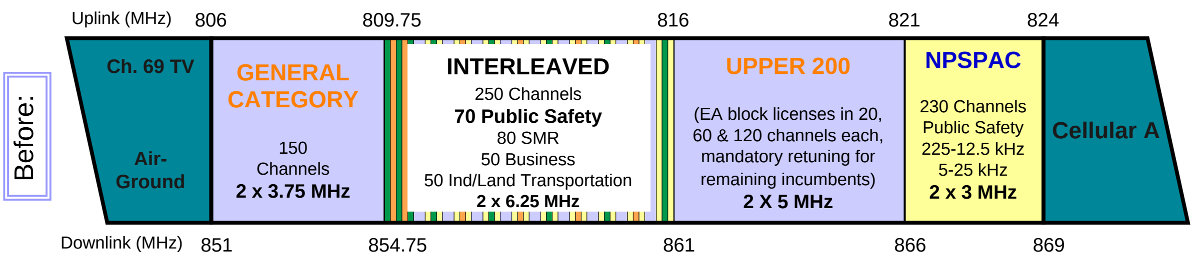
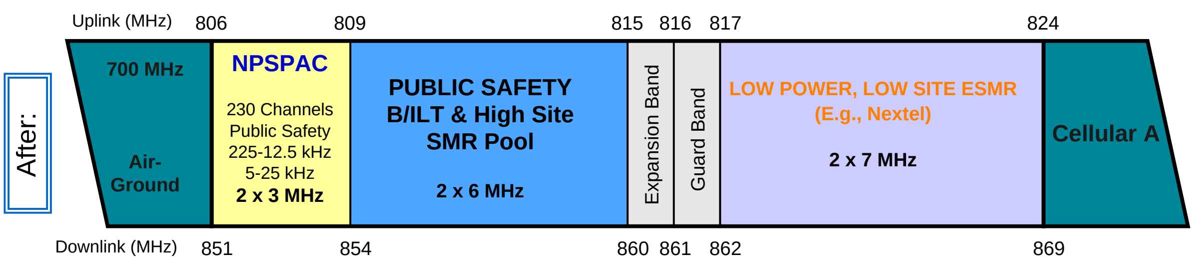
# Guidelines for Conducting Drive Test Surveys for 800 MHz Rebanding

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## 1.0 Description of the Problem

Rebanding requires modifications to both network infrastructure and user radios, so there is always some risk that the rebanded system will not match the performance of the original. The licensee naturally wants proof the two systems are equivalent, especially in terms of geographical coverage. For a simple conventional repeater system that reuses its original antennas, proof of equivalent coverage may only require functional tests of the transmitter, receiver, filters, transmission line, and antennas. From these tests, one can infer that system performance on the street will be equivalent.[1] On the other hand, for a large trunked radio system with multiple repeater sites, it may be necessary to conduct drive test surveys immediately before and immediately after rebanding to prove equivalent performance.

Drive testing has already been suggested as a tool to verify equivalent performance, but there is some confusion in the industry regarding how to conduct a drive test survey and what conclusions can realistically be drawn from such a survey. Because drive testing is labor intensive and expensive, it cannot be done haphazardly. One must employ accurate, efficient and thorough collection methods to ensure the results are unambiguous.

The purpose of this report is to establish guidelines for conducting drive test surveys and methods for analyzing drive test measurements. These guidelines should be used in all cases where a drive test survey is needed to verify equivalent coverage. In addition to proving equivalent coverage, a post-rebanding drive test survey can also be used to assess the potential for 800 MHz interference near Commercial Mobile Radio Service (CMRS) cell sites.[2] Because the CMRS operator may choose not to mitigate all cell sites with cavity filters and intermodulation tuning after rebanding, there is some chance that harmful interference will persist. Post-rebanding measurements can be used to baseline the worst-case carrier-to-interference ratio ($C/I$) near CMRS cell sites and help troubleshoot interference problems later, if they occur.

The remainder of this report is organized as follows: Section 2.0 suggests circumstances that justify drive test surveys. Section 3.0 describes survey methods for proving equivalent coverage. Section 4.0 defines the pass/fail criterion for proving equivalent coverage. After a brief tutorial on 800 MHz interference in Section 5.0, Section 6.0 describes survey

[1] Assuming the new frequency falls within the antenna manufacturer's specified band limits.

[2] The licensee might also be concerned about co-channel interference from other 800 MHz systems located outside the service area. The FCC will apply minimum spacing rules to minimize the likelihood of harmful co-channel interference, but the FCC will not necessarily provide equivalent or better co-channel interference ratios in rebanded systems. This problem, if it occurs at all, should not affect NPSPAC licensees as all of these channels are moved as a block nationwide. Co-channel interference from other 800 MHz systems is beyond the scope this report.

methods for accurately estimating potential 800 MHz interference near cell sites. Appendix A describes in detail the preferred collection methods for drive test surveys and Appendix B is a test plan for measuring intermodulation immunity in mobile and portable radio receivers.

## 2.0 Circumstances Justifying a Drive Test Survey

A drive test survey is perhaps the best way to ensure coverage is equivalent, but it is difficult to justify an expensive survey if functional tests of transmitter power and receiver sensitivity achieve the same objective. For simple repeater systems this will be the case, while more complex trunked systems with multiple sites may require a drive test survey. To see why this is so, consider two hypothetical case studies:

*A. Case Studies*

Case 1 - Single Channel Duplexed Repeater. The fire department in a small city operates a single channel duplexed conventional repeater operating on 866.1875/821.1875 MHz. According to the manufacturer, the repeater tunes across the entire 800 MHz band with no measurable loss in either transmit power or receiver sensitivity. The same is true of the 50 portable and mobile radios currently operating on the repeater. The duplexer filter passes 851-869 MHz (Tx) and 806-824 MHz (Rx) with an insertion loss of 0.5 dB +/- 0.1 dB across the band. The coaxial cable is 1-5/8" diameter semi-flexible coaxial cable with insertion loss of 0.7 dB per 100 feet with less than 0.05 dB per 100 feet variation across 18 MHz. The antenna is a broadband omnidirectional 9 dBd gain antenna that passes 806-869 MHz with less than 0.5 dB variation across the band. A system block diagram is shown in Figure 1.

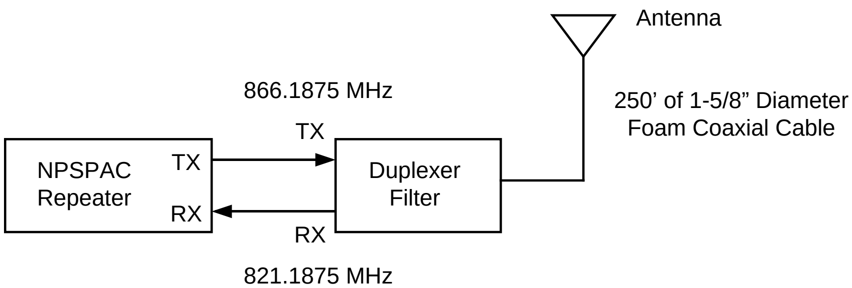


Figure 1 - Single Channel Duplexed Repeater

After rebanding, the licensee operates on 851.1875/806.1875 MHz, a shift downward of exactly 15 MHz. Because the original duplexer, coaxial cable and antenna are all designed to pass these frequencies with negligible performance variation, the licensee and the CMRS operator chose not to replace this equipment. The licensee did, however, conduct a complete set of measurements to include return loss sweep of the antenna and transmission line, insertion loss of the transmission line, and insertion loss and frequency response of the duplexer. All measurements were recorded and filed for later reference. The licensee also conducted a thorough co-site interference study for the repeater site.

In addition, the licensee measured transmitter output power and receiver sensitivity before and after rebanding to ensure there was no measurable difference in repeater performance on the new channel. After these measurements were collected and analyzed, the licensee and the CMRS operator agreed that a drive test survey was not necessary. This decision was based on the fact that radio wave propagation on average is virtually the same between the two pairs of frequencies and any potential degradation at the repeater site should have been discovered during testing.

Case 2 - Large Trunked Radio System. In this case, the public safety agency operates a trunked radio system comprising a combination of multisite (multicast) and simulcast. Three 20-channel sites in the downtown area are simulcast and a second 5-channel system operates from a tall tower outside the metropolitan area. The tall site provides both wide-area coverage outside the downtown area and fill-in coverage downtown for areas not covered well by the simulcast system. The manufacturer employs a handoff scheme that seamlessly transfers users from one system to the other when weak or distorted control channel signals are encountered. The tall site also employs two separate voting receiver sites to overcome system imbalances in weak signal areas. Five bi-directional amplifier systems are installed in downtown buildings and are donored from the 3-site simulcast network. There are 5,000 mobile and portable users on the network.

The public safety agency holds FCC licenses for 15 channels in the 854-861 MHz band and 10 channels in the NPSPAC band (866-869 MHz). Five of the ten NPSPAC channels are used in the simulcast network. The other five are used at the tall site. Two of the 15 channels fall between 860 and 861 MHz and will be moved below 860 MHz. At each of the simulcast sites, two transmitter combiners and transmit antennas are used, each with ten channels. The minimum spacing in each combiner is 500 kHz and the maximum combiner insertion loss is 3.1 dB. A single receive antenna with a receiver multicoupler is used at each repeater or voting receiver site. All transmit antennas are specified to pass 851-869 MHz and all receive antennas are specified to pass 806-824 MHz.

After rebanding, it was not possible to combine the two new channels from the 854-860 MHz band in the existing combiner without introducing an additional 1.5 dB insertion loss (due to closer channel spacing). For this reason, the TA approved funding of a new two-channel combiner and transmit antenna for these channels at each of the three simulcast sites. The original transmit antenna model was discontinued, so a new antenna with roughly equivalent performance specifications was selected. During pre-rebanding site measurements, a bad transmit antenna was discovered (poor return loss) and replaced by the public safety agency. New antennas are located on the same horizontal boom as the original transmit antennas at each of the three simulcast sites.

A complete set of tests was conducted at each site prior to rebanding to fully characterize the performance of transmitters, receivers, transmitter combiners, receiver multicouplers, transmission line, and antennas. All data were recorded and filed for later reference.

Following these tests, the parties discussed the need for drive test surveys immediately before and immediately after rebanding. The public safety agency argued that surveys were needed if for no other reason than the fact that the antenna for the two-channel combiner was different than the original transmit antenna. The agency also argued that tower effects on the pattern might be different. The CMRS operator countered that the manufacturer's supplied antenna pattern should be sufficient and that any pattern effects caused by the tower would be similar, on average, to the effects on the original antennas, especially because the manufacturer's mounting instructions were followed in both cases to minimize these effects. Also, the CMRS operator argued that antenna patterns are better measured using static measurements over eight line-of-sight paths from 0 to 360 degrees azimuth using high-gain, directional receive antennas. These line-of-sight measurements would be considerably less expensive than a full drive test survey.

In the end, the Transition Administrator approved the drive test measurements because they would serve to troubleshoot any problems with both handoff and simulcast overlap after rebanding. By collecting signal measurements from each of the four repeater sites (different frequencies at each site), capture ratios and other information could be calculated at discrete locations to troubleshoot potential problems. The Transition Administrator believed such measurements could eliminate "finger pointing" if post-rebanding performance problems occurred and save time and money in the long run.[3]

### *B. When to Use Drive Test Surveys*

From the two case studies described above, it should be clear that the complexity of the radio network is the driving consideration when choosing to conduct a drive test survey. For simple radio systems where antennas are not replaced, a thorough set of repeater site measurements should be sufficient to prove equivalent coverage. In fact, a 1 dB loss in output power is much more likely to be detected at the repeater site than during a drive test survey. Even if antennas are replaced, static measurements from line-of-sight locations using high-gain directional antennas will reveal problems with antenna patterns more readily than a drive test survey.

For more complex systems that involve networks of repeater sites, one might argue that the same physical laws apply and drive test surveys are still not required to prove equivalent

[3] This fictitious case study serves to illustrate a technical point. It has not been endorsed by any CMRS operator and it does not commit any operator or the Transition Administrator to a specific position on funding drive test surveys

coverage. The counter argument is that complexities of handoff and simulcast overlap result in more subtle performance changes that are best uncovered by actual field measurements. In other words, the drive test is useful to prove equivalent coverage, but it also provides test data to help troubleshoot subtle problems that might arise after rebanding. In some cases, these problems are not caused by rebanding *per se*, but by poor implementation. Without good before and after measurements, it will be difficult to identify the root cause of the problem. In a sense, the drive test survey is insurance for the licensee and the CMRS operator to mitigate the risk of unresolvable post-rebanding problems.

All projects require a thorough set of repeater site measurements before and after rebanding. These measurements should not be abandoned simply because drive test surveys will be conducted. Without a complete characterization of the system performance at the repeater site, one will not be able to explain differences in coverage performance uncovered by the drive test survey. Further, it is not desirable to discover a problem during the survey, correct the problem and re-do the survey when the problem should have been discovered during initial tests at the repeater site.

## 3.0 Survey Methods for Proving Equivalent Coverage

An acceptable survey will have the following characteristics:

- Receiver System:
  - Omnidirectional antenna comparable to mobile user antenna
  - Sensitivity equal to or better than user radio
  - Accurate (+/- 1.5 dB) and reproducible measurements
  - High dynamic range
  - Filters and attenuators as necessary to reject strong interferers
  - Fast scanning or fast wideband sampling
  - GPS position logging
  - Automated, computer-controlled operation

- Data Collection:
  - Well-defined service area and planned drive routes
  - Linear averaging over at least 40 wavelengths (40 feet at 850 MHz)
  - At least 50 samples per average

- Gridding:
  - Gridded measurement data on a uniform grid covering the service area
  - Grid tile size comparable to collection tile size
  - Comparison of before and after measurements using same grid

- Service Area Reliability:
  - Defined service area reliability threshold, e.g., -99 dBm
  - At least 1750 measurements to ensure a 90% confidence interval of +/- 2%

- Reproducibility:
  - Collect pre-rebanding measurements immediately before rebanding
  - Collect post-rebanding measurements immediately after rebanding
  - Ensure foliage conditions do not change between pre and post measurements
  - Use the identical receiver system for pre and post measurements
  - Ensure all functional tests pass before conducting the post-rebanding survey

For a detailed description of preferred survey methods, please refer to Appendix A.

## 4.0 Pass/Fail Criterion for Proving Equivalent Coverage

Drive test measurements are random variables and one should not assume that measurements taken at the same location on two different days will be identical. There are simply too many variables beyond the control of the survey engineer or technician. There is of course the measurement tolerance of the test receiver, but even a perfect receiver cannot control the time-varying environment surrounding the receiver. Before and after comparisons at specific locations will show some with stronger signals and others with weaker signals. As a matter of fact, measurements of the identical system on different days are unlikely to be identical. These are normal variations that do not necessarily indicate a problem with the rebanded system. Rather than compare discrete locations, one should compare performance using a city-wide metric, specifically the *service area reliability* [1]. The service area reliability is the probability that a particular location, picked at random, will have adequate service. Adequate service is typically defined as a measured signal above a threshold, say -99 dBm. The service area reliability is estimated by computing the ratio of the number of measured locations above the threshold to the total number of locations measured. For example, if 1,750 uniformly distributed locations are measured across the service area and 1,680 are above threshold, the service area reliability estimate is 96%.

The measured service area reliability is a point estimate. We generally want more than just a point estimate. We also want some measure of the accuracy of the estimate. The usual way to measure accuracy is to apply the *confidence level* and the *confidence interval*. The confidence level is the probability that the actual service area reliability falls within some range of the point estimate. The range is the confidence interval. For example, using the appropriate expressions (see Appendix A), we find that for 1,702 measurements (*samples*), the 90% confidence interval is +/- 2% (worst-case). In other words, the probability that the actual service area reliability is within two percentage points of the point estimate is 0.9 or 90%.

If before and after measurements are taken at the same time of year using the same test receiver and antenna, the measured service area reliability should be reproducible within a range equal to *twice* the confidence interval. Why twice the confidence interval? Because each value of measured service area reliability is only an estimate of the actual service area reliability. For example, let's assume a 90% confidence interval of +/- 2% and an actual service area reliability of 95%. If the pre-rebanding service area reliability estimate is 97% and the post-rebanding service area reliability estimate is 93%, both are within the confidence interval of the actual value, but they are not within +/- 2% of each other.[4]

The pass/fail criterion for equivalent coverage is stated as follows:

> *"If the post-rebanding service area reliability estimate falls inside a range equal to twice the 90% confidence interval of the pre-rebanding service area reliability estimate, the two systems have equivalent coverage."*

The converse is not necessarily true. If the post-rebanding service area reliability estimate falls below the confidence interval of the pre-rebanding service area reliability estimate, it may indicate a problem or it may simply be a statistical anomaly. In this case, the parties should analyze the measurements in more detail to see if there is an underlying physical cause. Was the power amplifier for the control channel transmitter operating at reduced power? If the replacement antenna is a directional type, was it installed incorrectly so the main lobe is misdirected? For antennas with electrical beamtilt, was there a manufacturing defect such that the beamtilt is incorrect or non-existent? Was the coaxial cable from the test antenna to the test receiver pinched, thereby introducing additional attenuation? Did the engineer or technician follow identical collection and calibration procedures and use identical test equipment during both surveys?

If there is no underlying cause, the difference may simply be due to a rare event — a statistical anomaly. Only a small number of rebanding cases should fall in this category.

In some cases, the service area reliability may be quite low, indicating a poorly performing system. Rebanding will not improve the coverage of an 800 MHz radio system, but tests associated with rebanding may reveal existing problems. The approach described above works well for any value of service area reliability.

The results of the pre-rebanding survey should be furnished to the CMRS operator as soon as possible following the survey. Those locations near the operator's cell sites with weak public safety or private radio signals will be more vulnerable to CMRS interference. The CMRS operator can combine the drive test information with predictions or measurements of its own signals to estimate the carrier-to-interference ratio near its cell sites and

[4] A doubling of the confidence interval is a simplified approach, but it is consistent with the principle that the variance of the sum of two identically distributed random variables is equal to twice the variance of one random variable.

therefore better determine the need for mitigation. Survey methods for estimating 800 MHz interference are discussed in Section 6.0 of this report.

## 5.0 800 MHz Interference

We will use the term "800 MHz interference" to describe radio interference created by 800 MHz ESMR operators, the A-Band cellular operator or the B-Band cellular operator. This interference appears on the downlink (repeater to portable) and falls into two categories:

- *Receiver intermodulation* is a non-linear combination of two or more interfering signals inside the receiver front-end (low-noise amplifier and/or mixer).

- *Out-of-Band Emissions* (OOBE) comprise radio frequency energy that falls outside the assigned channel for the transmitter. Out-of-band emissions include radio carrier harmonics, transmitter intermodulation products, and broadband transmitter "noise" that is typical of radio transmitters.

A block diagram for a typical land mobile radio receiver is shown in Figure 2. Mobile radio receivers in the 800 MHz band are vulnerable to receiver intermodulation because the front-end bandpass filter must pass all frequencies from 851 to 869 MHz. ESMR frequencies fall within this same band, so the low-noise amplifier that follows the bandpass filter is exposed to strong interfering signals that mix within the low-noise amplifier.

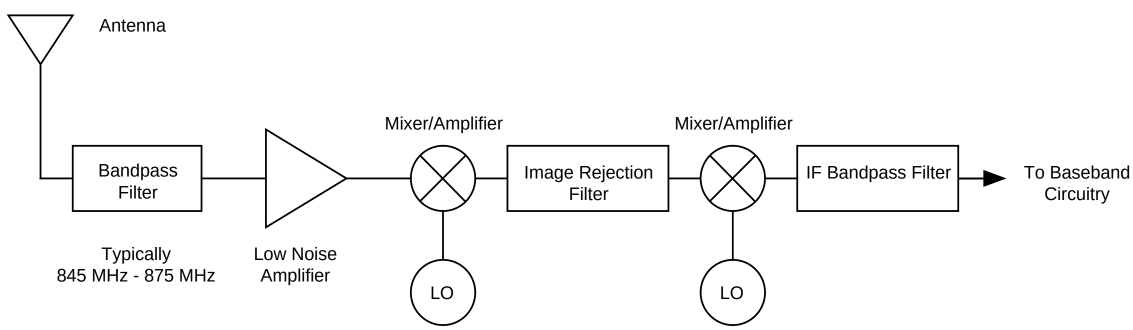


Figure 2 - Typical Public Safety Receiver Front-End[5]

Mathematically, an intermodulation (IM) product between two interferers with frequencies $f_1$ and $f_2$ can be represented by the following general equation:

$$f_{im} = nf_1 + mf_2$$

where $n$ and $m$ are non-zero integers. The order of the product is simply the sum of the

[5]A image reject filter between the LNA and the first mixer is also present, but not shown in the figure for simplicity.

absolute values of the coefficients, $|n| + |m|$.

For example, two interferers operating at 861.4875 and 862.4875 will create the following third-order intermodulation products inside the 800 MHz band:

$$2\,(861.4875\text{ MHz}) - 862.4875\text{ MHz} = 860.4875\text{ MHz}$$
$$2\,(862.4875\text{ MHz}) - 861.4875\text{ MHz} = 863.4875\text{ MHz}$$

Third-order products are also created by three carriers. These products have the form A + B - C rather than 2A - B. Three-carrier products are more numerous than two-carrier products because there are $N(N-1)(N-2)/2$ total three-carrier products and only $N(N-1)$ two-carrier products, where $N$ is the number of transmit frequencies.

Laboratory measurements show that 5th and higher order intermodulation products are much weaker than 3rd order products (in some cases, 25 dB weaker). Thus, it is reasonable to focus mitigation efforts solely on 3rd order products.

In general, given a set of potential interfering frequencies that fall within the range $[f_{min}, f_{max}]$, no third-order product can fall farther than $|f_{max} - f_{min}|$ below $f_{min}$ or above $f_{max}$. Mathematically, we can state a sufficient condition to preclude 3rd order IM products as

$$f_r < 2f_{min} - f_{max} \text{ or } f_r > 2f_{max} - f_{min}, \tag{1}$$

where $f_r$ is the nearest receive frequency requiring interference protection. This principle is shown graphically in Figure 3.

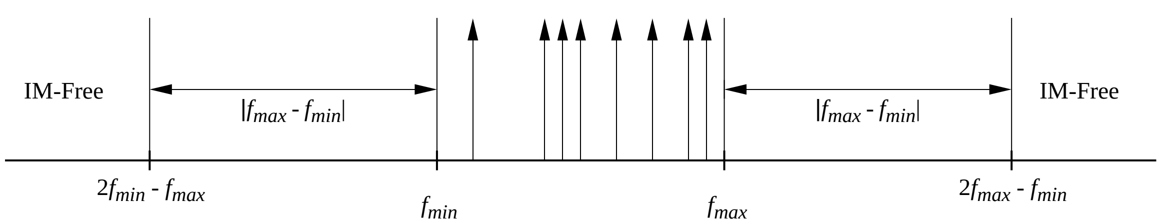


Figure 3 - Range Limits of 3rd Order IM Products

Thus, a simple way to eliminate receiver intermodulation is to first create a guard band between dissimilar services and then ensure frequency sets for the interfering service have a span no greater than the span of the guard band. Because guard bands waste spectrum, it is important to limit the number of band edges between the two dissimilar services so only one guard band is required. This is precisely what the FCC has done with its rebanding plan.

Today, the 851-869 MHz band consists of four subbands as shown in Figure 4 ("Before"). Note that public safety and private radio channels occur in the interleaved band *and* in the NPSPAC band. Interleaving alone creates insurmountable problems, but the four band edges also create problems.

The proposed rebanding in Figure 4 ("After" ) reduces the band edges from four to one and effectively creates a 2 MHz guard band where ESMR operators have agreed to certain significant service restrictions. This pseudo-guard band has a twofold purpose: it allows bandpass filters at the cell site to roll off and it enables the ESMR operator to create channel plans with intermodulation products that fall in the guard band, but not on public safety channels. Interference from the A-Band cellular operator is also reduced after rebanding because NPSPAC channels are moved 15 MHz away. Most IM products created by the A-Band operator will fall in the 862-869 MHz band where Nextel and other CMRS providers will operate.

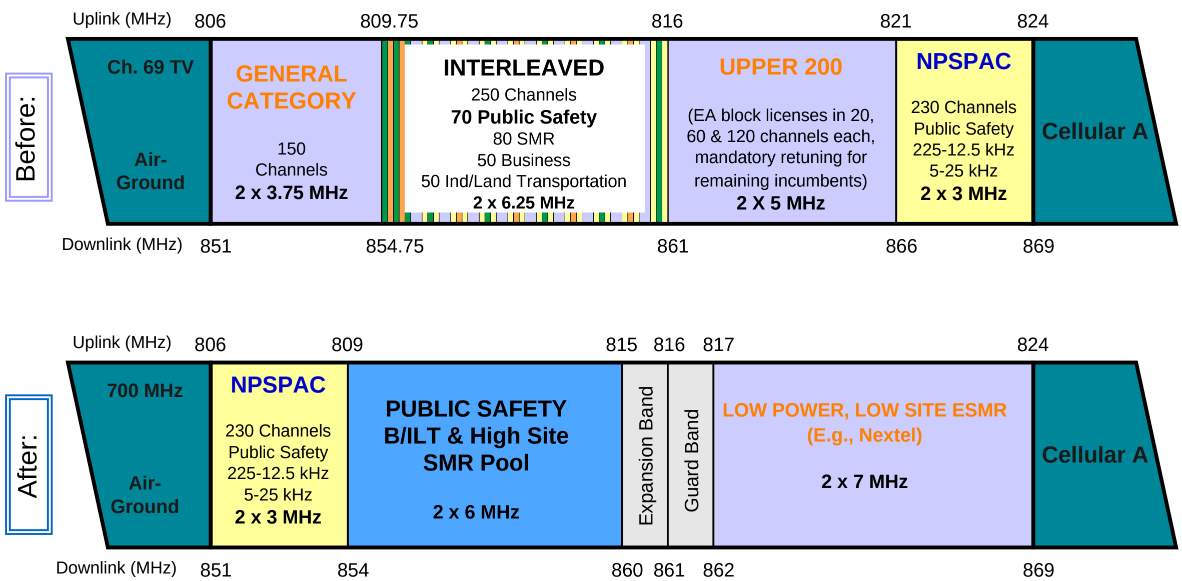


Figure 4 - FCC Rebanding Plan Spectrum Allocation[6]

After rebanding, the solution to OOBE is straightforward. Each of the CMRS operator's transmit antenna sectors at problem cell sites should have a cavity bandpass filter designed to pass 862-869 MHz and reject all frequencies below 860 MHz by at least 45 dB. Such a filter is well within the state-of-the-art. Existing bandpass filters at cellular A-Band cell sites should roll off sufficiently that the A-Band operator will no longer create an OOBE problem for public safety and private radio licensees.

Some engineers use the term "receiver overload" to describe strong interfering signals at the radio receiver that do not have the mathematical relationship to create harmful

[6]The 2 MHz between 860 and 862 MHz is subdivided into an Expansion Band (860-861) and a Guard Band (861-862). No public safety system is required to remain in or relocate to the Expansion Band; although they may do so voluntarily. The level of protection afforded in the Expansion Band creates the effect of a pseudo-guard band.

intermodulation products. These interferers may compress the front-end amplifier, activate automatic gain control circuits (AGC) and degrade the receiver sensitivity. Laboratory measurements of typical “Class A” portable and mobile receivers show that receiver overload is a minor problem and the dominant problem is receiver intermodulation. In other words, the portable or mobile receiver is robust in the presence of a single strong interferer, but vulnerable to multiple interferers if they create intermodulation products that fall on active frequencies.

## 6.0 Survey and Analytical Methods for Estimating Interference

We should first dispel the myth that rebanding by itself eliminates 800 MHz interference. Rebanding by itself does not eliminate interference. Instead, it creates necessary conditions so two important mitigation techniques can be effective:

- Intermodulation tuning to eliminate harmful 3rd order products
- Cavity bandpass filters to reduce out-of-band emissions

Of course these mitigation techniques are only effective if they are actually employed. We cannot assume that the CMRS operator will automatically use both techniques at every cell site. For example, the likelihood of harmful interference from a tall cell site in a rural area is small. The operator may choose not to mitigate such a site. On the other hand, a known problem site in a downtown area will certainly require mitigation.

Unless the operator employs both mitigation techniques at all cell sites in the service area, 800 MHz interference may persist. Experience has shown that identifying and correcting interfering cell sites is time-consuming and costly for both the licensee and the CMRS operator. The parties are naturally interested in ways to make interference diagnosis as efficient as possible after rebanding. The purpose of this section is to establish methods for collecting interference-related measurements and estimating the carrier-to-interference ratio in the vicinity of CMRS cell sites. This information can be used both to diagnose actual interference problems and to identify cell sites requiring mitigation due to their interference potential.

One might argue that interference measurements should be taken in conjunction with the post-rebanding drive test survey. This approach is not very practical in large metropolitan areas. Interference from 800 MHz CMRS cell sites tends to occur within a few hundred yards of the site. A post-rebanding drive test survey conducted for the purpose of proving equivalent coverage will generally not collect adequate measurements near each cell site. Furthermore, there may be hundreds of 800 MHz cell sites in the service area. We also know that the cell site environment changes as 800 MHz CMRS operators add cell sites or change power levels, frequencies, antennas, and airlink standards at existing cell sites.

Thus, there is a limit to the usefulness of post-rebanding drive test measurements with respect to interference. Instead, a separate survey is needed at the time an interference problem occurs to help identify the source.

To minimize the likelihood of harmful post-rebanding interference and to reduce the need for interference measurements, the CMRS operator should apply technical criteria to each of its cell sites to identify at the outset which sites require mitigation. Further, the licensee should have access to an up-to-date geographical database that identifies all 800 MHz cell sites in the service area and which sites have already been mitigated. A quick check of this database should show whether the complaint could be caused by 800 MHz interference and which CMRS operator is the likely source of interference.

If 800 MHz interference is suspected after rebanding, one should use the following guidelines to help diagnose the problem with drive test measurements:

Remember that the two dominant types of interference are receiver intermodulation and out-of-band emissions. Because receiver intermodulation is created inside the portable or mobile radio receiver, it cannot be measured directly during a drive test survey. Instead, one must apply analysis to three types of measurements:

- Measured amplitude of the public safety or private radio signal
- Measured amplitude of the CMRS control channel
- Receiver intermodulation performance curve for the portable or mobile radio

This information is used to compute the expected $C/I$ where $C$ is the measured public safety or private radio signal and $I$ is the power of the intermodulation product inside the receiver. We use the term *expected* $C/I$ because it is the $C/I$ when the combination of CMRS frequencies exists at the site to mathematically create on-channel IM products. If the operator has not committed to perform IM tuning at this site, we should assume that such combinations do or will exist.[7]

The receiver IM interference power, $I$, is not measured directly, but instead is derived from the measured power of the CMRS interferer and the IM performance curve for the radio receiver. Any locations where $C/(I+N)$ is less than 20 dB are considered unsatisfactory [5]. At these locations, the operator should conduct IM tuning so that 3rd order products do not fall below 860 MHz. In other words, mitigation is required at these sites whether the operator had previously planned to do so or not.

To compute the $C/(I+N)$ ratio at each measurement location, follow these steps:

Step 1: On the bench, measure and plot the strong signal IM rejection ratio as a

[7]With the possible exception of NPSPAC channels. If the CMRS operator operates in the band 861.5 - 869 MHz, the lowest third-order IM product falls on 854 MHz. Third order products in the new NPSPAC band are still possible at co-location sites, however, where an ESMR operator is co-located with the A-Band cellular operator.

function of interfering signal power. See Appendix B for the bench test procedure. A sample plot for a typical public safety portable radio is shown in Figure 5.

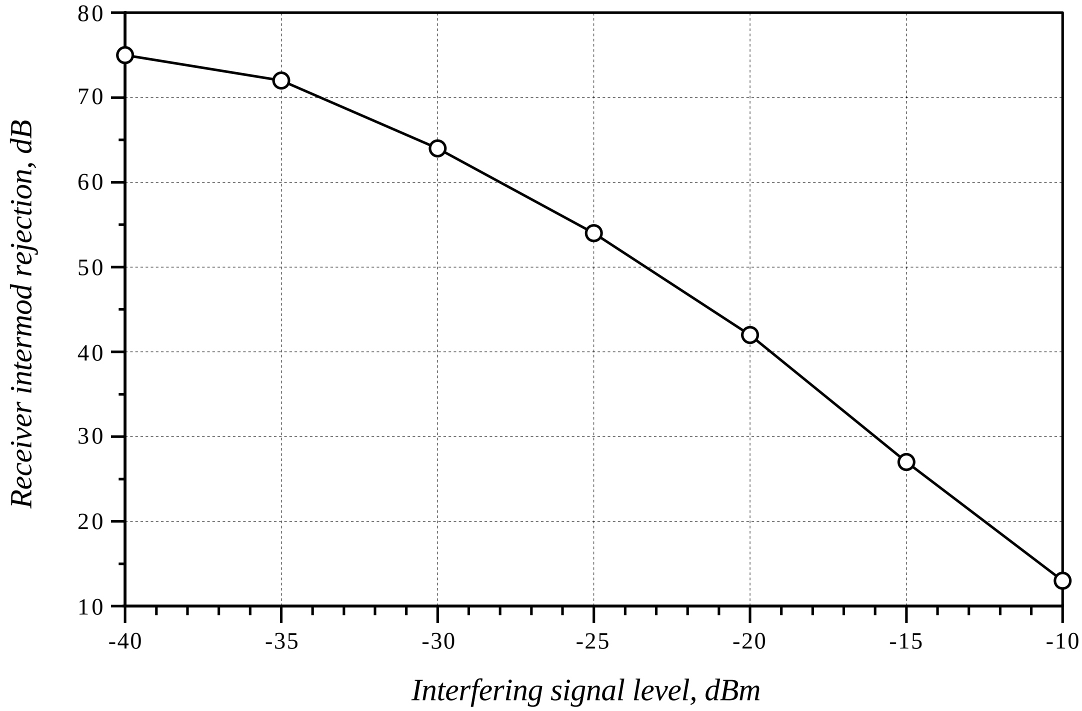


Figure 5- Typical Strong Signal Receiver Intermodulation Rejection
(3rd order, two frequencies, equal amplitude, 2 MHz separation, IIP3 = 3 dBm)

Step 2: Collect desired signal and interfering signal measurements near the ESMR or cellular operator cell site of interest.

Step 3: Using the curve developed in Step 1, compute the receiver IM interference power, *I*, as a function of the external interfering signal power. *I* = Interfering signal power in dBm - IM rejection ratio in dB - *C/I* required at threshold.[8]

Step 4: From the measured sensitivity of the receiver and the modulation type, determine the thermal noise floor, *N*, in dBm. See Annex A of TSB-88-B [1] for more guidance on determining the thermal noise floor from the measured sensitivity and the modulation type. At strong interfering signal levels, thermal noise will be negligible relative to receiver IM interference.

[8]If we assume the that the minimum *C/I* is equivalent to the minimum *C/N*, this ratio is found from Annex A of TSB-88-B. For example, an analog FM radio operating on a NPSPAC channel requires a *C/N* of 5 dB for 12 dB SINAD.

Step 5: Convert *I* and *N* to milliwatts, compute the sum and convert back to dBm.

Step 6: Compute the $C/(I{+}N)$ from the measured power of the desired signal, *C*, and the sum of the receiver IM interference power and thermal noise power, $(I{+}N)$, calculated in Step 5.

Note that some locations will have $C/(I{+}N)$ less than 20 dB simply because the *C/N* is less than 20 dB. These cases should be flagged as any performance loss is due primarily to a weak signal, not 800 MHz interference. Bear in mind that areas with weak signals (median power below –101 dBm for portables, -104 dBm for mobiles) are not afforded the same protection as stronger signals, in accordance with the FCC Report and Order [5].

Out-of-band emissions can be measured directly during the drive test survey by measuring power on an idle channel, but results from a single channel may not reflect conditions on all channels. Past measurements of iDEN signals at Nextel cell sites show that OOBE power relative to power at the iDEN carrier is a predictable function of the number of carriers and the frequency separation. Thus, one can estimate the OOBE power from the power of the interfering carrier(s), frequency of the desired carrier and frequency of the closest interfering carrier. See [6] and Appendix A of [7] for a more detailed discussion of OOBE from iDEN transmitters.

To reduce the number of discrete CMRS frequencies that must be measured during a drive test, ask the CMRS operator to temporarily take one frequency out of service city-wide and broadcast this frequency from *all* cell sites simultaneously. (This action may not be feasible in all cases.) Alternatively, to better identify which cell site is causing the problem (it may not always be the nearest site), a set of three frequencies could be used city-wide in a 3-cell reuse pattern.

## 7.0 References


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[2] W.C. Jakes, ed., Microwave Mobile Communications, IEEE Press Reissue, 1994.

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[5] R&O, FCC 04-168, "Improving Public Safety Communications in the 800 MHz Band, Consolidating the 900 MHz Industrial/Land Transportation and Business Pool Channels, etc." (WT Docket No. 02-55), Released August 6, 2004.

[6] J. M. Jacobsmeyer, "Cellular Radio Interference to Denver's 800 MHz Public Safety Network," June 10, 2003. Submitted as *ex parte* to FCC under Docket 02-55 on June 11, 2003.

[7] J. M. Jacobsmeyer and G. W. Weimer, "How Does the Consensus Plan Eliminate 800 MHz Public Safety Interference?", July 25, 2004. Available in pdf from *www.pericle.com*.

[8] EIA 603A, "Land Mobile (FM or PM) Communications Equipment Measurement and Performance Standards."

[9] C. Hill and B. Olson, "A Statistical Analysis of Radio System Coverage Acceptance Testing," *IEEE Vehicular Technology Society News*, February, 1994.

## 8.0 Questions & Comments

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## 9.0 Revision History

March 12, 2010: Revise Appendix A to include language regarding simultaneous collection of received signal strength, bit-error rate, and audio recordings.

## Appendix A - Methods for Drive Test Collection and Analysis

This appendix describes the recommended methods used for collecting drive test measurements and analyzing the results.

A.1 Properties of Fading Signals. The mobile radio channel is rarely line-of-sight and the received signal is the sum of many reflected and diffracted signals. The term *multipath fading* is used to describe the time-varying amplitude and phase that characterize the composite signal at the receiver. These fluctuations are usually modeled as Rayleigh fading with Rayleigh-distributed amplitude and uniformly distributed phase [1]. Figure A.1 is a plot of amplitude versus time for a typical Rayleigh fading mobile radio channel.

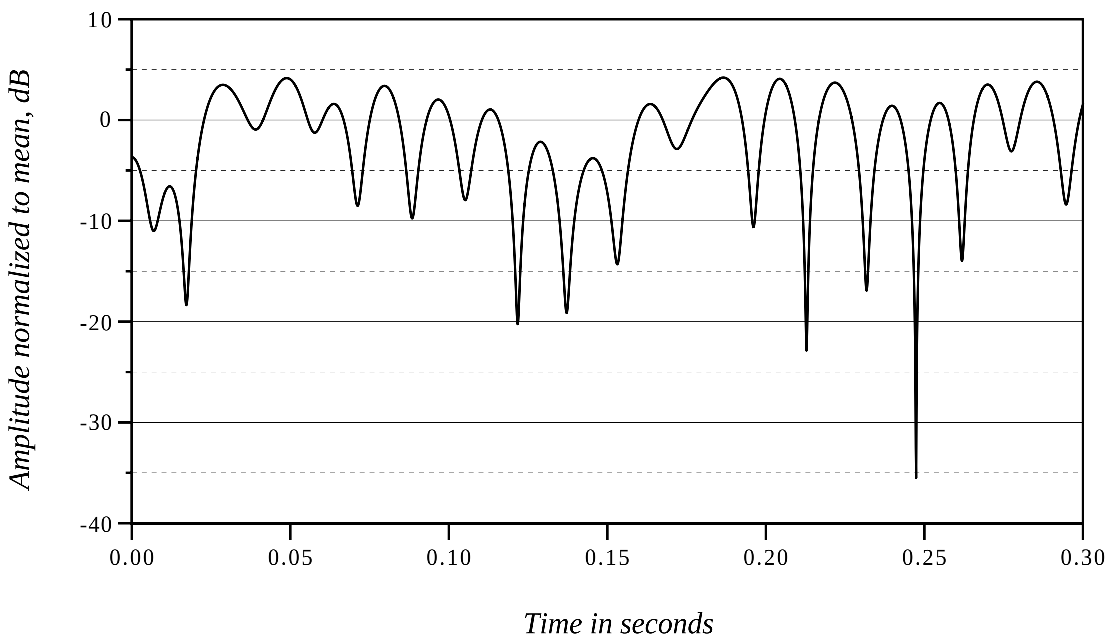


Figure A.1 - Time-Varying Amplitude on Rayleigh Fading Channel
($V$ = 30 mph, $f_c$ = 850 MHz)

The local mean of the Rayleigh fading signal varies more slowly than the instantaneous amplitude and is commonly referred to as *shadow loss*. The most widely used statistical model of shadow loss assumes that the loss is log-normally distributed. In other words, if the signal level is given in decibel form (e.g., dBm), the received signal level, $Y$, has the normal probability density function,

$$f_Y(y) = \frac{1}{\sqrt{2\pi}\,\sigma}\, e^{-\frac{(y-\mu)^2}{2\sigma^2}} \qquad \text{(A.1)}$$

where $\mu$ is the mean and $\sigma$ is the standard deviation.

In mobile radio, the standard deviation of the signal amplitude is typically 8 dB for large service areas and 6 dB for small service areas [1], [2]. TSB-88 suggests a standard deviation of 5.6 dB for predicted signal amplitude using computer models when high resolution terrain data (1 arc second) and good land clutter databases are used [5].

Mobile and portable receivers are usually specified to operate with a minimum local mean in the presence of Rayleigh fading. Thus, for the survey to be a useful indicator of receiver performance, we should estimate the local mean, *not* the instantaneous Rayleigh fading.

Estimating the local mean requires that we average subsample measurements over some distance. The preferred distance is 40λ as it adequately smoothes the Rayleigh fading [2], [5]. Long distances tend to include changes in the local mean due to location variability and are therefore not desirable. However, there is no ironclad rule on the maximum averaging distance. Table A.1 below lists the 40λ distance for typical land mobile radio bands.

**Table A.1 - Recommending Averaging Distance**

| Band | λ, meters | 40λ, meters | 40λ, feet |
|---|---|---|---|
| 150-174 MHz | 2.00 | 80 | 262 |
| 450-470 MHz | 0.67 | 27 | 87 |
| 769-775 MHz | 0.39 | 16 | 51 |
| 851-861 MHz | 0.35 | 14 | 46 |

A.2 Number of Subsamples Required. A minimum number of subsamples is required to get an accurate estimate of the local mean within the 40 wavelength measurement distance (roughly 45 feet at 850 MHz). The 90% confidence interval for a Rayleigh fading signal is given by

$$\text{90\% Confidence Interval (dB)} = 20\ \text{Log}\left(1 + \left(\frac{1.65}{\sqrt{T_s}}\sqrt{\frac{4-\pi}{\pi}}\right)\right) \tag{A.2}$$

where $T_S$ is the number of subsamples [2], [5]. Using (A.2), we find that a 90% confidence interval of +/- 1 dB requires at least 50 subsamples. See EIA TSB-88-C for a more complete treatment of this subject [5].[9]

A.3 Service Area Reliability (SAR). The service area reliability estimate is defined by the following expression:

[9]There appears to be an error in the equation on page 123 of TSB-88-B. See page 90 of TSB-88-A and (A.2) above or TSB-88-C for the correct expression.

$$\text{Service Area Reliability (\%)} = \frac{T_p}{T_t}\,100\% \tag{A.3}$$

where $T_p$ is the total number of grid tiles passed (e.g., those where $C > -106$ dBm), and
$T_t$ is the total number of grid tiles measured.

A.4 Confidence Intervals and Acceptance Tests. A SAR estimate alone is not normally sufficient to ensure the system passes the acceptance test. We also need to know the minimum number of spatially unbiased samples required to ensure the SAR estimate is accurate. To do so, let's first model each measurement sample as an independent trial with probability of success, *p*, where *p* is the probability that the measurement is above the service threshold. (Remember that the measurement sample is actually a linear average of at least 50 subsamples collected over at least 40 wavelengths.) The number of successes in *n* trials is a binomial random variable that we will designate *X*. If we conduct an experiment with *n* trials and observe *x* successes, the point estimate for *p* is simply *x/n*. However, a point estimate alone tells us nothing about the accuracy of the estimate. What we really need is a high confidence that the value *p* lies within a small interval around the point estimate, *x/n*. When the drive test is part of an acceptance test for a new system, one approach is to declare that the system passes the test when the upper edge of the confidence interval is above the Channel Performance Criterion (CPC).[10] TSB-88 refers to this pass/fail criterion as the "Acceptance Window" test.

A.4.1 Acceptance Window Test. Let's say that we are satisfied with a confidence level of 99% and a confidence interval of +/- .02. Given this confidence level and confidence interval, we want to know the required number of samples. In other words, we require a sufficient number of samples that we can say with 99% confidence that the actual service area reliability lies between +/- 2% of the point estimate.

Using the normal approximation to the binomial distribution, one can show that the required minimum number of samples is approximated by the following [4]:

$$n = \frac{z_{\alpha/2}^2\, p(1-p)}{d^2} \tag{A.4}$$

where $z_{\alpha/2}$ is the two-sided argument of the unit normal distribution for a confidence of 1-$\alpha$ and $d$ is one-half of the confidence interval [4]. For example, for 99% confidence, $z_{\alpha/2} = 2.58$.[11]

[10] Typical values for CPC are 95% coverage for mobile radios and 90% coverage for portable radios.

[11] The corresponding values for 90% and 95% confidence levels are 1.65 and 1.96, respectively.

Equation (A.4) is not entirely satisfactory because it includes the parameter we want to estimate, $p$. However, the product $p(1\text{-}p)$ will always be less than or equal to 1/4. Thus, the worst case minimum value of $n$ is given by

$$n = \frac{z_{\alpha/2}^2}{4d^2} \tag{A.5}$$

For $z_{\alpha/2}$ = 2.58 and $d$ = +/- .02, we find $n$ = 4,160. Thus, we require at least 4,160 samples to achieve the required confidence level and confidence interval. Because most surveys result in some bad data that cannot be used, the survey should be planned for some larger number of gridded measurements, say $n$ = 4,500.[12]

A.4.2 Greater Than Test. TSB-88 allows a second type of acceptance test called the "Greater Than" test. This test requires that the measured percentage of test locations strictly exceeds the CPC for the system to pass. Such a test can be more stringent than the confidence interval test, depending on the value of CPC. Typically, the customer specifies that the measured SAR must strictly exceed the CPC (e.g., 95%). Often, no other information is provided by the customer.

From the point of view of the vendor, the system must be designed for a SAR above the required CPC to be confident that when tested, the system will pass. If the system is designed for exactly the CPC and the actual SAR equals the CPC, the probability that the *measured* SAR exceeds the CPC is only 50%. In other words, on average, half of all coverage tests of this system will show a failing SAR and half will show a passing SAR. Most vendors are not willing to take such a risk, so they will design the system with a margin, $d$, above the CPC to ensure the coverage test passes with a high probability.

The expression for this margin is given by

$$d = \sqrt{\frac{z_\alpha^2 p(1-p)}{n}}\,, \tag{A.6}$$

where $z_\alpha$ is the one-sided argument of the unit normal distribution for a confidence level of 1-$\alpha$, $n$ is the number of samples, and $p$ is the CPC. For example, if the coverage test collects $n$ = 300 samples, the CPC is 95%, and the desired confidence level is 99%, then the value of $z_\alpha$ is 2.32 and the required margin is $d$ = 0.029 or 3%. Another way of stating this result is that if the installed system exactly meets the design value of 98%, then the probability that the measured SAR will be below 95% is only 1%. This is usually an acceptable risk for the vendor.

[12]The worst-case minimum value of $n$ occurs when $p$ = 0.5, equivalent to 50% coverage and a poor performing system. But the licensee cannot know the value of $p$ *a priori*, so surveys should always be planned for the value of $n$ corresponding to $p$ = 0.5.

To this point, we are depending on the vendor to implement a system that is at least as good as his design. The real world can differ from the design assumptions and the vendor might get lucky and pass the acceptance test when the actual SAR is below the CPC. In the case of the previous example, if the measured SAR is exactly 95%, the actual SAR might be as low as 92% because the 99% confidence interval is +/- 3% for a test with 300 samples.

To address this concern, we need to look at the "Greater Than" test from the point of view of the customer rather than the vendor. Let's say that the CPC is 95% *and* the customer is not willing to accept a system with an actual SAR below 95%. The customer wants to know what is the minimum measured SAR that ensures, with a 99% confidence, that the actual SAR is at least 95%?

This is a more stringent requirement and to keep $d$ as small as possible, the vendor will want to increase the number of samples. Let's assume $n = 1200$. Using (A.6) with $n = 1200$, $p = 0.95$, and $z_\alpha = 2.32$, we find that $d = 0.0146$ or 1.5%. Therefore, the customer will insist that the measured SAR exceed 95% + 1.5% = 96.5% for the system to be accepted. Given this requirement, the vendor must now design for a SAR above 96.5% to ensure he passes with a single coverage test. Specifically, for 99% confidence that the measured SAR is greater than 96.5%, he must design for at least 97.7% coverage, assuming 1200 samples. The reader should bear in mind that the more stringent the coverage requirement, the more costly the system.

Table A.2 lists the values of $z_\alpha$ and $z_{\alpha/2}$ for 90%, 95%, and 99% confidence levels.

**Table A.2 - Values of $z_\alpha$ and $z_{\alpha/2}$ for Various Confidence Levels**

| Confidence Level | $z_\alpha$ ("Greater Than" Test) | $z_{\alpha/2}$ ("Acceptance Window" Test) |
|---|---|---|
| 90% | 1.28 | 1.65 |
| 95% | 1.65 | 1.96 |
| 99% | 2.32 | 2.58 |

A.5 Service Threshold. The receiver threshold for reliable service (e.g., DAQ = 3.4) is usually provided by the manufacturer after the customer sets the threshold for quality of service. Often the thresholds for fading channels are not included in the manufacturer's data sheet, but representative values can be found in TSB-88. For DAQ = 3.4, common thresholds in fading channels are -101 dBm for analog NPSPAC band radios and -106 dBm for digital P25 radios.[13]

A.6 Test Equipment Characteristics. The test receiver should produce accurate and reproducible measurements. Measurement error should be no greater than 1.5 dB.

[13]The service threshold depends on the receiver's performance in Rayleigh fading, but also on the receiver noise floor which varies between manufacturers and between models.

To ensure at least 50 subsamples are collected in a relatively short distance (e.g., 250 feet), the receiver must scan quickly or the vehicle must move slowly. As a practical matter, the vehicle must keep up with other traffic, so a fast scanning receiver is mandatory. For example, if the vehicle is moving at 73 feet per second (50 mph) and the desired averaging distance is 100 feet, the receiver must collect one measurement every 37 milliseconds to ensure at least 50 subsamples are collected.[14] When multiple frequencies are measured during the same survey, it may be necessary to extend the collection distance beyond the preferred distance of 100 feet (for 800 MHz systems). There is no ironclad rule on the maximum distance for averaging subsample measurements, but longer distances will tend to include changes in the mean signal level which is not desirable. When multiple frequencies are measured during the same survey, each frequency subsample measurement should be interleaved so the computed average can be applied to the same geographical location for each frequency.

Like any radio receiver, the test receiver is susceptible to receiver intermodulation. It is important to eliminate receiver intermodulation in the test receiver so intermodulation signals are not mistaken for over-the-air measurements. Bench testing of typical good quality test receivers reveals that two-tone 3rd-order intermodulation products rise above the system noise floor of -120 dBm when the power of each interfering signal exceeds -40 dBm. To prevent signals above -40 dBm from entering the receiver, one should employ a bandpass or band-reject cavity filter designed to pass the desired signal and reject high-power interfering signals. When it is difficult to separate closely-spaced frequencies via filtering, an attenuator can be used as long as the attenuator does not attenuate the desired signal below the sensitivity of the receiver. Sometimes a combination of filters and attenuators is needed.

All measurements must be corrected during post processing for attenuation created by the filter and external attenuator (if any).

A.7 Route Planning and Gridding. Before planning the survey routes, a theoretical uniform grid should be placed over the service area with grid spacing sufficiently small to ensure at least 4,500 grid tiles (for a 99% confidence interval of +/- 2% for service area reliability and no *a priori* knowledge of the SAR). Plan the drive route so that parallel streets are covered with spacing no larger than the grid tile dimension, where possible. Because drive test survey measurements are typically collected continuously along the drive route, there will be more measurements than grid tiles. But to get an spatially unbiased SAR estimate, the final samples must come from a spatially uniform grid. For this reason, it is important to grid the randomly distributed measurement data to a uniform grid using some acceptable algorithm. One approach is to interpolate all measurements within a particular radius around each grid point using a two-dimensional interpolation algorithm that weighs points by their distance from the grid point. Alternatively, one can remove

[14]To this point, we have assumed a narrowband scanning receiver. A wideband sampling receiver is also acceptable provided it has sufficient dynamic range to operate in the presence of strong interferers and it samples fast enough.

spatial bias by randomly selecting one sample from each grid tile and discarding all others. We prefer the gridding approach because it uses all of the collected data and better represents the expected performance inside the grid tile. Specifically, we normally employ a search radius equal to twice the grid tile dimension and employ an interpolation algorithm with inverse distance squared weighting.

Grid points that are not accessible during the drive test are simply excluded from the calculation of service area reliability. They count neither as a "pass" or a "fail."

A.8 Signal Strength Versus Service Quality. Most drive test surveys are designed only to collect signal strength measurements. Unfortunately, an adequate signal strength alone does not guarantee acceptable service. Channel impairments other than weak signals also affect service quality. These include 800 MHz interference, intermodulation interference at the repeater site, delay spread, and simulcast overlap interference. If these and other impairments cannot be eliminated from consideration, it may be necessary to either instrument the drive test receiver system to collect relevant measurements (e.g., bit-error-rate or frame-error-rate) or conduct subjective push-to-talk voice quality tests during the drive test survey. Sophisticated test methods using digital audio recordings and machine scoring are becoming more common because they remove the variance and bias created by human scoring and reduce labor costs. Automated systems can and should be configured to collect signal level, bit-error rate, and audio recordings simultaneously. The same statistical tests described above can be used with audio recordings, but the service threshold is now defined as a DAQ level, not a signal amplitude.

A.9 Problems Peculiar to 800 MHz Rebanding. Drive test surveys are sometimes used during 800 MHz rebanding to prove the pre- and post-rebanded systems are equivalent. Experience with these types of drive test surveys shows that a 1-2 dB difference in transmitter output power can alter the service area reliability such that the post-rebanded SAR is more than two confidence intervals separated from the pre-rebanded SAR. It is important to carefully measure transmitter power at the combiner output before and after rebanding and to account for changes in transmission line loss and antenna gain. If transmit power has changed, it should be accounted for in calculation of service area reliability by adjusting the post-rebanding service threshold by the amount of power gain or loss. Note that conventional power meters with diode detectors cannot measure power accurately when two or more signals are present simultaneously. One must collect these measurements with only one carrier keyed at a time.

It is impossible to control all variables between the pre- and post-rebanding environments, resulting in SAR variability and failed statistical tests for equivalency. This problem is particularly true with a modest confidence level, high SAR, and large sample size. In these cases, the confidence interval is so tiny that it becomes unlikely that the pre- and post-rebanded SARs will fall within two confidence intervals of each other. To address this problem, it is advisable to increase the confidence level to 99% or reduce the assumed SAR to widen the confidence interval to a value near +/- 2%.

Another common problem with 800 MHz rebanding is that the wireless operator neglects to deactivate a rebanded frequency.  One should verify through over-the-air measurements or cell site inspections that all rebanded frequencies have been taken out of service.

A.10  References.

[1]  W.C. Jakes, ed., Microwave Mobile Communications, IEEE Press Reissue, 1994.

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## Appendix B - Test Plan for Measuring Receiver IM Rejection

B.1 Introduction. The purpose of this test is to measure the strong signal intermodulation rejection ratio of an 800 MHz portable or mobile radio. Two-tone and three-tone 3rd order IM will be tested. The test procedure generally follows EIA-603B [8] except that much stronger interfering signals are introduced (-50 dBm to -10 dBm) and the two interfering signals are separated by 2 MHz rather than one channel width (12.5 kHz or 25 kHz).[15]

B.2 Definitions.

The *standard input signal* is a frequency modulated signal with a 1,000 Hz modulating tone at a frequency deviation of 60% of maximum (3 kHz for 5 kHz max, 2.4 kHz for 4 kHz max) and an amplitude 60 dB above the reference sensitivity.

The *reference sensitivity* is either the 12 dB SINAD sensitivity of the radio under test (analog FM) or the specified bit-error rate (digital) as measured by the service monitor.

The *intermodulation immunity* is the ability of the receiver to prevent two or three unwanted input signals with a specific frequency relationship to the wanted signal frequency from causing an unwanted response at the output of the receiver due to intermodulation. It is expressed as the ratio, in dB, of the level of one of the equal-level unwanted signals that reduces the SINAD produced by the wanted signal 3 dB in excess of the reference sensitivity to the reference sensitivity. The intermodulation immunity is also the *standard* IM rejection ratio.

B.3 Method of Measurement.

(a) Setup. Connect the equipment as illustrated in Figure B.1. Note that the isolators and bandpass filters are required to prevent generation of intermodulation products inside the test instruments. Verify that instrument-generated IM products are low enough to not affect the results by measuring the output of the power combiner with a spectrum analyzer protected by a cavity bandpass filter. Ensure the analyzer is not creating IM products by checking for linearity with an attenuator. All cables and connectors should be low passive IM type (e.g., no nickel plated connectors). Select the desired frequency for test, $f_d$.

[15] Why are measurements necessary? Because the manufacturer generally does not conduct these measurements and therefore does not provide specifications for strong signal receiver intermodulation rejection. However, if the front end of the receiver can be modeled well by a single amplifier *not* in compression, one can derive the strong signal IM rejection from the intermodulation immunity specification and the third order input intercept point (IIP3). See TSB-88-B [1]. The problem with this analytical approach is that some of the interfering signal levels of interest do put the amplifier in compression and the standard expressions do not apply in this case.

The frequencies of the signal generators should be set so that $f_1 + f_2 - f_3 = f_d$ for the three-tone test and $2f_1 - f_2 = f_d$ for the two-tone test. Note that $f_d < f_1 < f_2 < f_3$. Separation between $f_1$ and $f_d$ is 2 MHz.

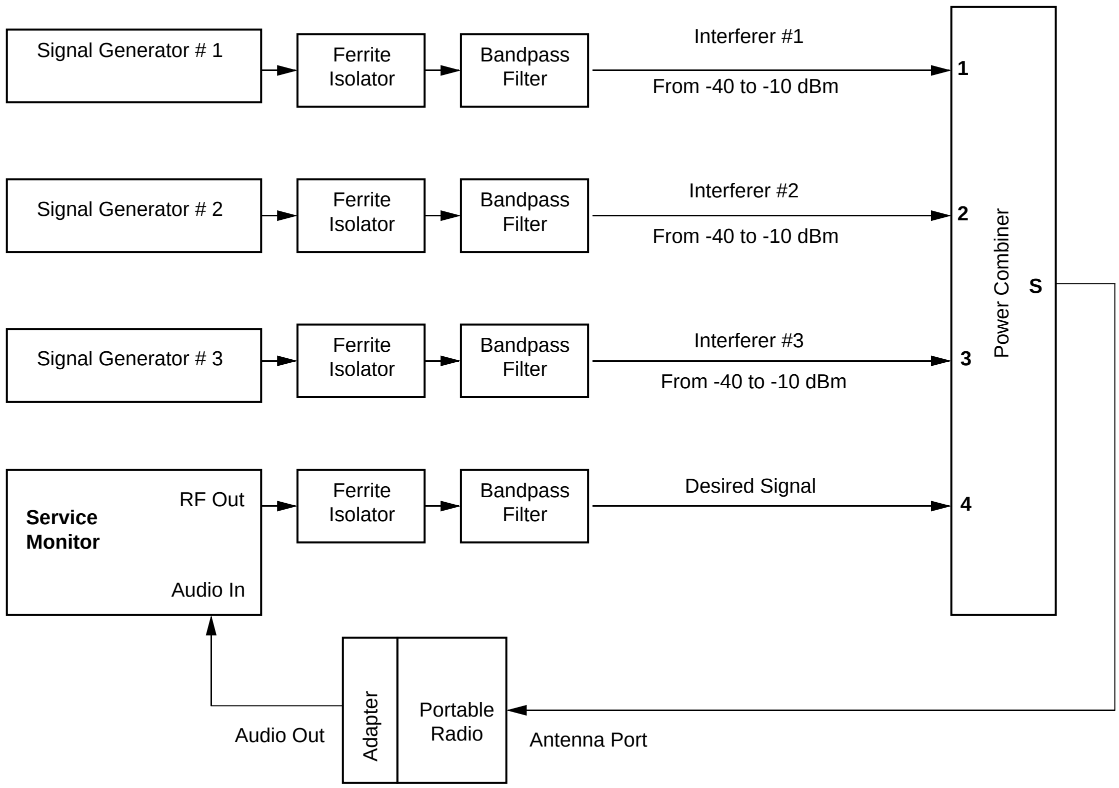


Figure B.1 - Test Equipment Configuration for IM Rejection Measurements

(b) Cable and Power Combiner Attenuation. Measure the attenuation of the cables and power combiner from the RF output of the service monitor to the antenna input of the radio under test. Record this attenuation value, *A*, in dB.

(c) Reference Sensitivity. Temporarily remove the interfering signals from the inputs to the power combiner and connect a 50 Ohm termination to each unused input. Apply the standard input signal at the desired frequency and reduce its level to obtain the reference sensitivity. The reference sensitivity is the output RF level at the service monitor minus the attenuation recorded in (b). I.e., Reference Sensitivity = RF Output - *A*. Re-connect the interfering signals.

(d) Increase the level of the desired input signal by 3 dB.

(e) Standard IM Rejection. Increase the power of the three signal generators with equal levels until the SINAD returns to 12 dB. Record the *intermodulation immunity* or standard IM rejection for three-tone IM as the difference between the amplitude of each signal generator (dBm) and the desired signal (dBm) at the antenna port of the radio. Temporarily terminate the third input to the power combiner (interferer #3) with a 50 Ohm termination. Repeat this step to determine the standard IM rejection for two tones. Note that this value will differ from the manufacturer's two-tone IM specification for the radio because (1) of normal variations between radios and (2) because the frequency separation is greater than 25 kHz.

(f) Repeat steps (e) and (f) for the two-tone and three-tone cases for amplitude levels between -50 dBm and -10 dBm in 5 dB steps. The computed ratio is the strong signal *IM rejection* ratio.

(g) If desired, these measurements can be repeated for interfering signals that fall below the desired signal frequency rather than above and for frequency separations other than 2 MHz.

(h) Performance will vary between individual radios. To characterize the performance of a manufacturer's model, one should measure three to five radios and average the results. Any unit that deviates significantly from the others or does not pass the manufacturer's standard tests for sensitivity and intermodulation immunity should be eliminated before averaging.