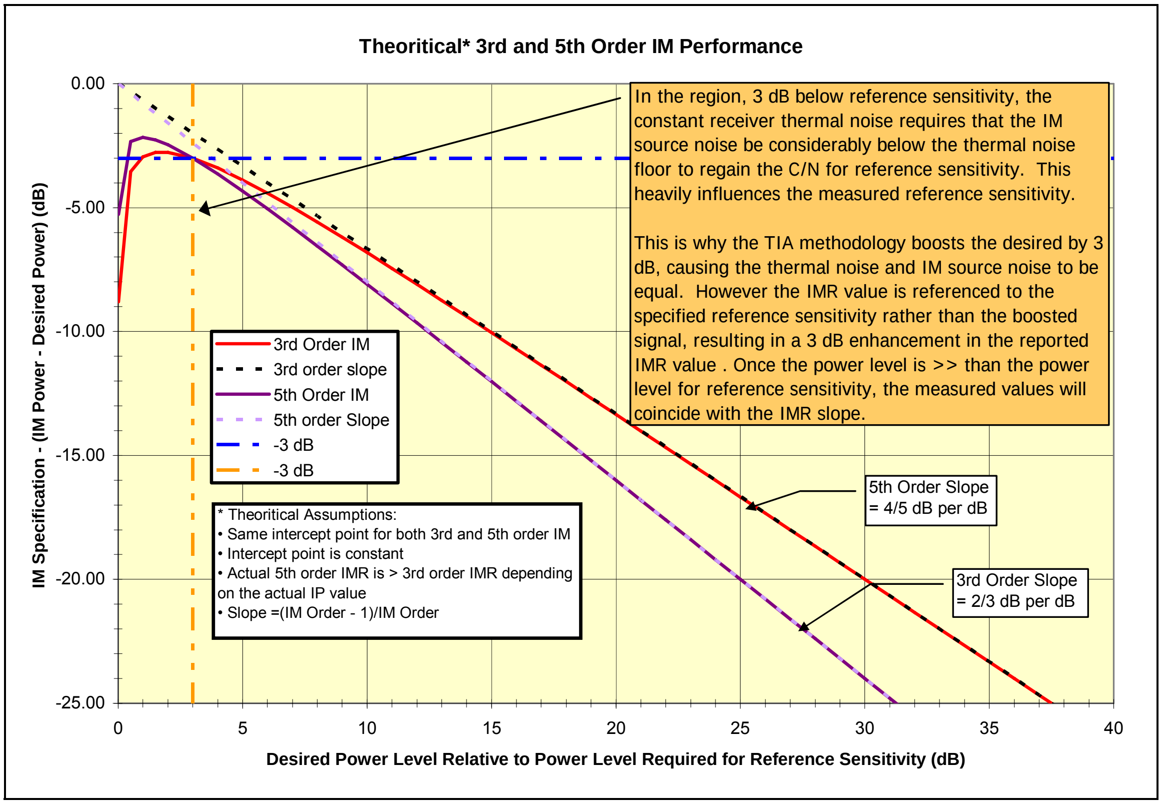



**Figure 21 - Normalized IM Performance, Example Receiver**

Figure 21 represents the calculation of $IMR$ based on perfect signal generators normalized to their TIA $IMR$ value. Note that in the region close to reference sensitivity, there is a 3 $dB$ difference between the $IMR$ value and the TIA value. This is a result of the 3 $dB$ boost. If the 3 $dB$ boost is not taken at reference sensitivity then the $IM_{Noise}$ has to be driven below the thermal noise resulting in a dramatic reduction in measured IMR.

Figure 22 is the same example, with the $IMR$ values calculated rather than normalized as in Figure 21.

Comparing Figure 22 to the previous examples, if you compare the measured $IMR^3$ value (60 $dB$ @ desired power level 30 $dB$ above reference sensitivity) and follow the slope line back to 0 $dB$, you find the actual receiver $IMR^3$ level of 80 $dB$. If you compare the measured $IMR^5$ value (73 $dB$ @ desired power level 30 $dB$ above reference sensitivity) and follow the slope line back to 0 $dB$, you find the actual receiver $IMR^5$ level of 97 $dB$.

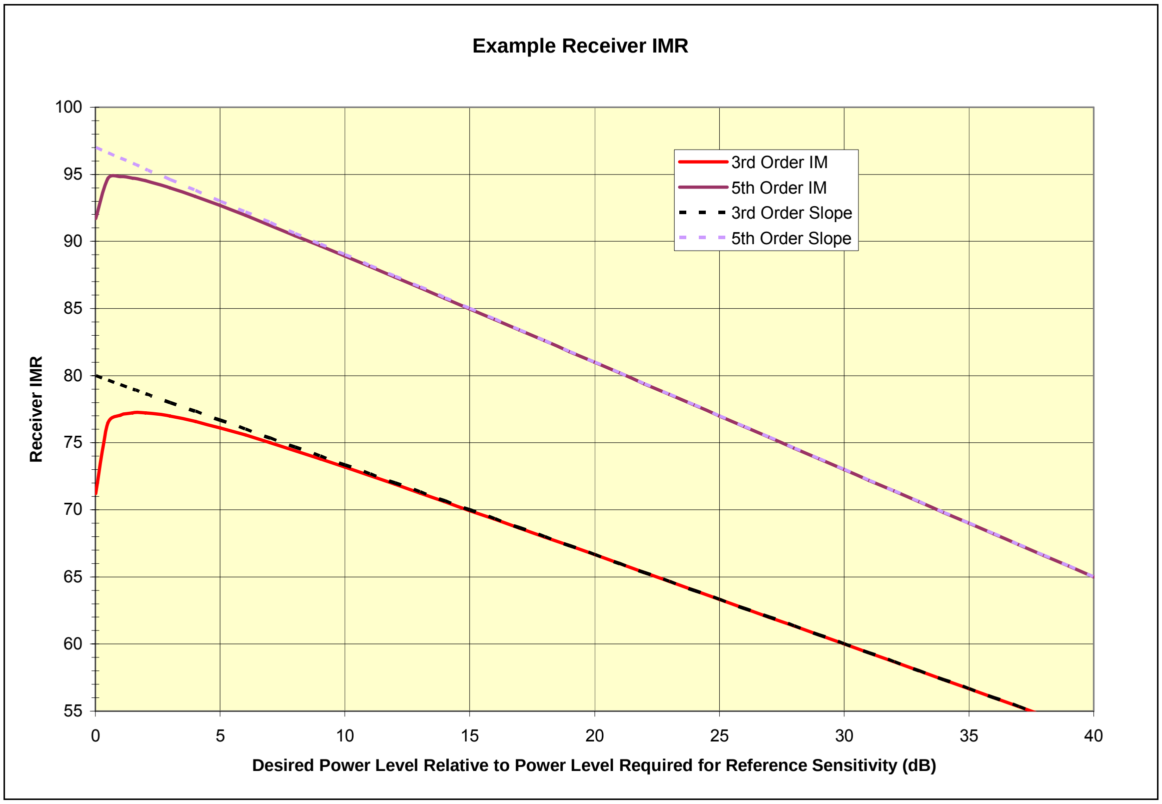



**Figure 22 - Example Receiver Theoretical IMR Performance**

### 5.11.4.4. Wide Band Data

Consider a new example case where a SAM 50 kHz channel Wide Band Data receiver uses a 42.6 kHz ENBW IF[25] compared to a Phase 1 P-25 narrow band receiver with a 5.5 kHz ENBW IF[26]. If the P-25 receiver has an 80 $dB$ IMR specification then the $IP^3$ is +4.8 $dBm$. Assume the Wide Band receiver has the same $IP^3$. Comparing the two configurations shows that although the $IP^3$ is the same, the measured IMR of the wide band system is 12.8 $dB$ different. This is due to the difference in the interfering signal levels and the $C/N$ necessary for reference sensitivity. When the $IP$'s are the same Equation(26) can be used to compute the reduction in $IMR$.

$$\text{IMR Reduction} = 2\left[WB_{Ci} - NB_{Ci}\right] + \left[WB_{C/N} - NB_{C/N}\right] \quad (26)$$

Figure 23 shows the comparison.

[25] Perfect filter (square) used in this simulation [88.1]
[26] The RRC filter is used in this simulation [88.1]

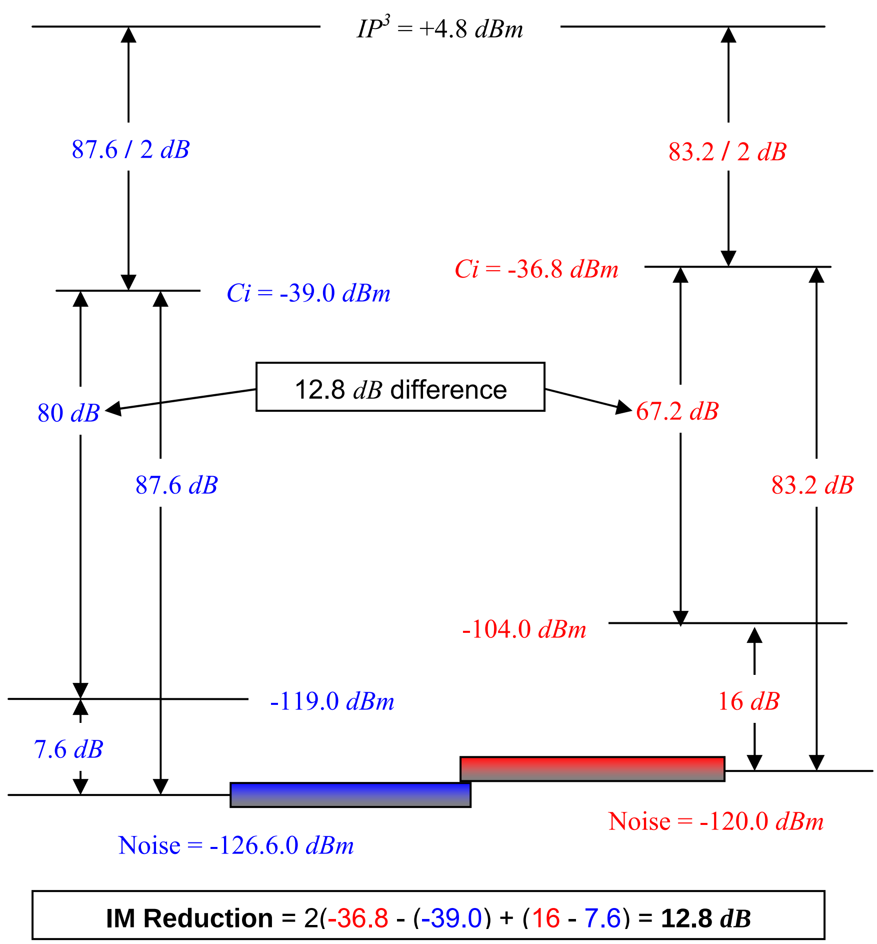



**Figure 23 - Comparison of P-25 narrow band and SAM 50 kHz wide band**

The affect of the signal generator phase noise for the 80 *dB* narrow band system is high enough to recommend the measurement to determine *IMR* and $IP^n$ at a signal power level greater than reference sensitivity and adjust for the order slope or use the higher 140 *dBc/Hz* signal generator. Figure 24 compares this recommendation as the 130 *dBc/Hz* generator's noise is almost the same as the receiver's internal thermal noise.

There is a significant difference in the phase noise of analog signal generators and digital signal generators. For the wide band data systems, the frequency offsets are significantly increased from 50/100 kHz to 600/1,200 kHz to lower the effect of phase noise. Using an analog signal generator for the unmodulated carrier will likewise further minimize the phase noise contributions.

When wide bandwidth signals intermodulate the energy is spread over a much wider frequency expanse compared to narrow bandwidth signals. With the lower *IMR* values, greater care is recommended to proactively mitigate potential IM interference via frequency coordination. Intermodulation computations ought to be considered part of the coordination process evaluating potential cases that are likely to occur due to proximity to sites within a defined service area.

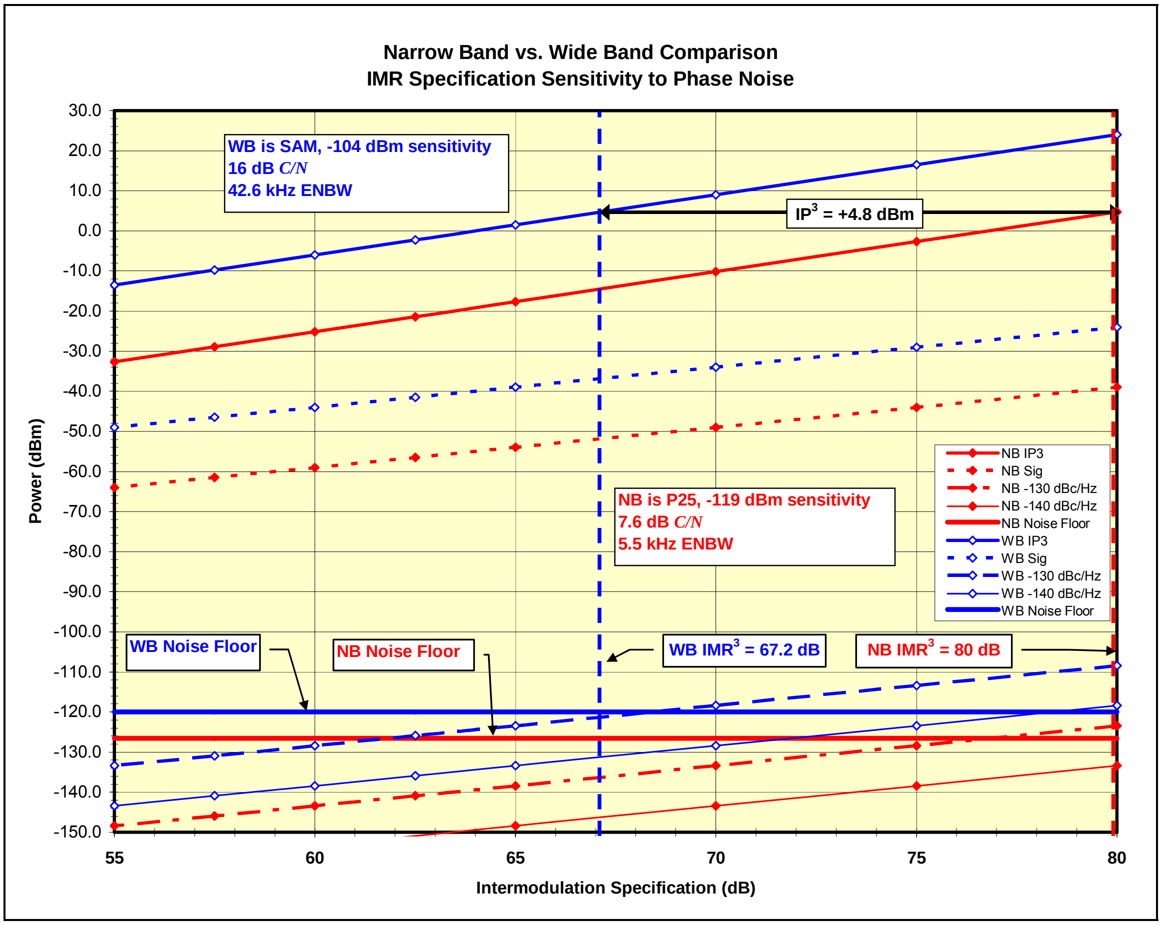



**Figure 24 - Comparaisons NB-WB Phase Noise Influence**

Although there is an 18.2 *dB* reduction in the specified *IMR*, the noise suppression is quite similar to what a receiver with an *IMR* of slightly less than an 80 *dB* receiver would produce. Manufacturing margins will also affect the calculation.

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## Annex A VOICE CATP USER CHOICES (informative)

### A.1 User Choices

The main body of this document does not present a "hard and fast" methodology. It presents the user with a number of choices that can be made to perform the system design, spectrum management, and performance confirmation functions. The purpose of this Annex is to present those choices in a simplified format so that users can clearly identify to others (e.g., prospective bidders) the specifics of the desired method. This Annex is similar to Annex E of [88.1], the differences being the references to the appropriate documents

Each choice is shown as a brief description along with a reference to the appropriatesubdivision of this document or the appropriate version of TSB-88.x, e.g. [88.x], where the choices are fully described. Follow the instructions where optional choices can be made. Recommended or preferred values are indicated with an astrick and enclosed in brackets. If, no choice is made, the recommended value(s) will be selected for any evaluation..

### A.2 Identify Service Area

Reference – [88.1] Service Area. Use any of the methods of service area definition indicated by the information in Annex B [88.1]

### A.3 Identify Channel Performance Criterion

Reference [88.1]. For DAQ definitions,.

DAQ: ______ (*3.4 Public Service only, else 3.0)

### A.4 Identify Reliability Design Targets

For advice,see [88.1]. Both percentage and whether CPC Contour or Service Area

☐ CPC Contour (90%)

______ % (select one)

☐ Service Area (*97%)

### A.5 Identify the acceptable terrain profile extraction methods

Reference [88.2]

☐ Bilinear Interpolation Method (check one or both)

☐ Snap to Grid Method (*)

### A.6 Identify acceptable interference calculation methods

Reference [88.2]

- ☐ Equivalent Interferer Method (check one or both)
- ☐ Monte Carlo Simulation Method (*)

### A.7 Identify the metaphor(s) to be used to describe the plane of the service area

Select one from those described in [88.2]

Select those that are acceptable (only the last two are acceptable for interference calculation or simulcast design):

- ☐ Radial Method
- ☐ Stepped Radial Method
- ☐ Grid Mapped from Radial Method
- ☐ Tiled Method (*)

### A.8 Determine desired service area reliability to be predicted

Reference [88.1] and [88.2].

______ % (*97% Public Safety only, else 90%)

### A.9 Willingness to accept a lower area reliability in order to obtain a frequency

Reference, Frequency Assignment Criteria, Interaction Between Shared and PSA Users Table [88.2]. Select one:

- ☐ Yes (*)
- ☐ No

### A.10 Adjacent channel drift confidence –

Reference {88.1} and [88.2], Determine Confidence Factor

Confidence that combined drift due to desired and adjacent-channel stations ought not to cause degradation:

________ % (*95%)

## A.11 Determine Conformance Test confidence level –

Reference §5.2.1 and §5.4.1. This interacts with A.7.

______ % (*95%)

## A.12 Determine Sampling Error Allowance

Reference §§ 5.2.1 & 5.4.2.

True Value Error ± ______ % (*1%)

Number of Subsamples _________# (*50)

## A.13 Determine which Pass/Fail Criterion to use

Reference §§ 5.3 - 5.3.2. Select one:

☐ "Greater than" test (*)

☐ Acceptance window test

## A.14 Treatment of Inaccessible Grids

Reference § 5.5.4. Select one:

☐ All are eliminated from the calculation (*)

☐ All are considered a "pass"

☐ Single isolated inaccessible tiles are estimated based upon "majority vote" of adjacent tiles; multiple adjacent inaccessible tiles are eliminated from the calculation

☐ Single isolated inaccessible tiles are estimated based upon "majority vote" of adjacent tiles; multiple adjacent inaccessible tiles are considered a "pass".

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## Annex B DATA CATP USER CHOICES (informative)

### B.1 User Choices

The main body of this document does not present a "hard and fast" methodology. It presents the user with a number of choices that can be made to perform the system design, spectrum management, and performance confirmation functions. The purpose of this Annex is to present those choices in a simplified format so that users can clearly identify to others (e.g., prospective bidders) the specifics of the desired method.

Each choice is shown as a brief description along with a reference to the appropriatesubdivision of this document or the appropriate version of TSB-88.x, e.g. [88.x], where the choices are fully described. Follow the instructions where optional choices can be made. Recommended or preferred values are indicated with an astrick and enclosed in brackets. If, no choice is made, the recommended value(s) will be selected for any evaluation..

### B.2 Identify Service Area

Reference – [88.1]. Use any of the methods of service area definition indicated by the information in Annex B [88.1]

### B.3 Identify Criterion Type

Message Success Rate ______ (*)

Data Throughput Rate ______

### B.4 Type of Test

☐ Moving (*)

☐ Stationary

### B.5 Test Units

If both types are being tested, see § 5.7.1.5.

☐ Mobiles (*)

☐ Portables

☐ Both Mobiles and Portables

### B.6 Portable Testing

If portable testing is selected, what environment is applicable.

- ☐ Outdoor Coverage (*)
- ☐ In-building Coverage
- ☐ In-vehicle Coverage

### B.7 Test Direction

- ☐ Outbound (*)
- ☐ Inbound
- ☐ Both Outbound and Inbound

### B.8 Identify the metaphor(s) to describe the plane of the service area

Select one from those described in [88.2]

Select those that are acceptable (only the last two are acceptable for interference calculation or simulcast design):

- ☐ Radial Method
- ☐ Stepped Radial Method
- ☐ Grid Mapped from Radial Method
- ☐ Tiled Method (*)

### B.9 Identify the acceptable terrain profile extraction methods

Reference [88.2]

- ☐ Bilinear Interpolation Method (check one or both)
- ☐ Snap to Grid Method (*)

### B.10 Identify Reliability Design Targets

For advice,see [88.1]. Both percentage and whether CPC Contour or Service Area

☐ CPC Contour (90%)

______ % (select one)

☐ Service Area (*97%)

### B.11

## B.12 Identify acceptable interference calculation methods

Reference [88.2]

- ☐ Equivalent Interferer Method (check one or both)
- ☐ Monte Carlo Simulation Method (*)

## B.13 Determine desired service area reliability to be predicted

Reference [88.1] and [88.2].

______ % (*95% Public Safety only, else 90%)

## B.14 Willingness to accept a lower criterion in order to obtain a frequency

Reference, Frequency Assignment Criteria, Interaction Between Shared and PSA Users Table [88.2]. Select one:

- ☐ Yes (*)
- ☐ No

## B.15 Adjacent channel drift confidence –

Reference {88.1} and [88.2], Determine Confidence Factor

Confidence that combined drift due to desired and adjacent-channel stations ought not to cause degradation:

________ % (*95%)

## B.16 Determine Conformance Test confidence level –

Reference §§5.2.1 and 5.4.1. This interacts with B.8.

______ % (*95%)

## B.17 Determine which Pass/Fail Criterion to use

Reference §§ 5.3 - 5.3.2. Select one:

- ☐ “Greater than” test (*)
- ☐ Acceptance window test

## B.18

### B.19 Treatment of Inaccessible Grids

Reference § 5.5.4. Select one:

- ☐ All are eliminated from the calculation (*)
- ☐ All are considered a "pass"
- ☐ Single isolated inaccessible tiles are estimated based upon "majority vote" of adjacent tiles; multiple adjacent inaccessible tiles are eliminated from the calculation
- ☐ Single isolated inaccessible tiles are estimated based upon "majority vote" of adjacent tiles; multiple adjacent inaccessible tiles are considered a "pass".

### B.20 Treatment of Test Anomolies

Reference § 5.5.5. Select one:

- ☐ All are eliminated from the calculation
- ☐ All are considered a "pass" (*)

# Annex C Intermodulation Measurement Application (Informative)

## C.1 Determining Interference Contributors

The following section describes how to measure the magnitude of the various interference contributors. It is primarily used to determine intermodulation order as well as contributors that are already on frequency. It is useful in advanced trouble shooting. An Excel spreadsheet is available to provide a curve fit that identifies the contribution power level of the following contributors. Figure C - 1, **Interference Contributors** shows some typical interference contributors that prevent the desired VCPC to be achieved.

- On frequency components (could be OOBE or on frequency IM)
- 3rd Order contributors
- 5th Order contributors
- External Noise contributors

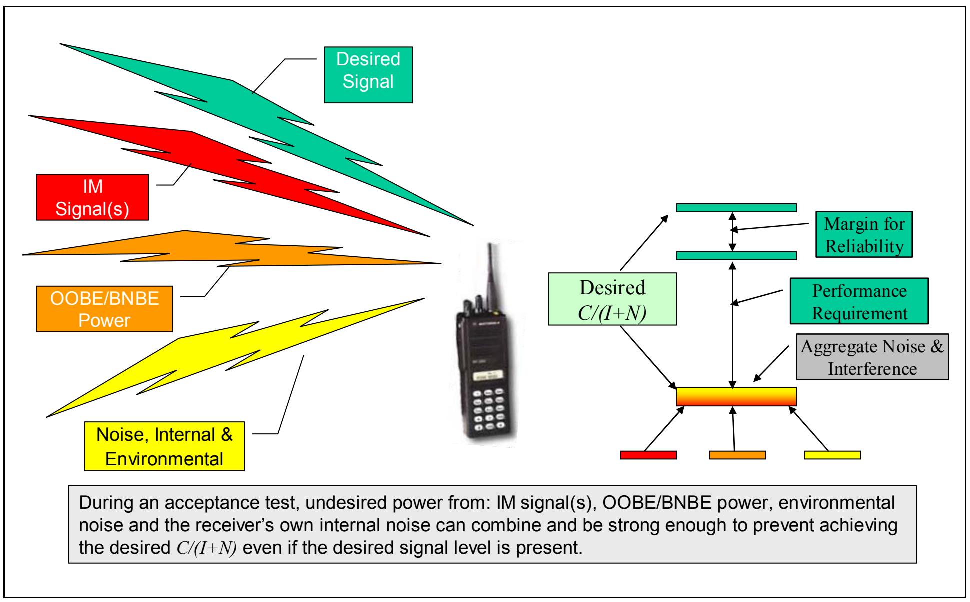



**Figure C - 1, Interference Contributors**

## C.2 Measurement Test Setup

The recommended test setup is in shown in Figure C - 2.

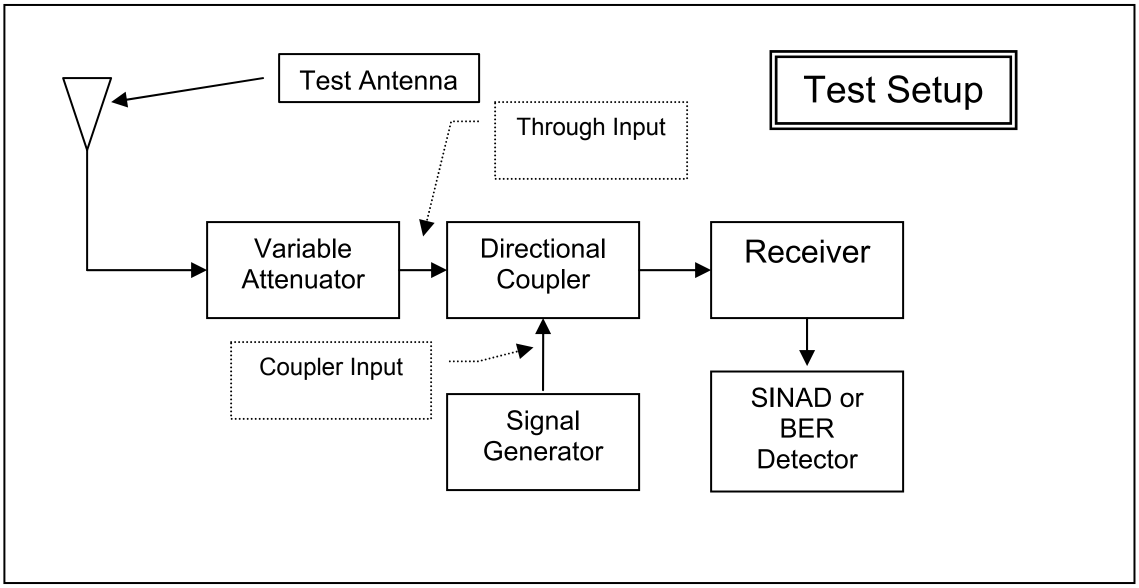



**Figure C - 2, Measurement Test Setup**

1) Measure the receiver reference sensitivity directly, bypassing the directional coupler, record as Ref Direct.
2) With the attenuator set at maximum, measure the reference sensitivity through the coupled port (high loss port) of the directional coupler[27], record as Ref SG Coupler.
3) Determine the directional coupler insertion loss[28] and record as SG Coupler IL (dB) = Ref Direct ($dBm$) - Ref SG Coupler ($dBm$).
4) Terminate the coupled port of the directional coupler and measure the reference sensitivity through the through line (low loss port), record as Ref Antenna Coupler.
5) Determine the directional coupler through line insertion loss as Ant Coupler IL (dB) = Ref Direct ($dBm$) - Ref Ant Coupler ($dBm$)
6) Increment the Variable Attenuator from 0 dB to 24 dB in 2 $dB$ steps and record the Signal Generator power level necessary to establish reference sensitivity. Sig Gen Power.
7) Input the measured Sig Gen Power levels into the spreadsheet tool[29] (orange cells).
8) Use “Solver”[30] to drive the blue cell to zero by changing the values in the green cells.
    a. Observe the match between the black (data) line and the Least Square Fit Model (orange line).

---

[27] Use a directional coupler with a directivity of ≥20 $dB$, insertion loss ≤ 1 $dB$ and VSWR for all ports of ≤1.2:1, [603],[102.CAAA], [905.CAAA] [902.CAAA] and [902.CBAA].
[28] Use a directional coupler with a low insertion loss, ≤ 1 $dB$ on the through port. If this is not provided the insertion loss of the coupler will enhance the receiver’s intermodulation characteristics.
[29] Interference Analysis Tool-V1.xls
[30] To activate “solver”, open Tools/Add-Ins then check the box for Solver Add-in.

b. For initialization it is recommended that the green cells be manually set equal and approximately 5 $dB$ less than the 0 $dB$ attenuator sensitivity value. This initialization approach generally results in the Solver being able to converge.
c. The blue cell will never reach zero. Multiple iterations can be executed to minimize the value of blue cell.

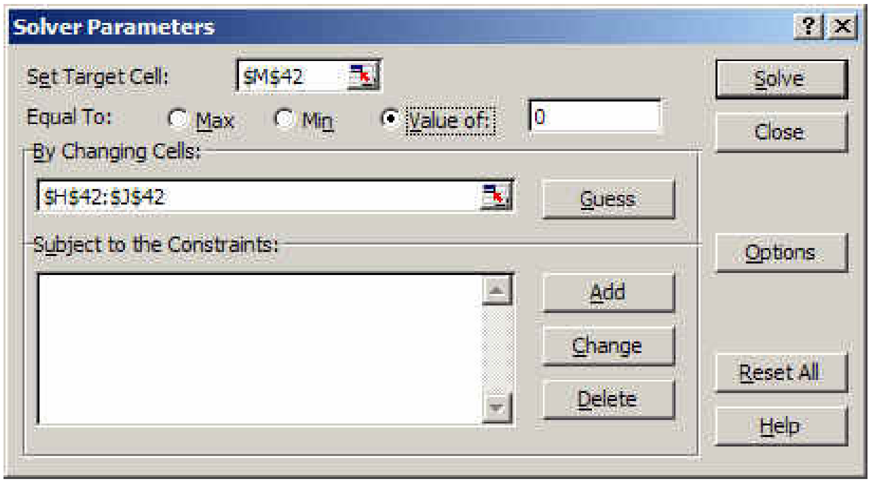



**Figure C - 3, Solver Add-in Application**

Figure C - 3 shows the results after multiple iterations. Figure C - 4 shows the entire spreadsheet tool.

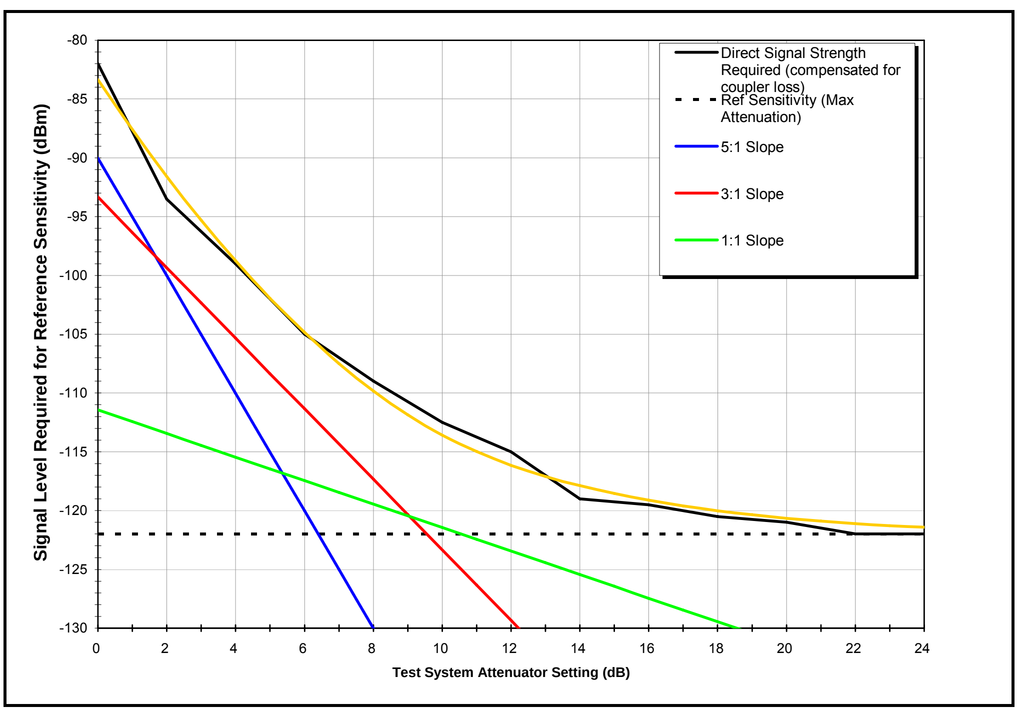



**Figure C - 4, Example Curve Fit Results**

In this example, 5th order IM contributors have the highest signal level followed by the 3rd order IM contributors. The specific contributors can then be determined mathematically or by viewing the spectrum with a spectrum analyzer.

Note that the determination of the local median, §5.7.3.2, utilizes a filter to minimize the effect of receiver intermodulation. It is possible that frequencies that are filtered out represent the primary degradation contributors. If this is the case, and the victim receiver meets its' IMR specification, frequency changes or adding attenuation could be necessary to resolve this type of interference.

**Instructions:**
Load the signal strengths required for Ref Sens in the orange cells
Load the direction coupler losses and the C/N value at sensitivity in the yellow cells
Use "Solver" (a tools Add-in) to drive the blue cell (M42) to zero by changing the green cells (H42, I42 & J42)

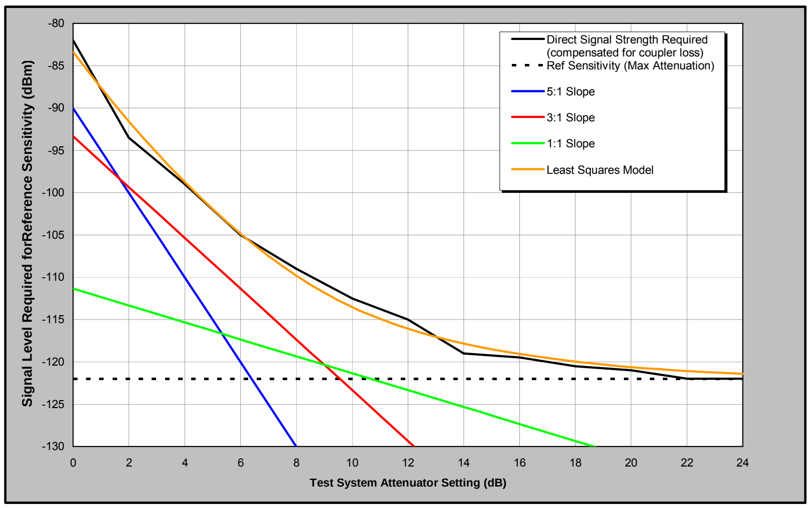
| Measured | |
|---|---|
| -122.0 dBm | **Ref Direct** |
| -102.0 dBm | **Ref SG Cplr** |
| -121.8 dBm | **Ref Ant Cplr** |

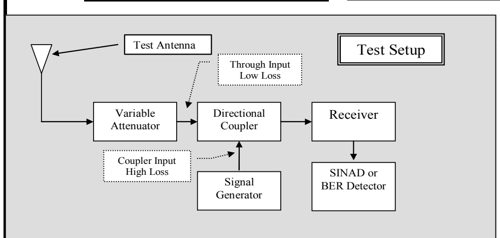
| | |
|---|---|
| **C/N for Ref Sens** | 5.0 dB |
| **SG Coupler Loss:** | 20.0 dB |
| **Ant Cplr Loss** | 0.2 dB |

| | Attenuation | Measured Required Signal Strength |
|---|---|---|
| Max | 110 dB | -102.0 dBm |
| | 0 dB | -62.0 dBm |
| | 2 dB | -73.5 dBm |
| | 4 dB | -79.0 dBm |
| | 6 dB | -85.0 dBm |
| | 8 dB | -89.0 dBm |
| | 10 dB | -92.5 dBm |
| | 12 dB | -95.0 dBm |
| | 14 dB | -99.0 dBm |
| | 16 dB | -99.5 dBm |
| | 18 dB | -100.5 dBm |
| | 20 dB | -101.0 dBm |
| | 22 dB | -102.0 dBm |
| | 24 dB | -102.0 dBm |

| Attenuation | **Direct Signal Strength Required (compensated for coupler loss)** |
|---|---|
| 0 dB | -82.0 dBm |
| 2 dB | -93.5 dBm |
| 4 dB | -99.0 dBm |
| 6 dB | -105.0 dBm |
| 8 dB | -109.0 dBm |
| 10 dB | -112.5 dBm |
| 12 dB | -115.0 dBm |
| 14 dB | -119.0 dBm |
| 16 dB | -119.5 dBm |
| 18 dB | -120.5 dBm |
| 20 dB | -121.0 dBm |
| 22 dB | -122.0 dBm |
| 24 dB | -122.0 dBm |

| | Ref Sensitivity (Max Attenuation) |
|---|---|
| 0 dB | -122.0 dBm |
| 24 dB | -122.0 dBm |




| Attenuator | **5:1 Slope** | **3:1 Slope** | **1:1 Slope** | Least Squares Model | | | Modeled Required Power at Attenuator Input |
|---|---|---|---|---|---|---|---|
| 0 dB | **-90.02252** | **-93.35511044** | **-111.347516** | -83.34400256 | 1.806343 | **11.62577** | -83.1 dBm |
| 1 dB | -95.02252 | -96.35511044 | -112.347516 | -87.5799544 | | | -86.4 dBm |
| 2 dB | -100.0225 | -99.35511044 | -113.347516 | -91.56951774 | 3.726762 | | -89.4 dBm |
| 3 dB | -105.0225 | -102.3551104 | -114.347516 | -95.29301939 | | | -92.1 dBm |
| 4 dB | -110.0225 | -105.3551104 | -115.347516 | -98.7461687 | 0.06443 | | -94.5 dBm |
| 5 dB | -115.0225 | -108.3551104 | -116.347516 | -101.931731 | | | -96.7 dBm |
| 6 dB | -120.0225 | -111.3551104 | -117.347516 | -104.8481605 | 0.023055 | | -98.6 dBm |
| 7 dB | -125.0225 | -114.3551104 | -118.347516 | -107.4828712 | | | -100.3 dBm |
| 8 dB | -130.0225 | -117.3551104 | -119.347516 | -109.8152167 | 0.664578 | | -101.6 dBm |
| 9 dB | -135.0225 | -120.3551104 | -120.347516 | -111.8286237 | | | -102.6 dBm |
| 10 dB | -140.0225 | -123.3551104 | -121.347516 | -113.5246107 | 1.049827 | | -103.3 dBm |
| 11 dB | -145.0225 | -126.3551104 | -122.347516 | -114.9286043 | | | -103.7 dBm |
| 12 dB | -150.0225 | -129.3551104 | -123.347516 | -116.0836505 | 1.174298 | | -103.9 dBm |
| 13 dB | -155.0225 | -132.3551104 | -124.347516 | -117.0378996 | | | -103.8 dBm |
| 14 dB | -160.0225 | -135.3551104 | -125.347516 | -117.8343303 | 1.358786 | | -103.6 dBm |
| 15 dB | -165.0225 | -138.3551104 | -126.347516 | -118.5063173 | | | -103.3 dBm |
| 16 dB | -170.0225 | -141.3551104 | -127.347516 | -119.0778068 | 0.178247 | | -102.9 dBm |
| 17 dB | -175.0225 | -144.3551104 | -128.347516 | -119.5655375 | | | -102.4 dBm |
| 18 dB | -180.0225 | -147.3551104 | -129.347516 | -119.9815076 | 0.268834 | | -101.8 dBm |
| 19 dB | -185.0225 | -150.3551104 | -130.347516 | -120.3349129 | | | -101.1 dBm |
| 20 dB | -190.0225 | -153.3551104 | -131.347516 | -120.6334043 | 0.134392 | | -100.4 dBm |
| 21 dB | -195.0225 | -156.3551104 | -132.347516 | -120.8837801 | | | -99.7 dBm |
| 22 dB | -200.0225 | -159.3551104 | -133.347516 | -121.0922945 | 0.823929 | | -98.9 dBm |
| 23 dB | -205.0225 | -162.3551104 | -134.347516 | -121.2647449 | | | -98.1 dBm |
| 24 dB | -210.0225 | -165.3551104 | -135.347516 | -121.4064586 | 0.352291 | | -97.2 dBm |

r.

**Figure C - 5, Spreadsheet "Interference Analysis Tool-V1.xls**

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