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At the TSG-RAN WG4, Edinburgh, 3-7 September 2001, the following documents were presented:

- R4-011086 Feasibility Study of UE antenna efficiency test methods performance requirements-final report (Allgon)
- R4-011228 Proposal for feasibility on UE antenna performance (Motorola)

Based on discussions in WG4 on this study item, it was agreed that that detailed technical discussion should take place in Cellular Telecommunications & Internet Association (CTIA) as CTIA has been active in developing a radiated performance requirement for 2G systems. The understanding is WG4 would be to follow the CTIA document and to re-use their test methodology (R4-010954).

It was also agreed that the chairman would ask the 3GPP PCG to add CTIA to the list of bodies with liaison to 3GPP and to send CTIA an LS regarding this aspect.

The group agrees to keep the WG4 technical report (R4-011086) as an internal RAN4 document.

TSG-RAN Working Group 4 (Radio) Meeting #19 ***TSGR4#19(01)1086***
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0. Content

1. Scope

During the TSGR4#13 meeting a study item was established titled “Feasibility Study of UE antenna efficiency test methods performance requirements”. See ref [1]. This is the final report of the study item and the references [2]-[5] are papers presented at RAN4 meetings in between excluding a number of short status reports etc. The scope is to define test methods for radiated power, receiving sensitivity etc. including the antennas in real use and applicable to the wide use of various types of 3G terminals. Another scope is to define the test methods in such a way that they are applicable or at least translatable to measurements done for different purposes during the whole development chain from prototype antennas over type approval to comparisons of products on the market.

For type approval alone the suggestion (ref [5]) is to keep to a method close to the newly presented CTIA draft for mobile telephones in ref [7] and its associated ref [6].

In this paper a fairly general study of the methods for measurement of terminal antennas is done. The first step in the classification used below is based of the fields used for communication with the terminal antennas. Several limitations for antenna measurements are investigated with special regard for omnidirectional antennas. This is as a continuation of ref [2]-[3] and an addition to ref [4] which is a part of the investigations behind the CTIA draft [7]. One of the conclusions from this study is that the mobile communication systems of today incl. 3G systems calls for other types of antenna test facilities than the very old mobile phone systems (at 450 MHz or lower) which so far appear to have set much of the industrial standard. They also call for other types of antenna test ranges than presently in use for high gain antennas as the optimum test range for low gain antennas is very different from the optimum one for high gain antennas.

2. References

[1] R4-000732. Feasibility Study of UE antenna efficiency test methods performance requirements. Rapporteur is Olle Edvardsson for Allgon Mobile Communication AB (present mail: olle@vosab.se).

[2] R4-010396. Feasibility Study of UE antenna efficiency test methods performance requirements-summary of methods (Allgon).

[3] R4-010630. Feasibility Study of UE antenna efficiency test methods-status report (Allgon).

[4] R4-010656. Methodology for Characterization Real-World Radiated Performance of Mobile Phones (Motorola).

[5] R4-010966. UE antenna efficiency test method (Motorola).

[6] R4-010954. Mail from Susan Pollard at CTIA regarding the use of ref [7] below

[7] CTIA Method of Measurement for Radiated RF Power and Receiver Performance– May 2001, Draft Revision 1.0

[8] Luis Correira: Wireless flexible personalized communication. “COST259 book”. Wiley 2001

[9] Fujimoto: Mobile antenna systems. Artech House 2001.

[10] Kent Rosengren: Lic thesis CTH 2001.

[11] J E Hansen: Spherical near-field antenna measurements. Peter Peregrinus Ltd 1988

[12] R Harrington: Time-harmonic electromagnetic fields. McGraw Hill 1961

3. Background

The measurement of antenna efficiency is a fairly complex task and to sort it up a survey of basic test parameters, test conditions and basic test methods is done below. At first sight it appears straightforward to translate system requirements to a suitable selection of test parameters/test cases to design kind of “ideal test method”. At least with traditional antenna test methods however neither the complexity nor the test time of such an “ideal test method” did meet the expectations of the users. In most test methods presently in use some simplified method is used or proposed and from the survey below it can be deduced which the losses of information can be expected when various simplifications are applied. The last few years the development of instrumentation has made it possible to achieve the something similar to the above mentioned “ideal test method” with short test times combined with high accuracy. The final conclusion in this report is intended to be a sketch of a tool to make a choice between different methods but also to create a sort of cross reference to translate different methods to each other or rather to tell which measured parameters can be translated or not. It is recognized that even if an “ideal test method” can be advised and implemented a lot of less demanding tests will be done with existing (and perhaps simpler) test methods but it is good to know where a data translation is feasible or not.

Type testing of mobile phones so far has been done with galvanic connections and excluding the antennas. The last 10 years it is from numerous measurements well established that the efficiency loss when a conventionally designed voice phone is used in talk position is in the order of 10 dB (ref [8]-[9]) which is far too much to be neglected and left unlimited. Obviously it takes a verified test method to include this important need in a test like a type approval but earlier the practical difficulty to formulate a good test method made it not acceptable for the users.

It would be valuable with a generally accepted test method for all kinds of tests related to mobile terminal antennas. It should finally be added that there is a newly issued draft for test specification for type testing voice terminals from CTIA (ref [7]) which in many parts follows the conclusions (mainly based on physical considerations) given below. In this report the intention is a wider scope than type approvals of voice terminals but anyway some kind of cooperation is recommended for the further development (see ref [5]).

4. Test philosophy and use

Type approval and production of mobile phones have traditionally been done with some kind of galvanic connection (typically a 50 ohms connector) but on the contrary all phones are fitted with antennas while they are in practical use. Besides the number of phone models fitted with a separate 50 ohms connector are decreasing. From present mobile terminals it is known that the loss in talk position is several dB and in many cases even over 10 dB and it is thus inevitable to include the antennas in any realistic test. Especially with third generation systems the need for antenna gain is bigger in order to achieve the wide bandwidth without unnecessary loading of the system. Thus it is even more important than in the present systems (GSM, D-AMPS, CDMA etc.) to formulate minimum requirements for the antenna gain while in practical use. “Practical use” means for GSM phones that typically 10 dB is lost in the head and hand of the user. In the long run it will be necessary to improve this and a standardized test methods is obviously an important tool to accomplish that. For different reasons quite a number of methods for antenna measurements have been used in the past but a single well defined method is urgently required for the third generation terminals. Furthermore a kind of translation to other methods is required as we must assume that a number of different methods will be in use parallel. That may be acceptable but may also imply that some parameters measured by different methods are not comparable while other are. Furthermore an increasing number of systems will have diversity so within the same test set-up parameters for diversity must be possible to measure.

For transmitter and receiver band two basic parameters are TRP and TIS. The term total radiated power (TRP) refers to all radiated power over all directions and polarizations. With knowledge of the power fed to the antenna TRP can if desired be translated to average gain which is closely related to antenna efficiency. The corresponding measurable quantity on the receiver side is TIS (total integrated sensitivity) which also is closely related to antenna efficiency. TRP and TIS are defined in R4-010656. With TRP and TIS introduced this discrepancy between practical use and lab tests can be bridged. Five test needs for a good definition are:

> UE certification obviously is an important use with high accuracy requirements. A selected number of characteristic test cases are chosen. For certifications the accuracy and calibration process is necessary to define accurately as otherwise different test labs might arrive to different results which in worst case could give different (i.e. unacceptable) approved/disapproved logic.
>
> In power budget calculations (even for coverage predictions) many times a supposed standard-value (like –3 dBi or even 0 dBi for UMTS) is used. This assumed value needs to be replaced by a value deduced from TRP/TIS which can be measured and specified. This would give more realistic coverage calculations which is especially important for UMTS system where wideband coverage anyway will be somewhat local.
>
> A third use is to compare different implementations like different handsets, different antenna solutions or different uses. This may appear as less important than type testing but in a world of competition it is important to get correct steering information to develop and evaluate new equipment.
>
> Another very important use is to have comparable test methods over the development cycle aiming to ensure that the early antenna prototype giving the best performance also should lead to a performance among the best when finally measured on a live handset. Published test methods so far have not focused on this point.
>
> Production test is another test which should be able to deduce from the full test but the production test of course is very reduced and should be seen together with all other production test cases to sort out faulty units or a faulty process rather than verify basic system function.

Below the test parameters are listed and compared to different basic test methods. The investigation is focused on the electromagnetic fields and how they are created while test instrumentation etc. is of standard type. Test instrumentation will develop over the time and be a bit different for different systems but a formulation around the wireless propagation should aim to be sustainable for such changes. A matrix will be derived to see how well different methods fulfills the stated requirements and where improvements are needed. If hypothetically testing time and costs should be without importance an ideal method can be thought of and starting from that ideal test case the losses in accuracy etc. by different methods can be estimated for different practical simplifications.

The test parameters are listed under point 5 below while the test conditions are listed under point 6. For a well defined test a number of test conditions are chosen and the full or a limited range of test parameters are chosen. Depending of the purpose of the test the list can be of very different length. For some purposes (such as type approvals) many tests and good accuracy are needed while other purposes might be less demanding and consequently demanding less test time. One part of the future work is to formulate the ideal test method while another part of the future work is a kind of cross-reference table telling which methods/results are comparable. The practical possibilities to implement a good and fast “ideal method” have greatly increased the last few years.

5. Test parameters

In a way “antenna efficiency” can be said to be the basic parameter to be measured by the methods discussed in this paper. The efficiency can not be measured directly but is based on the TRP (Total Radiated Power) and TIS (Total integrated sensitivity) discussed above and defined in R4-010656. A number of parameters can be listed which are supplementary parameters for the efficiency:

1. Primary test parameters are power, amplitude, phase, BER etc. and may be a bit different for different systems. However some conclusions may require some of this parameters and the choice of instrumentation must be done accordingly. TRP and TIS are the two most important parameters and are defined in R4-010656. It should be noted that TRP/TIS typically refers to a omnidirectional weighting factor which is different from the concept MEG (Mean Effective Gain) where a weighting factor corresponding to real field distribution is used. As will be discussed later a recalculation can be applied if MEG is required. Even if an omnidirectional weighting factor is used for practical reasons the MEG is required when it comes to power budget calculation.

2. Absolute accuracy of efficiency is obviously important both for power budget use and for comparison of measurements done at different labs using different methods. Methods and instrument calibrations are two of the many contributions. Some methods may show limited capability for absolute accuracy. The accuracy is TBD but must be about ±1 dB (or preferably better) in order to get comparable type approval results from different test houses.

3. Repeatability of efficiency is important to consider as many methods using real or simulated fields are by their nature are statistical. Repeatability will always be an issue when it comes to comparisons using a limited testing effort.

4. Directional properties must be taken into account as both fields and terminals have directional properties. Different fields (indoor, outdoor etc) will interact different with different terminals and must be known. For instance free space and talk position for a voice terminal will be very different. Associated with this is a need for investigation of how dense the measurements must be done to make a fair average.

5. Polarization properties must be taken into account and generally both polarization, phase and amplitude must be known to calculate the influence of various environments. Normally horizontal and vertical polarization have a few dB different propagation properties.

6. Diversity parameters are basically gain for the two antennas, correlation between signals from them and coupling between them. For active phones this are replaced by system specific parameters.

7. Trace-ability means that basically the same method must be possible to use all the way from early antenna prototypes to a phone from the shelf in order to get comparable results. Instruments will be different for tests at various stages but the basic way of treating the fields should be similar to make it possible to translate the test values.

8. Equipment complexity should preferable be simple but a scientific correct method is more important at least as a standard. Various simplifications will be studied to see what information is lost for various simplifications.

9. Measurement time is very important as most tests include a number of different positions etc. Especially tests using statistical properties may be time consuming as something like a few hundred to 1000 samples typically are required to estimate a Rayleigh distributed signal as accurate as a deterministic signal.

6. Test conditions

The test parameters are measured for a number of test conditions. There is some mixing between conditions and measured parameters but basically the test conditions are chosen from a list while the results are measured or observed.

1. Free space measurement is an important and uncontroversial standard test however with very limited connection to real use. It should also be recalled that there is a big difference between real “free space” for an insulated phone and the case with a phone connected by a cable to some test equipment. For antenna measurements on a passive mobile phone the cable and the support structure are potentially big sources of error.

2. Talk position with a real person is important as a kind of reference for research purposes but must be understood in a statistical sense as all persons are different both as individuals and from time to time. The gripping of the phone has been shown to be very important. One position each in both left and right position should at least be measured.

3. Talk position with phantom is the typical practical method but needs a number of definitions like type of phantom, positions etc. Similarity with SAR phantoms is used for practical reasons but there are definite difference in regard to what should be seen as “worst case” for SAR and efficiency testing respectively. A number of different phantoms have been used in the past for efficiency measurements but the similarity with the SAR needs and the increasing importance of SAR is a strong argument for the SAR phantom.

4. Dummy hand and other near zone effects are of comparable importance as the head phantom and for many 3G terminals the head phantom may even less adequate than hand and other near zone influence. For 3G UEs there is a lot to investigate here and among the new test cases “on a wooden table” and “on a metal table” are obvious.

5. Frequency dependence (incl. up/down-link) is important as most antenna structures are narrow-band and will change their center frequency due to near zone effects. Usually the phone antennas are narrow-band devices and the center frequency will for most phones be lower in talk position as compared to free space. It is thus necessary to arrange antenna gain tests to take such changes into account. Type testing requires

channel by channel measurements (each 0.2 MHz etc.) while as a minimum at least three channels (lowest-middle-highest) should be measured in both TX and RX band to reveal poor bandwidth.

6. Up-link/down-link test methods are different for real phones and generally includes a network tester. For up-link the power received from the phone is measured while typically BER in the terminal is measured for down-link. The BER measurements takes several times longer time than a plain power measurement but there are simplified methods based on for instance RXLEV in GSM which can be temporarily calibrated to increase its accuracy on the fast RXLEV data.

7. Different phone systems must be possible to measure with the same basic methods but with some different instrument (or settings). Development goes toward a system tester capable for many systems.

8. Active/passive phone may be more or less complicated to implement with different methods but it is of course important to include both. Preliminary antenna tests are passive only while tests on live phones are active only. A unified methodology is thus desired to compare measurements made during different development stages.

7. Principal methods for antenna efficiency testing in a wide sense

As the focus here is on the wireless propagation the main division of various test methods is made after the method of creating or simulating the fields and three basically different methods have been employed. The list below is a list of used possibilities and after comparing to the list of required performance a selection of one or more principal methods can be done.

7.1 Real field measurements.

In a very theoretical way a sufficiently big and diversified practical test will give the efficiency etc. to an arbitrary accuracy. The basic principle was applied by the pioneer company Motorola long time ago where they used a person walking around a prescribed path while communicating with a base station or a system test instrument (like the much newer instruments CMD55 or CMU from Rohde &Schwartz). Telia in Sweden use a related method adaptable for a phantom head and published in a number of SMG2, COST259 and RAN4 papers (ref[8]). The “walking around” is by Telia substituted by repeatable rotations still in a typical propagation environment and arranged to give a sufficient number of stochastically independent samples. This can be done with fairly simple instruments but the statistical basis will anyway require extensive measurements to make the result converge to an average with a good accuracy. One obvious problem is the number of measurements to test many different environments. This method produces the mean effective gain (MEG) but only for the used environment. It can be assumed that the variation different “typical indoor” environments is much smaller than between “typical indoor” and uniform field distribution. It is obviously desirable to get MEG for different and typical environments but if a “typical indoor” environment could be defined that could serve as a base for comparison.

As digital phones are registered and can be reasonable localized the “walking around” idea can even be extended to a full network in a large or very large scale. This will in a sense result in readings finally converging to a true result related to real use.

However two of the obvious drawbacks are that the result will arrive far too late for a model under preliminary design and that the effort is unacceptably expensive or impossible for other reasons.

The real test obviously relates to the whole unit rather than the antenna. In case isolated antenna data are required calibration have to be done by a known antenna. If the DUT is much depending on the environment (i.e. if it is pronounced directional especially in elevation) different environments will give different results but probably to a limited extent. By comparing with a known DUT and by testing the stochastic distribution of the samples the results can be reproduced but the stochastic method still has its weak point in the test time and besides very different environment with pronounced different elevation distribution will give different results.

7.2 Full antenna pattern measurement

The by far most common measurement is based on measurements made in an echo free chamber. The make the result accurately applicable to the real case we also need field data of measured input field. This will give access to all information about the fields around the terminal with its user and with knowledge of the fields in various environments this method will give full information without the extensive set of data required for a method based on real fields. As will be discussed later typically amplitude and phase in both polarizations will be required with sufficiently good angular resolution. Many antenna pattern test methods were developed when the frequencies were 450 MHz or lower and at that time a three-cut pattern test was sufficient (i.e. xy-, xz amd yz-plane). However the higher frequencies make the old test methods obsolete as is discussed in appendix C on required angular resolution. For the earlier low frequencies all patterns looked very similar (like dipole patterns) and were easy to characterize for instance by their maximum gain.

Many reported tests still are related to this basic method with usually a few cuts only for the measurement of antenna pattern. The actual need for angular resolution is much bigger than that as will be discussed in appendix C. The use of an old test methods means a hard data reduction and it is an important question to judge the capability of various simplified methods where the number of antenna test cuts are chosen after what is considered as practical rather than after what is actually needed. Historically the instrument development works in favor of better resolution as faster and more advanced instruments are available. System development (5 times higher frequencies (2250/450 MHz)) even makes it necessary with much more measurement cuts now than earlier but a number of better and faster antenna test systems have also occurred on the instrument market.

As long as linear operation only is considered there is no limitation in the possibilities to obtain data accurately simulating any case of real scattered field by post processing of test data from sufficiently good full antenna pattern measurements.

7.3 Artificial scattered field

In various environments it has been proposed to use an artificial scattered field for antenna efficiency tests. One method is a metallic chamber with one or more stirrers in which the transmission between two units (DUT and a test antenna) is measured to evaluate an average value while the stirrers are moving. Possibly several antennas (pseudo randomly fed) in an echo free chamber can do the same. The metallic chamber with stirrers is a method used for EMC tests. In contrast to the two basic methods mentioned above there is, at least for the metallic chamber, no obvious convergence to a true value. Lack of similarity between the real field and the artificial one is likely to get differences in the final result (which may be of acceptable size or not). The signals in the mode stirred chamber are very different from what is experienced in real use (like bigger delay spread) so real phones may experience problems. A new and extensive treatment of this method is found in ref [10].

A conceptual understanding of this kind of chamber is based on the number of resonant modes within the frequency band used for averaging. Each resonant mode corresponds to a direction. With a sufficient number of resonant modes a sufficient averaging over the directions and a sufficient statistical sampling can be obtained. The number of resonant modes increases with the chamber volume in λ^3 and from the presentation of ref [10] around 50-60 λ^3 seems to be a lower limit for the full TX-band 880-915 MHz. A good frequency resolution thus needs a quite big box and a long test time to cover a small fraction of the frequency band.

7.4 Other methods

Among dedicated antenna efficiency test methods the well known “Wheeler Cup” could be mentioned. As it is only usable on separate antennas (possibly including some passive phones) in free space it is not considered further here.

7.5 Some examples of implementations

The various practical implementations of the three basic methods to treat the fields can be sorted in the following list. Most of the examples refer to papers presented in COST273SWG2.2 or its practical predecessor formed by ECTEL/SMG2:

Real field: “Walking around” in a literary sense (old method from Motorola and others), “double rotating” (Telia), “passive use of network” (walking or driving around in a real environment), “network based local” (single mobile recorded during known movements close to a base station or a test instrument) and “network based large scale” (large scale recording of actual traffic). This kind of measurements are important for validation of other methods but with few exceptions they are far too time consuming for routine tests. The main limitation is that the statistical nature of the measurement requires quite a number of tests to get the stochastic variation down.

Full antenna pattern: True “2-axis test chamber using mechanical/mechanical movement” (Alcatel, Toshiba, Orbit, Nokia, CPK and others), true “2-axis chamber using electrical/mechanical movement” (Satimo) and “1-axis chamber with a number of cuts” (CSELT, IMST, Orange etc). Various use of environment measurements or estimations for evaluation. Incoming fields have been studied by CPK, Nokia and others. Compared to the other two methods this has the potential of being very fast as it do not use stochastic methods.

Artificial fields: ”Reverberating chamber” (FOI, Sweden(Mats Bäckström)), “Mode stirred chamber” (Chalmers and other) and “multiple antenna chamber” (not reported) can be thought of. It is not clear how much attenuation is acceptable within the chamber before the statistics will turn bad. Another question mark is how well a phone will work is this special signal environment which is quite different from a real signal.

8. Basic fulfillment of requirements

The three basic ways to treat the radio fields will have different influence on the different test parameters. It is fairly complicated with the big number of systems but in a simplified way the following matrix can be set up. The term “convergence” is used to indicate ability to improve measurements by increasing the number of samples:

	Real field	Full antenna pattern	Artificial field
Primary test parameters	Through system tester/base station only	Phase/polarization necessary	Amplitude only. System tests may be difficult.
Absolute accuracy	Long convergence time needed due to the statistics	Can be good already for a small number of measurements	Statistical convergence is OK but a big chamber may be required.
Repeatability	Statistic variation	Good	Statistic variation
Directional	As good as real field is known	OK	Can not be included
Polarization	As good as real field is known	OK	Can not be included
Free space	OK as a comparison	OK	Non real distr.
TP real (=human)	OK as a comparison	OK	Difficult
TP Phantom	OK as a comparison	OK	OK
TP phantom+hand	OK as a comparison	OK	OK
Frequency dep.	OK but limited by available channels	OK	Limited resolution related to chamber size and test time.
Up/down-link	OK	OK	?
Different systems	OK	OK	OK
Active/passive	Passive may be difficult fore some.	OK but different systems may have different solutions	Active may be difficult/impossible.
Trace-ability	Comparison	OK	Comparison
Complexity	Fairly simple and using standard type equipment	Standard antenna test equipment if designed for omni antennas.	Special box less costly than antenna test chamber.
Time	Around 10 minutes per each measurement	5 min and up but heavily depending on system	10-20 minutes per each measurement.

9. Some basic limitations related to use

For each of the three groups there are some typical limitations some of which are listed below.

	Real field	Full antenna pattern	Artificial field
Data for power budget calculation using real phones	Slow convergence but ultimately to a correct value corresponding to chosen fields.	Fast measurement but depending on the use of correct field assumptions.	Fast measurement but limited to an average of the artificial field used. Chamber size etc may limit accuracy, frequency resolution etc.
Comparing different phones and antennas, research etc.	Slow convergence or poor accuracy.	Good accuracy and fast results. A straight average may be used.	Faster and more controllable than a real field. Slower and less accurate than a good antenna pattern.
Antenna development (on phones)	Too slow convergence.	Good	Fair
Early antenna development	Too slow convergence.	Standard method	Fair for gain but no details available.

10. Conclusions of test methods

The points 5-6 above and the appendices below give a number of conclusions:

> A method based on the full antenna pattern should be used both to give all required data and to avoid the long test times associated with the scattered field methods based on stochastic evaluation. The full antenna pattern can typically be used to post-process any type of real field as long as systems working in the linear range are concerned. The antenna pattern measurement technique can also be used at all stages of the development procedure in a comparable way.
>
> The choice of method for measuring the full antenna pattern must be done by great care to obtain a reasonable accuracy. Only the spherical geometry seems to fulfil this among realisations presented so far. The residual echo level of the room is one of the accuracy limitations and is also generally improved by the spherical geometry.
>
> Conical cuts are most easy to adopt to real field by inserting a weighting factor depending on the angle Θ from the vertical axis (with “vertical” referring to a head in normal position which as a reference can be substituted by a real person).
>
> Measured data and measurement conditions are not critical for the choice of method but depending on the type of system the choice of instrumentation will influence the test time. It should be pointed out that the frequency resolution is important and even in cases where each channel is not measured a minimum resolution of 3+3 frequencies (min, middle and max in RX and TX bands) is required to distinguish how well the many times narrow band antenna matches the requirements.

11. Recommendations

An echo free chamber with a spherical turntable geometry and preferably conical cuts seems to be the only realistic implementation for high accuracy measurements allowing short test time. A sufficiently low residual echo level (maybe 0.5 dB peak to peak) and a good angular resolution (15° if at least a coarse pattern estimation is required or 30° if power integration is sufficient) are two basic requirements.

Appendices on important associated topics

Appendix A. Residual reflection level in echo free chambers with regard to omnidirectional measurements

A1 General

Accurate measurements on low gain (omnidirectional) antennas for rather low frequencies are in many ways much more demanding on the chamber than more conventional antenna measurements for high gain/high frequencies. This appendix A discusses the residual echo level while appendix B is about rotation geometry.

Three typical problems with “echo free chambers” have to be taken into account:

> They are not literary “echo free” but a spatially oscillating deviation (residual echo level) of the fields in the order of 0.5-2 dB (or more) can be experienced as a result of stray reflections and this is an important part of a verification procedure of the chamber. The residual echo level will set an ultimate limit on the accuracy obtainable in that chamber and the level depend on the attenuation material as well as on the geometry.
>
> The performance due to the residual reflections is sharply worsening at lower frequencies. The thickness of the attenuating materials should be at least 2-3 wavelengths which is quite thick below 1 GHz. The thickness is subordinate to the reflection level and the residual echo level is depends booth on the material and the geometry.
>
> Echo free chambers are fairly heavy investments for most organizations and are typically built for a wide range of purposes of which directional antennas in many cases are the critical ones. Rooms which are not built for omnidirectional antennas tend to be un-sufficient for that purpose. Residual echo levels verified for directional DUTs (such as >10dBi) can be completely misleading when it comes to low gain antennas (≈0dBi excl losses).

Thus various types of geometries are optimal for different purposes. Quite many chambers are built for preferably high gain antennas having rather narrow lobes. In such cases the distance is the most critical parameter for a classical far field room. A long and rather narrow indoor room is thus the most common solution for a room optimized for high gain antennas. That geometry is generally not good for essentially omnidirectional antennas (low gain antennas) where reflections will occur in all directions. For rooms optimised for low gain antennas the geometry (or geometrical angles) and especially the type of absorbing material is more important than the size. Outdoor ranges can be used to suppress ground reflections by high masts thus decreasing the problems associated with large areas of attenuating material.

A2 Function in general terms

The typical function is that the transmission between a common room antenna (CRA) and the device under test (DUT) is measured with suitable type of instrument (typically an ANA for passive antennas and a mobile phone system tester for evaluation of live phones). One or both CRA/DUT are moved while transmission parameters (amplitude, phase etc) are registered to get the spatial antenna pattern. The geometry of movement is very important and the performance of the echo free chamber has to be evaluated during movements similar to those used for the tests or more elaborated movements including those used under the test. For such an evaluation a well known DUT (typically a dipole or a standard gain horn) can be used.

A3 Characterization of echo free chambers

Ideally one intention with an “echo free chamber” is to expose the DUT to a plane wave but due to (weak) internal reflections the plane wave is a bit rippled. For a typical room a “quiet zone” is defined and the variation of the fields <u>within that zone are measured and the result is given as ±x dB residual echo level</u>. Depending on the geometry the “quiet zone” may or may not be more quite than other parts of the room but the concept “quite zone” should rather be understood as a specified, usable and verified volume where the DUT can be located. The residual echo level is important but is not a fixed number for the room. It can for instance be very different for high gain or low gain DUTs where low gain DUTs are much more demanding for good reflection material etc. Thus the verification must be done under assumptions fairly similar to the planned measurements. Especially it should be pointed out that various disturbing obstacles (here called SDO=Suspected Disturbing Obstacle) may have a disastrous effect on the residual echo level. Turn table, cables, various supports and installations (like light fittings) are common examples of SDOs.

A4 Equipment

The equipment is an important part but is not much discussed here as it is assumed to be chosen among modern equipment to match the mobile phone system in question if live phones are measured or microwave network analysers etc for passive phones. One important aspect is that the type of equipment may have a big influence on the test time. A passive antenna pattern measurement around both axis will take in the order of 5 minutes with modern equipment and will not require any entries in the room for realignments etc. It should be noted that the same measurement can take several hours in a classical type of antenna test chamber with instrumentation not intended for full 2-axis measurements of omnidirectional antennas.

In a certain contrast to standard antenna measurements both polarizations are necessary to measure here either by 2 repeated measurements or by a two channel system measuring two polarizations simultaneous. The total radiated power is the sum of both polarizations and to find data for diversity amplitude and phase for both polarizations are required.

Appendix B. Turn-table geometry in echo-free chambers

B1 General

The conventional geometry and implementation for the 2-axis rotations in an echo free chamber is typically not well suited for accurate measurement on low gain antennas.

As will be discussed in appendix C below a real two axis (sometimes called 3D) system must be used to make measurements in "all" directions which in our case means something like every 15° or more dense. Simplifications may be done if the frequency is below 0.5 GHz and the DUT is fairly small ($\approx<0.5\lambda$ or <0.3 m at 450 MHz). Much of the antenna measuring technique used for telephones today seems to have been developed at the time when those assumptions were valid. To get good results for omnidirectional antennas another geometry than one optimized for directional antennas should be used. In the high directional case it is many times easy to avoid reflections even from big obstacles (like heave two-axis turntables) by suitable location avoiding the antenna beam to hit the obstacles but for omnidirectional antennas the situation is much worse. Thus the number of possible geometries usable for accurate measurements on such antennas is limited.

B2 Geometries for two-axis measurements of high-gain antennas.

Classical turntable arrangements are "azimute only", "elevation over azimuth" or "azimuth over elevation". Practical implementations from manufacturers catalogues shows quite heavy constructions which will give big disturbances when omni-directional antennas are measured. The reason for the heavy constructions is of course to allow a wide range of test objects (incl. heavy ones) to be moved with great accuracy. For small units like a mobile phone (with or without a phantom head) a smaller support can be used and by suitable construction materials (e.g. polystyrene foam etc.) a low reflectivity support can be possible to implement but still on the basic principles "elevation over azimuth" or "azimuth over elevation".

In mathematical terms the scanning over the sphere can be done (among other) along "conical cuts" (following the latitudes with geographical terms) or along "great circle cuts" (typically following the longitudes using geographical terms). Using the standard spherical coordinates θ and ϕ conical cuts are along constant θ and simplest case of great circle cuts along constant ϕ. Conical cuts can be said to correspond to "azimuth over elevation" while great circle cuts may correspond to "elevation over azimuth".

It can be remarked that the near-field principle is generally not applicable as it is the measurement on live phones which is the most important test or at least a test which can not be excluded. Besides the near field principle has its main use to avoid the very long distances required for classical far field measurements of high gain antennas (such as >60 m for a 1 m satellite TV parabola). This is not to say that near field antenna measurements can't be used but just that the spherical near field geometry is more important than the near field calculations in the low gain case.

B3 Geometries for low gain antennas.

There are at least four conditions or constraints important for the practical application of phone antennas and partly also for low gain antennas in general:

> Scattering from the support structure is a big potential nuisance for all omni-directional antennas. Foamed plastic and no mechanics may be one solution.
>
> The measuring distance can be rather small which opens for some other geometries than are possible for high gain antennas. For a 0.1 dB accuracy the distance still can be down to 1.5-2 m according to appendix D.
>
> The head (real or phantom) or corresponding near zone objects must be properly oriented to the phone and the need for accuracy is high here to make the result reproducible. Thus it is natural to let the vertical direction ($\theta=0$) be defined by the head regardless of how the measurements actually are done and how the phone is directed.
>
> It is highly desirable to have the possibility to use a real person as a reference from time to time. This obviously excludes some geometries and is an argument for using the vertical direction relative to the head as $\theta=0$.
>
> With this orientation the measurements should preferable be divided as conical scans as this will simplify a post-processing implying a Θ-depending weighting factor to convert the straight average to a real MEG based on field data.

The arrangement which appears to fulfil the requirements best is the spherical geometry where the two axis movement is separated in that the DUT is rotated in one direction (azimuth) while the CRA (common room antenna) is rotated in a circle around the DUT. The DUT is located on a pillar which in the active case can be made of Styrofoam only while the passive case requires a cable inside then pillar or a corresponding wireless transmission. The CRA is moved along a rail or alternatively many CRAs are used with a system solution including switches. Three important advantages of the spherical solution are:

> The division of the movement in θ and ϕ enables an empty space completely without disturbing objects between DUT and the radius where the CRA is located. Some support of course will be required which at least in the active case can be made of Styrofoam or strong dielectric wires (such as Kelvar or Filestran).
>
> The reflections from the walls will come from a much longer distance (2-3 times) than the intended transmission DUT-CRA and the main reflections will be nearly perpendicular to the walls. This means that we with an essentially cubic room enclosing a spherical arrangement can expect 8-10 dB improvement as compared to a traditional far field room using the same material but being longer.
>
> The really spherical geometry will enable the measurement in all or practically all directions and simplify the weighting between different directions.

There are a number of existing commercial implementations of the true spherical geometry. Both switched CRAs (such as 64 pcs.) and rail movement are available.

Appendix C. Required angular resolution for antenna measurements

C1 Introduction

Based on general field expressions it is possible to formulate detailed requirements on the need for angular resolution which in turns is critical for the choice of geometry. For the frequencies in use today this requirements make many older test methods obsolete.

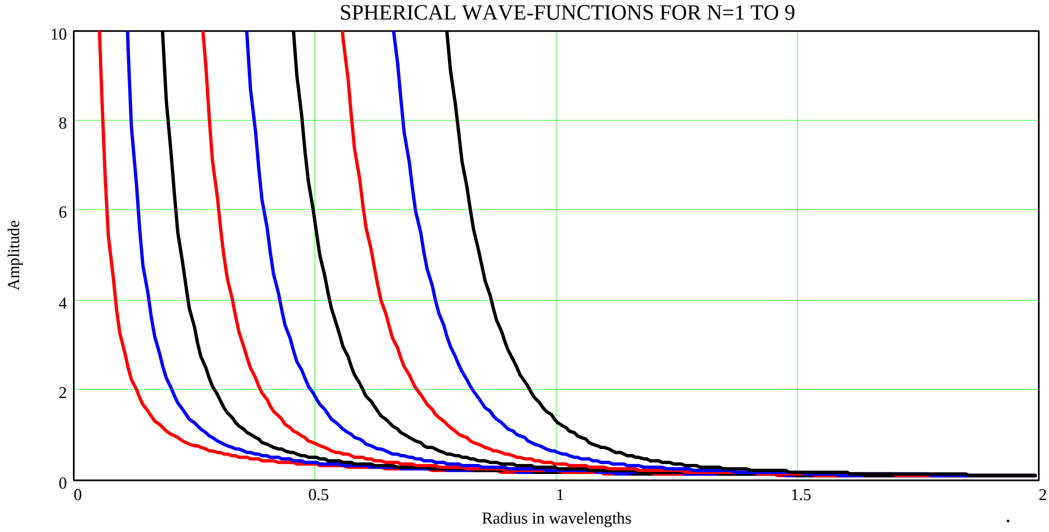
All measurements associated with antenna pattern are based on some kind of measurements in a selection of directions rather than “all directions”. Traditionally for essentially omnidirectional antennas (on mobile phones, com-radios etc.) the number of directions have been limited for practical reasons. In the early days for up to 450 MHz a 3 cut measurement (xy-, xz- and yz-plane) was considered to be a good compromise giving acceptable accuracy and many times even limited to 1 or 2 cuts. As will be shown below this is by not at all sufficient for present mobile phone frequencies and it can safely be said that the 1-3 cut antenna test methods have became out of date for this purpose. Especially in talk position for the bands at 1.7 GHz and above the antenna pattern will have rather fast variations and basing an estimation on a 3 cut measurement will contain a high degree of lottery among other creating big variations between results from those different test-labs using such a method but slightly different planes. On the other hand it is important to minimize the number of tests and for that reason the following estimation is done to set the upper limit of angular steps to maintain accuracy.

C.*2 Theoretical background*

Any antenna (including a possible more or less conducting support structure) which can be thought to be entirely enclosed within a sphere can have its fields outside of said sphere exactly described as a sum of spherical wave functions. See ref[11]. As this sum has good convergence conditions the (in its mathematical sense) infinite series can be truncated after a number proportional to the size of the DUT expressed in wavelengths. The spherical wave functions are ordered in a two dimensional way (n,m) by integers n (positive) and m where m is azimutal variation (like cos(mϕ) etc) and n(>=|m|) describes the variation with elevation in a coordinate system where z-axis is vertical. The scalar wave functions (from which the vector wave functions are derived) is described in spherical Bessel functions and associated Legendre function as illustrated in the equation:

$$S_{n,m} = h_n^{(2)}(kr) L_n^m(\cos(\Theta)) \sin(m\varphi)$$

$h_n^{(2)}(kr)$ is the spherical Hankel function for an outgoing wave with the product of wave number and radius as argument. $L_n^m(\cos\Theta)$ is the associated Legendre function describing the Θ-dependence and for which m<=n. For increasing integer n and fixed radius r the spherical wave functions will decay very fast and as a very coarse estimate the minimum number of harmonic components can be said to be required to be in the order of ka where k is the wave number ($2\pi/\lambda$) and a the radius of the sphere supposed to be as small as possible to contain antenna and supporting structure (i.e. phone plus dummy head and hand). The product ka is the circumference in wavelengths and for instance 40 cm diameter and 2.3 GHz gives ka=9.7 while 0.96 GHz (lower GSM-band) gives ka=4.0. Spherical wave functions are extensively treated in textbooks and will not be discussed in detail here but the radial dependence of the amplitude can be illustrated by the figure below where the first 9 wave functions (N=1 to 9) without azimutal variation are drawn (N=1 is a dipole field and is the curve on the very left):



For each function a clear “knee” occurs and for a big radius (which roughly coincides with N=ka) they have a similar distance dependence. For smaller radius the diagram shows strongly increasing amplitude. For a practical application (with the above mentioned sphere in mind) the different wave functions may have similar amplitude on the sphere and then the curves should be read as a fast decrease in amplitude close outside of the sphere. Conceptually it can simplified be said that wave-functions having N up to ka forms the radiating field. Wave-functions having higher N surely may exist in the near field but will not have any influence in the far field.

C3 Estimation of the resolution limits

To quantify this heuristic limits the curves above have been used to calculate the number of wave functions (or rather the highest N in the used wave functions) required for a certain suppression assuming one disturbing wave function of the same amplitude as the dipole field when it is being exited on the limiting sphere mentioned above. Suppression on big distances is the interesting quantity and the calculation starts with a desired suppression (say –26 dB) and ends with the lowest wave number N which can be omitted to maintain the desired suppression. Wave functions up to N should thus be included to represent the radiation and a good antenna measurement on the device in question must be arranged to include all wave functions up to N. Most antenna measurements are a kind of sampling (“number of cuts” etc) and the sampling must be sufficiently dense to measure wave functions up to N. In the table below approximate formulas are given to deduce minimum N for a given sphere circumference (in wavelengths) ka for 4 different suppressions (-26 dB to –10 dB). An optimistic maximum angular sampling interval (2 samples per period) is also given for threes cases (960 MHz, 2000 MHz and 2500 MHz tailored to cover common bands) with 0.4 m sphere diameter (≈head+phone):

Suppression of disturb-ing mode	Deviation from non disturbed	N estimation caused by sphere size ka	0.45GHz	0.96 GHz	2.0 GHz	2.5 GHz
			Angular sampling	Angular sampling	Angular sampling	Angular sampling
-26 dB	0.4 dB	(ka+1.55)/0.85	44°	27.4°	15.4°	12.7°
-20 dB	0.9 dB	(ka+1.3)/0.88	50°	29.7°	16.4°	13.4°
-15 dB	1.6 dB	(ka+1)/0.9	56°	32.1°	17.3°	14.1°
-10 dB	2.8 dB	(ka+0.7)/0.92	63°	35.0°	18.2°	14.8°

For a typical case (<2 GHz) the table indicated that a sampling interval of maximum 15°(or possibly 18°) should be used. It should be remarked that the “knee” is fairly sudden implying that the choice of suppression level is not too critical (18° to 15° for –26 dB to –10 dB). It should be stressed that the assumption of equal amplitudes on the sphere is a kind of worst case and for instance a phone on a head will surely not generate big amplitudes of high modes. Thus if for instance –26 dB suppression is required (±0.4 dB) then probably the –10 dB case can be used instead but as the level is not utterly critical but we can not expect that big deviations from the table can be used for accurate measurements. On the contrary the assumption of only two samplings points per period variation is very optimistic and requires very advanced interpolation technique to be able to get a plot. Normally 4-5 sampling points per period are used in nice case a nice and accurate plot is required without too advanced interpolation. If we on the other hand do not need an accurate plot but just an integration of the radiated power then down to one sample per period (for a contribution that safely can be neglected) can be used in our case when we know that the signal is periodic and continuous.

The use of 15° angular sampling interval for accurate measurements is reported and used from different sources. The calculations above add the advice that an increase of these figure is never feasible unless we know that the structure to be measured on is very simple (i.e. that it can be enclosed within a much smaller sphere). As the integrated power (or sensitivity) probably is more important than a plot of the pattern a compromise can be to measure for instance TX with 15° and RX with 30°.

It should be remarked that even when the test restricted to the lower phone bands (<1 GHz) the conventional 3 cut measurement is clearly not sufficient to get an antenna pattern from measuring error standpoint. The 3 cut method is only usable with reasonable accuracy (and strictly for power integration only) at 450 MHz and lower in the case of phone plus a dummy head.

C4 Translation to number of directions.

Depending on the measuring schemes this 15° can be translated to a minimum number of directions where we measure the radiation. To fill the whole sphere (41252 square degrees) with 15° squares would require 183 squares but as the pattern rather are circular than square at least 259 samples would be required. Depending on the measuring pattern this can (still for phone plus dummy head) be slightly more but can be rounded off to “200-260” for <2 GHz and “50-65” if the measurement is restricted to <1GHz.

Appendix D. Minimum measuring distance.

D1 General

Appendices B-C ends up in some spherical geometry and to implement such a geometry rather small test distances are necessary to make the volume of the room feasible. In this appendix the reasons behind “near field” and “far field” are discussed in detail and one conclusion is that measurements can be done at rather small distances in the UE case without loss of accuracy. The small distance reduces the errors caused by wall reflections.

D2 Near- and far field definitions

Generally it is a useful condition if the distance between CRA and DUT is small as compared to the distance from DUT to the walls, ceiling and floor. This will make the wall absorbers to appear better than they are and a similar argument applies especially to spherical geometries where the path from CRA to DUT is such that the slanting angles are avoided. A closer and general look on small measuring distances will be done in this appendix.

Three distance regions are defined for antenna measurements:

> Fraunhofer region or “far field” where the complex amplitudes have the distance dependence 1/r and otherwise only an angular dependence. E- and H-fields are transverse and the quotient E/H is Z_0=376.6 ohm. Traditional far field measurements are restricted to this region.
>
> Fresnel region or “radiating near field” where the quotient E/H still is close to Z_0 but where then angular dependence gradually is reshaped and is changing with the distance in a non trivial way. This region is used for near field antenna measurements (NF) which obviously can be done in the Fraunhofer region too. In the NF procedure the measured fields will be transformed to far field.
>
> Reactive near field where the quotient E/H is not Z_0 and generally the field is gradually transforming to a dominating electric or magnetic field. Reactive near field are not used to estimate far field (i.e. not suited for near- to far field transformation) but only for special measurements like SAR tests.

In most textbooks the inner limit for the Fraunhofer region is given as $r=2D^2/\lambda$ and the inner limit of the Fresnel region as 3λ. As these are very analogue values they depend on the DUT and the accuracy requirements and the figures “2” and “3” are just typical. The table below will give more specific values where the amplitude errors are tied to the distances. For three desired accuracy limits (deviations from 1/r-dependence) the boundaries in distance r can be given as:

Amplitude accuracy	Inner Fresnel limit or “avoid reactive nearfield”	Boundary Fresnel/Fraunhofer or “real far field”
0.1 dB (or 1.2% ampl.)	$r>1.8\lambda$	$r>1.53D^2/\lambda$
0.2 dB (or 2.3% ampl.)	$r>1.3\lambda$	$r>1.09D^2/\lambda$
0.5 dB (or 5.9% ampl.)	$r>0.8\lambda$	$r>0.7D^2/\lambda$

This limits assumes that the distance variation due to a non perfect centered DUT is compensated for as given in R4-010656 which just means that the 1/r-variation of the amplitude is compensated for as otherwise x% amplitude accuracy would imply <x% distance variation allowance only. Further it assumes that the far field limit of the CRA is adequate (i.e. if it is a large horn it must be far away or quantified as $G_{CRA}\lambda/3$).

The inner Fresnel limit is based on a dipole field for which the squared amplitude has a distance variation like $(1+3(kr)^{-2}+5(kr)^{-4})/r$ and a more complex body will not have a worse variation. The Fresnel/Fraunhofer boundary above is for the amplitude (or "main lobe amplitude") a conservative limit based on uniform amplitude over the width D of the DUT. The phase can be said to be less sensitive (1 dB amplitude corresponds to 6°) but obviously depending on the use. For high gain antennas and for antennas with specified nulls or low sidelobes the Fresnel/Fraunhofer boundary is the important one and in many cases $r=2D^2/\lambda$ must be substituted by $r=4D^2/\lambda$ or even more. For fairly omnidirectional antennas of phone-size the table above should be applicable as it is rather the amplitude than the side lobe ripple which is important for the efficiency calculations.

D3 Conclusions

Consequently there is a clear potential to use rather small distances and with for example D=0.4 m or smaller (phantom head plus phone) and 0.1 dB amplitude accuracy 2 m will be sufficient for frequencies between 0.3 and 2.5 GHz. It can also be noted that the simple distance variation 1/r actually can be said to give the biggest error contribution and should be compensated for but on the other hand it will give a small influence on the average.

Appendix E. Consequences of Suspected Disturbing objects (SDOs)

E1 General

For omnidirectional or low gain antennas any kind of disturbing objects in the vicinity of the DUT may cause big deviations while the corresponding problem for high gain antennas is much simpler as the structures in question generally can be located on the back side of the DUT or anyway located well outside of its antenna lobe. To calculate the disturbance for a low-gain antenna even in a special case is quite complex but some simplified estimations are done below just as an illustration of the problem.

E2 Estimation

A possibly disturbing object (SDO) is supposed to be located at the distance r_1 from the DUT and at the distance r_2 from the CRA. The distance DUT-CRA is r_3 and we assume as a typical cases that $r_1 << r_3$ and that consequently $r_2 \approx r_3$. The bistatic scattering cross section of the SDO is σ and depending on both directions and polarization. The direct wave between DUT and CRA will simplified give a power transmission of $G_{DUT}G_{CRA}(\lambda/4\pi r_3)^2$ by Fries law. This will be disturbed by a scattering via the SDO which by Fries law will give $G_{DUT}G_{CRA}(\lambda/4\pi r_2)^2[\sigma/(4\pi r_1^2)]$. Both gains are directional dependent so this is highly simplified. As $r_2 \approx r_3$ it is only the last factor which significantly differs so if the accuracy demands for instance <-30 dB SDO echo level (±0.25 dB deviation) then we should ensure $\sigma < 0.001(4\pi r_1^2)$. Closer calculations can be done for possible structures. They are omitted here but the practical result is that close to the DUT we can only stand very small disturbing structures in the case of a more or less omnidirectional DUT. Supports of foamed plastic will generally work but more or less all kinds of mechanically moved structures containing metallic parts or even parts of massive plastic or wood must be avoided. Except for the foamed materials thin wires or sticks of dielectric materials are useful as their scattering area declines sharply if their diameter is a few times below $\lambda/\pi\mathrm{sqrt}(\varepsilon)$. Thus (as a simple example) pins roughly <5 mm made of normal plastic material ($\varepsilon < 3$) can be compared to foamed materials form reflection viewpoint.

E3 Conclusions

To ensure a prescribed echo level possible SDOs must have a scattering area which is smaller the closer the SDO is from the DUT. The practical consequence of this is a strong preference for the “spherical geometry” discussed in appendix B above as it is a way to eliminate all SDOs in the sensitive area.

Appendix F. Use of phantoms

F1 General use

The big source for antenna efficiency loss is in general terms interaction with materials close to the antenna or terminal. For voice terminal it is the head and hand of the user but for the more general types of 3G user equipment the situation will be different. Because of its big importance it is necessary to include what can be deemed as “a realistic worst case” in the test but on the other hand it must for practical reasons be a very limited number of well repeatable cases. For a common voice terminal the standardized SAR test cases are well defined and available. They are thus a suitable choice of test cases and form a reasonable compromise but for quite other types of terminals other test cases have to be defined such as “on a wooden table”, “on a metal table” etc.

F2 Typical use for voice terminals

Typically for present voice terminals the antenna gain in talk position is 8 dB or more below the free space gain and a fair talk position measurement is thus necessary. Practical tests have reveled big differences between different persons so a better defined way is to use a phantom head but then it should be verified that it really represents the actual case. Several such heads have been demonstrated but for practical reasons the same standard as for SAR measurements is supposed to be used. There is a fairly good consensus about which SAR head to use and the existence of a usable and available phantom head is important for the choice. This is not to say that the SAR head is ideal for this purpose but it is fair enough. The biggest shortcoming is that the efforts spent on a corresponding phantom hand so far are insufficient even if they are not small. For SAR purpose the hand is supposed to decrease the fields in the head and with SAR treated as a safety issue a kind of global worst case is sought for so the hand is simply omitted for SAR tests. Thus there will still be a need to define a phantom hand but meanwhile “head only” is a good starting point. A simple guess is that many internal antennas will get too low an attenuation by this model which put some attention to the importance of being able to measure on a real person as a reference.

F3 Other typical uses

A few more test cases have to be defined for “typical used position”. For 3G terminals this still are to be defined but a number of suggestions for typical used positions are:

> Present “talk position” for voice terminals. Related to SAR standard just because it is well developed and defined.
>
> “In hand” in front of the user for PDA like terminals. Even if they have voice facilities too the wide band applications are likely be associated with data reception. It is to be investigated whether the phantom is needed or not to give a significant result as the phantom body will scatter rather than attenuate.
>
> “On wooden table” will be a typical use for many PDA-like terminals or laptops.
>
> “On a metal table” is a case associated to the previous one. It is likely that a user phantom is less important than the position on the table in this case.

> "In the pocket" may be a typical position for a number of terminals consisting of two units one of which may be a talk device.

It should be stressed that the list above is just a suggestion to illustrate the complexity of he problem. It should also be remarked that the "phantoms" should be suited for diversity test as well as power attenuation.

F4 Phantom summary

For the general 3G case "phantoms" remains to be defined but a choice between a small number of alternatives is foreseen. For voice terminals "head only" according to SAR standard is suggested until a realistic hand model can be agreed upon. Tests on real persons will remain to be an important reference but will be too complicated as a standard test as a big number of tests will be required to get a stable average in spite of the big variation from person to person.

Appendix G. Stochastic accuracy

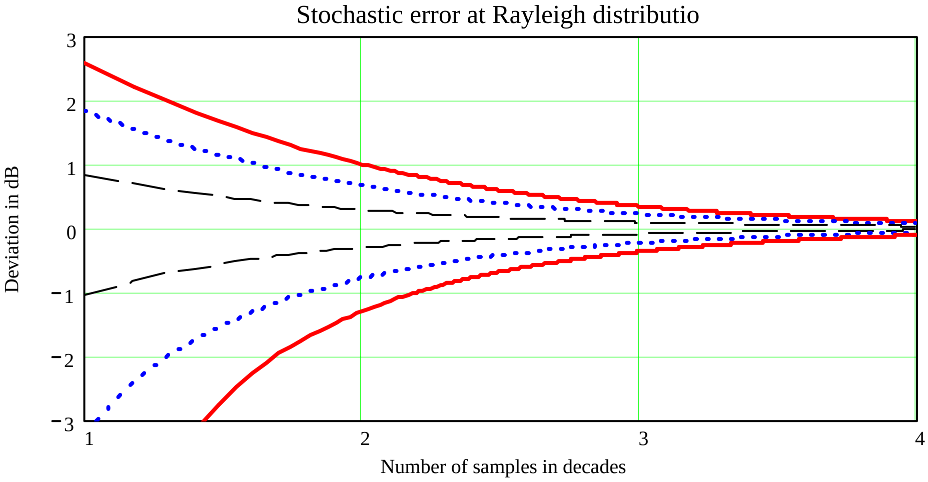
G1 General

Under quite general conditions when the line of sight propagation is negligible the received electromagnetic fields appears to have a stochastic behavior with an amplitude having a Rayleigh distribution (ref [9]). If an average field strength is calculated from a number of measurements the average A will have a stochastic distribution too with a standard deviation which is A/sqrt(N), where N is the number of samples used for the average.

Some of the measuring methods discussed above (real or artificial scattered field) relay on stochastic methods. As compared to the instrument accuracies (“deterministic measurements”) the errors by stochastic measurements will be bigger and be depending on the number of samples so a minimum number of samples can be deduced from the accuracy requirements.

G2 Examples

If for instance 1000 samples are used for an averaging of a Rayleigh distributed signal that means an accuracy in the order of ±0.3 dB which is close to minimum to be useful (99% level of confidence). The accuracy varies like $N^{-0.5}$ with varying number of samples N. The curve below gives the expected variations for 10-10000 samples in dB for 50%, 90% and 99% within the lines:



As is indicated typically a few hundred samples are needed. Depending on the situation it might be necessary to make a test to see whether the Rayleigh assumption is valid or not. As the accuracy changes as the square root of the number of samples is practically difficult to make the accuracy much better by increasing the number of samples.

G3 Conclusions

The test methods related to real scattered field and artificial scattered field are depending on this stochastic accuracy to give results comparable those obtained in an echo free chamber. The corresponding antenna movements must also be taken into account for a comparison and to make the comparison fair only tests giving the same data (frequency resolution etc.) should be compared.

TSG-RAN Working Group 4 (Radio) meeting #19 **R4-0111228**
Edinburgh, Scotland, 3rd – 7th September 2001

Source: Motorola

Title: Proposal for feasibility study on UE antenna

Agenda item: 8.1

Document for: Discussion and Approval

1.0 Introduction

In the feasibility study of UE antenna efficiency is was indicated the procedure for the measurement of the terminal antenna performance is to follow the method as defined in the CTIA document [1]. This document lists the key aspects of the CTIA report, which can be used to progress this study item and can form the bases for the technical report on this study item.

2.0 Proposal

Specific test methodology recommendations (with references to CTIA document):

2.1 Anechoic Chamber Configuration and Requirements

Both open air test sites and enclosed anechoic chambers have been used to evaluate the performance of antennas and radiating devices such as cellular phones. Cellular phones have the relatively unique characteristic that their radiation pattern is considerably more isotropic than are many antennas, especially high gain antennas. If reflections from scatterers in the test environment are not carefully limited, these reflections can easily degrade the accuracy of the test results. This becomes a matter of particular interest as the radiation pattern becomes isotropic in nature. Also, in order to capture the total power radiated from such isotropic radiators, the test chamber must have the capability of scanning as much of the total surface of the radiated sphere as possible. Although actual implementations will differ, a typical implementation is to mount the phone/phantom on a turntable that will rotate the head/phone from 0 to 360 degrees in phi. The measurement probe is then mounted on a single axis positioner that moves from 0 to –180 degrees in theta, or certainly as close to –180 degrees as is practical.

Therefore Motorola proposes a spherical measurement in an anechoic chamber that has a very well controlled quiet zone. The probe antenna should be moved about a sphere with a radius of at least three wavelengths from the device under test. Furthermore, in order to maintain a ±1 dB measurement accuracy, the device under test must remain in a quite zone with a ±0.5 dB ripple. It can be shown that it is possible to achieve this level of quiet zone ripple if reflections are kept to –30 dB or better. The chamber and device positioning equipment should be configured so as to allow the measurement probe to traverse as much of the surface of a sphere centered about the device under test as possible. The sphere can be scanned using conic or great circle cuts, depending on the configuration of the device-mounting fixture. The probe antenna must be capable of measuring two orthogonal polarizations at each measurement location.

The device must be supported with a non-reflective holding fixture so as to achieve the required quite zone accuracy. Also, provisions should be made to incorporate a simulated human head, or head phantom so as to properly replicate the actual use conditions of a cellular phone. In order to maintain low chamber scattering parameters, control of the phone is best accomplished without connecting any wires to it. Over the air control of the phone allows this to be accomplished readily and Motorola highly recommends the use of such over the air control.

References: CTIA Test Plan [1], §2.3

2.2 Anechoic Chamber Validation

One of the largest single sources of error in radiated measurements is ripple due to reflections in the anechoic chamber. For this reason, it is necessary to validate that the quiet zone in the chamber is sufficiently free from ripple to support the accuracy desired for the measurements. Since the device under test (a cell phone) has a relatively isotropic or low-gain radiation characteristic, which is likely to illuminate all parts of the chamber, it is necessary to perform this quiet zone test using similar low-gain reference antennas. The orbiting dipole and orbiting loop antenna tests are an effective and efficient method to accomplish this. This validation should be performed at at least one frequency in each band of interest, and should be repeated periodically to detect any degradation in the chamber environment.

Reference: CTIA Test Plan [1], Appendices C and J

2.3 Anechoic Chamber Calibration

Calibration for both transmit and receive measurements is accomplished by a substitution method. This is based on applying a known power to a reference antenna with a known gain, and then measuring the power received by the measurement system. The difference between the known power and gain at the reference antenna and the power received by the measurement system is then the path loss for the frequency being calibrated. At transmit frequencies, this path loss term, when added to the raw power measured with a DUT in the chamber, yields the EIRP or ERP. At receive frequencies, the path loss term, when subtracted from the power being output from the measurement system to the chamber, yields the Effective Isotropic Sensitivity (EIS). Appropriate calibration antennas and/or orientations of the chamber's measurement antenna should be employed to allow establishing a path loss term for each of the two linear polarisations measured in the chamber.

Motorola recommends that, for maximum accuracy, a calibration standard antenna that has directivity characteristics similar to the DUT be employed. At the frequencies of interest, a half-wave dipole is a good choice.

Reference: CTIA Test Plan [1], Appendix D.

2.4 Test Condition(s)

As mentioned earlier, the phone should be controlled over the air so as to avoid introducing further uncertainty into the test results due to unnecessary scatterers. Modern day base station simulators allow the control of the power level, channel, and modulation conditions of the cellular phone. It is recommended that the cellular phone be tested in all manufacturer recommended antenna positions, at the highest transmitter power (or other powers as desired), and in a standard head adjacent position against a head phantom. For future devices that are primarily envisaged to have PDA-like usage models, an appropriate test condition in a phantom hand should be defined. Since considerable historical data exists measuring the radiated performance of cellular phones in free space, yet another test condition of free space may optionally be added to the sequence. The radiated performance of a device as small as a cellular phone often changes over frequency, so it is also recommended to measure at least three frequencies, typically lowest, middle and highest operating frequencies or channels, and on each band of operation. For example, many GSM based phones operate on three bands (900, 1800 and 1900MHz), and this would result in nine different spherical scans for each antenna position. Lastly, since the phone can be held against either side of the user's head, measurements should be taken on both the left and right head adjacent side of the phantom. This would then raise the number of spherical scans for the above example to eighteen.

Many head phantoms have been developed over the years. Recently the IEEE has designed a Specific Anthropomorphic Mannequin, or "SAM" phantom, specifically for the purposes of use with cellular phones. Although this phantom was developed for the measurement of SAR, incorporation into TRP or EIS measurements, using tissue simulants appropriate for each band, is logical in that it gives both phone manufacturers and carriers a consistent measurement condition for phones.

It is recognised that the user's hand on the phone is a significant source of additional loss in the link, so a hand simulation ultimately is desirable as part of the test condition. At this time, an agreed-upon hand phantom and positioning methods are not well-defined, so testing with a head phantom only is recommended. At such time when a hand phantom and positioning has gained acceptance, Motorola recommends its use be added to the preferred test condition.

References: CTIA Test Plan [1], §1.7, 2.3, 2.4 and Appendix E

2.5 Data Gathered and Measurement Procedure

The spherical scans may of course be gathered in any order that makes sense as is relevant to the particular test set-up and equipment. Typically, a single spherical scan will be performed with the phone set to a single channel, power level, antenna position, and phantom head side. Then one individual parameter will be changed, and a new spherical scan will be performed. At each measurement angle in the scan, the pattern quantities of interest, EIRP and EIS for transmit and receive, respectively, are recorded for each of the two linear polarisations. Ideally the entire sphere must be scanned with sufficiently small resolution so as to capture all the necessary nuances in the phones radiation pattern. It can be demonstrated that data taken every 15 degrees in both the phi and theta axes are sufficient to meet the ±1 dB overall accuracy at typical cellular frequencies. Coarser measurement increments can result in poorer accuracy, and this possibility should be assessed before hand. This results in 277 data points spread over the surface of a sphere. Combined with 2 polarisations taken at every phi/theta location, 454 data points will then have to be reduced to the single performance figure.

References: CTIA Test Plan [1], §2.2 – 2.5

2.6 Data Post Processing

For both transmit and receive tests, the resultant data are complete spherical patterns, in two polarisations, of EIRP or EIS, respectively. To reduce these data to a single figure of merit requires an appropriate integration technique. A spherical integration of EIRP, with a sin-theta weighing function to compensate for the uniform angular sampling method employed in this test, yields the total radiated power (TRP) of the DUT. A spherical integration of EIS yields total isotropic sensitivity (TIS). These integrations reduce to summations for the discretely sampled data resulting from the tests.

Motorola submits that these total integrated quantities are the best compromise as predictors of performance, even for environments where the local scattering may show a statistical trend toward a particular range of angles-of-arrival. This is because of the variation in orientation of the phone when in use at either side of the head, in the hand, or in a belt clip, and because of the variation in scattering models for the various environments in which people use their phones.

Reference: CTIA Test Plan [1], Appendix I and Appendix B, equations B.2.1-1 and B.2.3-1
Motorola 3GPP submission [2], Appendix A1

Annex A. Criteria

Criteria should be based on total integrated quantities as described above, rather than peak pattern quantities or averages in a single pattern cut only. The use of the total integrated quantities makes it easy to relate criteria to simple physical parameters like conducted power of the phone and known antenna efficiency ranges, which will help in establishing these criteria scientifically. Selecting criteria will require consensus of the entire group. It is advisable to survey performance of existing products in the field and to examine link requirements to select these criteria. CTIA has chosen not to set criteria until after an interim period while data is gathered on existing and new phones.

Reference

[1] R4-010954: Method of Measurement for Radiated RF Power and Receiver Performance - Cellular Telecommunications & Internet Association (CTIA)

[2] R4-010656: Methodology for Characterising Real-World Radiated Performance of Mobile Phones – Motorola

UE antenna efficiency test-final study report

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This is a ppt-summary of R4-011086 written for Allgon Mobile Communication AB August 2001

Present situation

- For a typical voice handset the loss in talk position is 8-10 dB as compared to a good omni-directional antenna
- This surprisingly big loss is not limited by specifications like GSM 05.05 and type approvals use connectors only (=neglecting the antennas!)
- The practical problems to find a good and practical test method has been an obstacle. Many different local tests are in use.
- Physically smaller units tend to increase the losses.

3G versus 2G situation

- The wider bandwidth will require better antenna efficiency to obtain high speed without excessive loading of the network
- The user will experience better high speed coverage on UEs with high antenna efficiency especially in areas having high speed in spots only
- “Talk position/free space” is not a good description of all 3G units. “On wooden table”, “on metal” etc must be included

Needs for a test method

1. Type approval. High accuracy needed
2. Values for coverage predictions. “0 dB” in present specification is misleading
3. Diversity will be increasingly used which requires a new set of data
4. A method (or group of methods) which can be used from antenna prototype tests through all the development to type approval/market surveys is desirable
5. Comparisons between final products will simplify long term development

Recent changes in test prerequisites

- General increase in data capacity, measuring speed etc. of common instruments
- Some well known handset antenna test methods were developed for <500 MHz and are now obsolete
- Mobile communication is now big enough to motivate the building test chambers really optimized for this use
- SAR test development has supplied standardized phantoms for well defined tests

Conclusions from this background

- Frequency increase and 3G needs have stressed the need for dense sampling of antenna patterns and improved general measuring quality
- Instrumentation has developed to be able to meet the needs
- So far many old fashioned test methods have dominated practical use
- The application of modern methods can now be implemented!

Fields used for the tests

- Real scattered fields can be used and are important for reference
- Artificial scattered fields have been tested.
- The scattered fields needs some 100 samples to reduce the stochastic error implying long test time/bad resolution
- A full 2-axis measurement in an echo-free chamber can supply all data which can be post-processed. Deterministic measurements enable fast measurements
- Under linear conditions there is no limitation in the possibilities for post processing

Conclusions for the choice of fields

- A full 2-axis measurement in echo free chamber is preferred as it will give all required data in a short time
- The choice of chamber and set-up is critical for the full 2-axis measurement. Wrong chamber (for this purpose) can give bad results in too long time.
- Stochastic field measurement will be time consuming unless just an average is requested.
- Real fields are always important as reference

Key parameters

- The fine structure of the antenna pattern in talk position at higher frequencies (>1.5 GHz) requires many tested directions (15°). Otherwise the result will gradually turn random due to pattern ripple
- A good spherical geometry measures “all” directions
- Small distances can be used which simplifies a spherical geometry in a chamber of feasible size and it also improves the residual echo level.
- Residual echo level is an accuracy limitation especially at low frequencies
- Time can be reduced to <10 min for TX

Summary

- The conditions for fast and accurate terminal antenna measurements are investigated
- The development of frequency and accuracy requirement has went on faster than the so far commonly used used antenna test technique
- Use of what is possible with modern instrument-ation will enable both fast and accurate tests
- A cross reference should be a part of the final result to enable tests with existing equipment to be partly comparable to ideal tests. Type approval however needs the best equipment
- The new CTIA draft for 2G type approval is fairly close to this paper

CTIA

Wireless Subscriber
Station Certification
Program

Method of Measurement
for Radiated RF Power
and Receiver Performance

™

Cellular Telecommunications & Internet Association
Method of Measurement for Radiated RF Power and Receiver Performance

May, 2001
Draft Revision 1.0

CTIA Certification Program

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Section 1: Introduction

1.1 Purpose:

This Test Plan defines the methodology and procedures to be followed in the laboratory evaluation for conducting Radiated RF Power and Receiver Performance measurements on wireless subscriber stations.

This Test Plan is part of a CTIA Certification Program as described in a separate document entitled CTIA Terminal Unit Certification Program Management Document. This document contains criteria, in addition to laboratory performance tests, that must be met for CTIA certification.

1.2 Scope:

This Test Plan details specific hardware, software, laboratory techniques, test methodology, test procedures and technical criteria used during a CTIA product evaluation. This Test Plan does not include the test requirements or test methodology for other aspects for evaluating terminal equipment or technologies. Where applicable, other Test Plans exist or will be prepared for inclusion into the CTIA Certification Program.

This Test Plan gives a practical methodology for the accurate testing of wireless subscriber stations to ensure that they meet current industry standards.

1.3 Applicable Documents:

The baseline standards for the Certification Program's test plans are listed below. CTIA will incorporate revised industry standards, as they become available. As additional programs are added additional standards will be referenced. All referenced standards may cross reference additional standards.

Recommended Minimum Standard for 800 MHz Dual Mode Narrowband Analog Cellular Subscriber Units. TIA/EIA/IS-90, January 1993, Telecommunications Industry Association.

Mobile Station - Base Station Compatibility Standard for 800 MHz Analog Cellular. TIA/EIA/IS-91, October 1994, Telecommunications Industry Association.

Recommended Minimum Performance Standards of 800 MHz Cellular Subscriber Units. TIA/EIA/IS-19-B, May 1988, Telecommunications Industry Association.

800 MHz Mobile Stations Authentication Test Procedure. Rev. 3.1, July 1998. CTIA.

Cellular System Mobile Station-Base Station Compatibility Standard. EIA/TIA Interim Standard, EIA/TIA IS-553, June 1996, Telecommunications Industry Association.

Recommended Minimum Performance Standards for Dual-Mode Wideband Spread Spectrum Cellular Mobile Stations. TIA/EIA-98-B, August 1998, Telecommunications Industry Association.

Recommended Minimum Performance Requirements for 1.8 to 2.0 GHz Code Division Multiple Access (CDMA) Personal Stations. J-STD-018, September 1995, Telecommunications Industry Association.

Mobile Station–Base Station Compatibility Standard for Dual-Mode Wideband Spread Spectrum Cellular Systems. TIA/EIA/IS-95-A, May 1995, Telecommunications Industry Association.

TDMA Cellular/PCS - Radio Interface - Mobile Station - Base Station Compatibility. TIA/EIA/IS-136-A, October 1996, Telecommunications Industry Association

TDMA Cellular/PCS- Radio Interface - Minimum Performance Standard for Mobile Stations. TIA/EIA/IS-137-A, July 1996, Telecommunications Industry Association.

Cellular Mobile Telephone Equipment Specifications, Preliminary, Advanced Mobile Phone Service, Inc.

TIA/EI -136-A, Telecommunications Industry Association, Standards and Technology Department, 2001 Pennsylvania Ave. NW, Washington, DC 20006.

ANSI/IEEE Std 149-1979, IEEE Standard Test Procedures for Antennas, IEEE, Inc., 1979, p. 100.

Mobile Station (MS) conformance specification, *GSM 11.10-1(ETS 300 607-1)*

Electromagnetic compatibility and Radio Spectrum Matters (ERM) for radio communications equipment, *EN 300 339*

Radio Equipment and Systems (RES); Electromagnetic compatibility (EMC) for Digital Enhanced Cordless Telecommunications (DECT) equipment, *ETS 300 329*

Radio Equipment and Systems(RES); Electromagnetic compatibility(EMC) for European Digital Enhanced Cordless telecommunications(DECT) equipment, *ETS 300 342-1*

1.4 Certification Test Plans:

Detailed laboratory test procedures and technical requirements for certification are contained in the following documents. Test plans provide detailed information regarding the type of test equipment typically used to perform the evaluation (i.e., manufacturer, model, and firmware release). See appropriate test plans for a detailed description of each test performed.

- *Test Plan for 800 MHz AMPS & Cellular/PCS TDMA Dual Mode Wireless Subscriber Stations*
- *Test Plan for 800 MHz AMPS & Dual Mode AMPS/NAMPS Wireless Subscriber Stations*
- *Test Plan for 800 MHz AMPS & Cellular/PCS CDMA Dual Mode Wireless Subscriber Stations*
- *Test Plan for 800 MHz AMPS Analog Wireless Subscriber Stations*
- *800 MHz Mobile Station Authentication Test Procedure*

1.5 Test Overview:

This Test Plan presents the individual test procedures bulked by type of test and/or technology (Transmitter, Receiver, AMPS, CDMA, TDMA, & GSM).

1.6 EUT - The Cellular Subscriber Station:

Devices for test are to be supplied with all required peripherals and accessories, in accordance with the Program Management Document for CTIA Mobile Station Certification Programs. This includes:

Table 1.2 - EUT Peripherals and Accessories

Mobile Units	Transportable Units	Handheld Units	Other
1. Transceiver Unit 2. Handset/Cradle 3. Hands-free speaker and microphone 4. All interconnecting and power cables 5. EUT mounting hardware 6. Test Interface Adapter (TIA)	1. Transceiver Unit and Carrying Case 2. Handset/Cradle 3. Rechargeable Batteries 4. Power Cables (Charging and battery adapter) 5. Antenna and Adapter 6. Test Interface Adapter (TIA)	1. Transceiver Unit 2. Rechargeable Battery and Battery Charger 3. Antenna Adapter 4. Power Cables (charging and car adapter) 5. Mobile/car adapter apparatus (including hands-free equipment) 6. Test Interface Adapter (TIA)	1. Transceiver Unit 2. Antenna Adapter 3. Power cables 4. Test Interface Adapter (TIA) 5. Appropriate ancillary equipment required for normal operation of the EUT.

In addition, any auxiliary equipment which is available as part of the product, either for installation or as an option, should be supplied.

1.7 Subscriber Unit Test Interface (TIA) Requirements:

Detailed requirements for the Test Interface Adapter (TIA) are defined in TIA/EIA Interim Standard, TIA/EIA/IS-137-A, TDMA Cellular/PCS - Radio Interface - Minimum Performance Standard for Mobile Stations, Section 8, Mobile Station Test Interface. These requirements represent an attempt to standardize the test interface, including access to all points required for testing. This allows automatic tests to be carried out, specify audio impedances, and Equipment Under Test (EUT) control codes for manual testing.

No laboratory attempt will be made to “kludge” patches for any test requiring internal test point connections. Physical access to the relevant test points in the subscriber set, and clear instructions must be provided from the manufacturer.

The TIA, together with appropriate documentation and labeling, must be supplied with each unit submitted for testing. The TIA, including all associated connectors and cables, must operate without degrading the performance of the EUT.

The cables supplied to connect the TIA and the unit under test must be of sufficient length to permit the physical separation of the TIA from the EUT in environmental testing (approximately 5 to 6 feet).

The connectors supplied for connection of the TIA and/or the EUT to the test equipment must be standard connectors (N-type, BNC [recommended for 800 MHz only] or SMA). If specialized or proprietary connectors are used, adapters must be provided.

Additional criteria may be added to the TIA requirement if deemed necessary by the testing laboratory.

1.8 Subscriber Unit Documentation:

All documentation associated with the installation and operation of the equipment shall be supplied in accordance with the CTIA Program Management Document-Mobile Station Certification Programs. This includes:

- User guides or manuals
- Programming instructions
- Installation guides or manuals
- Service manuals, including manual control of EUT from TIA and/or keypad
- Identification of the IF frequencies used in the receiver.
- Diagram of the Test Interface Adapter, giving details of the pin connections.
- Submission checklist (Appendix B: Test Result Reporting).

A telephone number and contact person at the manufacturer shall also be supplied to provide backup, and to answer technical or operational questions.

1.9 Test Equipment and Software:

The "core" test equipment used during the evaluation will be identified in each individual Test Procedure/Section. Core test equipment may be substituted if test equipment equivalency can be confirmed. Should this occur, such change shall be noted in the Test Report. Equipment shall be calibrated to standards traceable to NIST.

1.10 Test Environment:

All tests as described in this Test Plan will be performed at a CTIA Authorized Test Laboratory (CATL) for CTIA Certification. Personnel performing the test will be experienced in the testing of mobile communications equipment with respect to radiated power measurements. Special instructions where needed for operation of EUT, will be provided by the manufacturer.

Manufacturers will work directly with a CATL (of their choice) to have equipment tested. All tests will be performed at test facilities accredited to ISO/IEC Guide 17025.

1.11 Failure Criteria:

Failure during the tests may occur as:

a) ***Failure to Meet a Required Parameter/Specification*** - If this condition is observed, a reasonable check of the unit shall be carried out to ensure that no catastrophic failure has taken place. If the unit under test is functional, the tests shall be continued and failures reported in the Test Report, and/or the second test sample substituted when reasonable.
b) ***Serious Failure*** - This shall include failure to function, physical failure, burning, etc. If such failure occurs, the tests will be stopped and the second test sample substituted for the balance of the tests.

All failures of any type will be noted in the Test Report. Where deemed appropriate by the testing laboratory, interim failures will also be reported for recommended action. Repairs or alterations to the EUT will not be made unless specifically instruction to do so by the manufacturer/client. Such work is not considered within the scope of testing to this procedure.

For certification purposes, tests different from those shown in this Test Plan will only be conducted upon instruction by CTIA. Certain tests are conducted for informational purposes only.

1.12 Test Reports:

The test report will provide the results of the tests, and will include:

1. The type, serial number and description of the equipment tested.
2. FCC ID Number and Software Revision.
3. The date of the tests.
4. The person who performed the tests.
5. The laboratory facility used for the tests.
6. The reference Test Plan to which the units were tested.
7. The test results, identifying each set of results for each individual procedure.
8. A list of where the unit did not meet the specified criteria (failures).
9. Data and plots.
10. Contact Point.
11. Chamber characterization data and date of last characterization.

The Certification Test Report will not normally provide any analysis of why the unit might have failed any test, and will not suggest any modifications to correct the problem.

Two copies of all Certification Test Reports will be delivered to CTIA. Requests for additional copies should be made through CTIA.

Specific test results will only be released to the submitting manufacturer. CTIA will maintain complete confidentiality of specific test results. Upon satisfaction of the CTIA Certification Program Manager that all Certification Program requirements have been met, a unit will be added to the CTIA List of Certified Mobile Stations. This list is made available to the industry and the general public.

Neither public nor industry notifications will be made upon the failure of a unit to meet Certification Program Requirements. Specific test data results will not be released without the written approval of the submitting manufacturer.

Section 2: Scope of Measurements

Good antenna performance is critical to the effective operation of a cellular or PCS device in today's networks. As devices become smaller antenna performance is often compromised. Achieving an efficient antenna in a small size and over both cellular and PCS frequency bands is a difficult task. A comprehensive and accurate characterization of antenna performance will enable cellular/PCS carriers and device manufacturers to determine how well devices will work within the constraints of a specific cellular network design.

Generally, peak EIRP (Effective Isotropic Radiated Power) is not a good indication of mobile performance in the field. For example, if the radiation pattern of the device's antenna system is highly directive, the peak EIRP would be high (since the antenna gain is high in one direction), while coverage is poor in other directions. In a cellular environment it is best to maximize the spatial coverage of the antenna system so the user does not have to point the antenna in one particular direction to get good call performance. Further, the human head can alter the shape and peak value of the EUT radiation pattern and hence radiated power pattern. Losses due to the head can vary significantly with frequency, device size, and the antenna design implemented. From a field performance perspective, measurement of the average and peak EIRP on a head model is more meaningful than measurement of peak EIRP in free-space conditions.

Receiver performance is considered as important to over all system performance as is Transmitter performance. The downlink, or subscriber unit receive path. is integral to the quality of the device's operation. Poor receiver radiated performance will cause the user of the subscriber unit to hear a low quality voice signal. This also causes the subscriber unit to loose the base station signal resulting in abrupt termination of the call. This test specification requires spherical effective radiated receiver sensitivity (Receiver Total Isotropic Sensitivity) to be measured. A frequent cause of poor sensitivity on a single channel, or a small number of channels, is due to receiver in-band noise, or spurious signals from the transmitter itself being radiated back into the receiver. The receiver sensitivity will be measured with the transmitter set to the maximum power output allowed by the particular EUT and technology combination.

The procedures defined herein will verify acceptable test chambers for measurements in both cellular and PCS (if applicable) bands; measure terminal EIRP and receiver performance for digital cellular/PCS, and analog cellular; measure mobile performance in free-space and with a simulated head/head and torso.

2.1 Device Measurements--Transmitter:

The radiated RF performance of the Equipment Under Test (EUT) is measured by sampling the radiated transmit power of the mobile at various locations surrounding the device. A three-dimensional characterization of the 'transmit' performance of the EUT is pieced together by analyzing the data from the spatially distributed measurements. Data points taken every 15 degrees in the Theta (θ) and in the Phi (Φ) axes are sufficient to fully characterize the EUT's far field radiation pattern and total radiated power. This accounts for a total of 277 measurements for each measurement antenna polarization.

2.2 Device Measurements--Receiver:

The receiver performance of the Equipment Under Test (EUT) is measured utilizing Bit Error Rate (BER) or Frame Errasure Rate (FER). This test specification uses the appropriate digital error rate (as measured by the subscriber unit) to evaluate effective radiated receiver sensitivity at each spatial measurement location. A three-dimensional characterization of the receiver performance of the EUT is pieced together by analyzing the data from the spatially distributed measurements. Data points taken every 30 degrees[1] in the Theta (θ) and in the Phi (Φ) axes are sufficient to fully characterize the EUT's receiver pattern. All of the measured sensitivity values for each EUT test condition will be integrated to give a single figure of merit referred to as Total Isotropic Sensitivity (TIS).

Some digital technologies and/or EUT's may not allow the measurement of digital error rate without special procedures for controlling the EUT. In this case, external cables and manual test commands may be applied to the EUT for setup purposes only. All such cables must be removed and the EUT operated in stand-alone self contained battery powered mode during the data collection process.

2.3 Device Measurements--General:

Two acceptable methods of scanning the EUT are proposed. (1) The "conical" cut method, whereby the EUT rotates on its long axis and the measurement antenna is moved to several locations over head for each rotation. (2) The measurement antenna remains fixed and the EUT is rotated about two axes in sequential order, typically referred to as a "great circle" cut method. Section 2.5 Great Circle Test Method describes the great circle cut method, and Section 2.4 Conical Cut Test Method describes the conical cut method.

In both methods, the angle of elevation in the long axis of the EUT is referred to as the Theta angle, and the azimuth angle of the EUT is referred to as the Phi angle. The axis of turntable rotation will measure along the Theta axis for the great circle cut method, and along the Phi axis for the conical cut method. Although the data is gathered in a different order, the resultant data from both methods is processed in the same manner. The measurement antenna should be capable of measuring in two polarizations; horizontal and vertical. These two polarizations may be measured simultaneous with the EUT rotation or with sequential rotations. A separate rotation in the Phi plane with the EUT vertically orientated may be scanned for easy visualization of the more traditional H-plane radiation pattern.

Measurement makes use of the calibration data obtained from Appendix D: Test Site Calibration to normalize measurements of RF power radiated by the EUT performed over a spherical surface with the EUT's antenna centered at the sphere. A Base Station

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[1] The use of a 30 degree spatial separation increment is preliminary. An investigation is underway to determine the loss in overall accuracy vs. the 15 degree spatial separation increment used in the transmitter tests. The agreed goal of the receiver test is to find TIS with an accuracy of 2dB or better with a certainty of 95%.

Simulator is used to setup calls to the EUT and to request reports of signal strength that the EUT is measuring on the 'receive' frequency of the call. These two measurements may be taken individually or together as part of a single set of sampling scans. Data is collected and stored during the measurement step for delivery with the test report for each device tested.

Measurements will be made in a (1) "free-space" configuration whereby the EUT will be placed directly on a turntable, and; (2) "simulated-use[2]" configuration whereby the EUT will be placed against a simulated head/head and torso phantom meeting the characteristics defined in Appendix E: Simulated Head Design and Construction. Measurements will be performed with the antenna of the EUT extended and retracted (if applicable) in these two test configurations. Refer to Appendix A:Test Set-up Configurations for illustration of a "free-space" configuration. "Simulated-use" configuration will place the EUT against a simulated head/head and torso phantom with the simulated head/head and torso placed atop the turntable.

Different measurement results may be obtained between positioning the EUT on the left or right ear of the phantom. Measurement variability may also be attributed to the level of fluid in the phantom; especially when the phantom is positioned horizontally (Great Circle Cut). To minimize measurement uncertainties, air bubbles in the phantom should be eliminated by completely filling the phantom with fluid. Special care should be taken when performing Great Circle Cut measurements on the phantom to ensure the center of rotation is indeed about the EUT in each measurement axis.

Tests shall be conducted on all possible EUT configurations (i.e., battery pack configurations, housing schemes) unless it is demonstrated that there is negligible impact to performance with the different options. It is the responsibility of the manufacturer to define which options represent the "baseline" configuration and to provide adequate supporting data that validates assumptions for reduced testing of the remaining options. At a minimum, a complete set of measurements is required for the baseline EUT configuration.

2.4 Conical Cut Test Method

Appendix A: Test Set-up Configurations shows a diagram of the conical cut measurement method. The conical cut method requires the ability of the measurement antenna to be rotated in the Theta plane (overhead) of the EUT. Thirteen conical cuts are required to capture data every 15 degrees from the EUT; with the top (0 degrees) and bottom (minus 180 degree) cuts being at only one Phi angle. Typically, the EUT will remain affixed to a turntable during the entire measurement process. The measurement antenna will be positioned in at a starting Theta angle. The EUT will then be rotated around the full 360 degrees of Phi rotation. The EUT then be moved to the next Theta angle, and the process repeated.

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[2] The simulated-use configuration applies to handheld portable units only.

Measurements of the radiated transmit power and receiver sensitivity should be recorded in both vertical and horizontal polarizations simultaneously to reduce measurement uncertainties due to EUT repositioning. The EUT will report the power it measures in the receive-band by sending a message to the Base Station Simulator (for technologies that support this function).

2.5 Great Circle Test Method

Appendix G: Great Circle Measurement Orientation Diagrams shows diagrams of some of the Great Circle (Theta rotation) cuts. Twelve Theta rotation cuts are measured while rotating the EUT in the Phi plane (end-over-end) in 15 degree increments over the entire 360 degree Theta rotation range. The composite of the Theta cuts provides a three-dimensional view of the antenna pattern and performance. Some reference Theta rotation cuts are measured as described in the table below. The full list of Theta rotation cuts is: T0, T15, T30, T45, T60, T75, T90, T105, T120, T135, T150, & T165.

Table 2.3-1: Great Circle Cut Designations

Cut Designation	Description
T0	0-degree Cut: the plane normal to the faceplate of the EUT and parallel with the long dimension of the phone
T45	45-degree Cut: the plane at 45-degrees clockwise from the normal to the faceplate of the EUT and parallel with the long dimension of the EUT
T90	90-degree Cut: the plane normal to the narrow dimension of the EUT and parallel with the long dimension of the EUT
T135	135-degree Cut: the plane at 45-degrees counterclockwise from the normal to the faceplate of the EUT and parallel with the long dimension of the EUT

Refer to Appendix G:Great Circle Measurement Orientation Diagrams for graphic illustrations for the four reference measurement orientations. The other listed orientations are in-between the reference orientations respectively. For most turntable configurations, it is generally convenient to place the EUT horizontally to measure the Theta rotation cuts. Jigs that are fabricated using a low loss, low dielectric constant material may be constructed to assist in positioning the EUT on the turntable so that it remains stable during the measurements.

Measurements of the radiated transmit power and receiver sensitivity should be recorded in both vertical and horizontal polarizations simultaneously to reduce measurement uncertainties due to EUT repositioning. The EUT will report the power it measures in the receive-band by sending a message to the Base Station Simulator (for technologies that support this function).

The figure shown in Appendix A: Test Set-up Configurations illustrates the measurement configuration for the Great Circle cut method[3]. The EUT is oriented to measure the T0 cut in this illustration.

2.6 Traditional H-Plane Measurements:

A single H-plane cut at bore-sight will be measured by orienting the long dimension of the EUT vertically. Signal strengths will be recorded while rotating the EUT in 6 degree increments over the entire 360 degree azimuthal range. Measurements of the radiated transmit power can be recorded in both vertical and horizontal polarizations simultaneously. Received signal strength will be reported by the EUT to the Base Station Simulator.

The figure show in Appendix A: Test Set-up Configurations illustrates the measurement configuration for the H-plane cut. Note: the **vertically oriented** measurement antenna should be connected to the cable feeding the Power Splitter/Base Station Simulator for this orientation.

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[3] If the laboratory is equipped with a suitable three-dimensional positioner, then this may be used to improve results and reduce measurement time over taking twelve E-plane cuts. This type of measurement method would be the Conical Cut method as described in Section 2.4 Conical Cut Test Method

Section 3: Test Procedure – Radiated Power

Evaluations herein will be conducted in locations meeting the requirements specified in Appendix C: Test Site Characteristics & Quiet Zone Accuracy. Test sites shall be calibrated in accordance with the procedures specified in Appendix D: Test Site Calibration. Calibration data shall be included in the final test report of the EUT (Equipment Under Test). Unless otherwise noted, all evaluations will be performed in 'conversational' mode, at maximum transmit power.

Products supporting multiple air-interface technologies will be tested in accordance with all relevant test procedures. Test results will be provided for each test performed in the format defined in Appendix B: Test Result Reporting.

3.1 Analog TIA/EIA/IS-91A:

The measurement site and EUT shall be configured as specified in Appendix A: Test Set-up Configurations. The power radiated by the EUT shall be measured using a calibrated and accurate RF measuring instrument (e.g., *Spectrum Analyzers/Measurement Receivers/Power Meter)*.

Using the parameters in Table 3.1-1 for the Analog Control Channel, and related parameters for the mobile station, page the EUT and direct it to a voice/traffic channel.

Table 3.1-1: Analog Base Station Parameters

Parameter	Setting
Type	AMPS/NAMPS
Band	800
System	B
Channel	334
SID	1234
VMAC	0
DCC	1
Initial AVC	991
Base Station Power	-50 dBm

Tests shall be conducted for three different frequency pairs across the Cellular Bands, as defined in Table 3.1-2. Efficiency may be gained by performing handoffs to each frequency pair while the EUT is positioned at each measurement coordinate. Handoffs can be accomplished using the Base Station Simulator thereby eliminating the need to disturb the test configuration or adjust the EUT. The test site/chamber shall be calibrated for these frequencies, and calibration data provided in the report.

Table 3.1-2 TIA/EIA-91A Test Frequencies

Band	Channel Pair	Designation	Frequency (MHz)
Cellular A	991	CH$_1$-TX	824.04
Cellular A	991	CH$_1$-RX	Not Applicable
Cellular B	384	CH$_2$-TX	836.52
Cellular B	384	CH$_2$-RX	Not Applicable
Cellular B	799	CH$_3$-TX	836.52
Cellular B	799	CH$_3$-RX	Not Applicable

Radiated power measurements will be recorded in the ”free-space” configuration on all applicable frequencies with the EUT antenna configurations extended and retracted, if applicable.

For handheld portable units, radiated power measurements will be repeated on all applicable frequencies, and with all antenna configurations, with the EUT placed against a simulated head/head and torso phantom to simulate the effects a human head would have on the antenna performance.

A diagram with the example procedural flow is shown in Appendix H: Example Flow Diagram for the Device Measurement Procedure for Each Cut. This diagram describes the procedure for cycling through all frequencies and all azimuthal positions for a single antenna configuration and great-circle antenna pattern cut. It must be repeated when a different cut and/or antenna configuration is required. It also must be repeated for characterizing the effects of the simulated head/head and torso.

3.1.1 Criteria – Analog Radiated Power

Radiated RF Power shall be reported using the Figure of Merit for industry analyzes, as specified in Appendix B.2Calculating Spatially Averaged Quantities. Reports shall include results for free-space and simulated-use configurations (if applicable) across all channels measured with the EUT antenna extended and retracted.

Table 3.1.1-1: Analog Minimum Radiated Power Level Requirements

Device Power (Class)	Free-Space Radiated Power Extended/Retracted	Simulated Head Radiated Power Extended/Retracted
Class I	TBD	TBD
Class II	TBD	TBD
Class III	TBD	TBD

Note: RF Power measured conductivity shall comply with the power levels specified in relevant industry standard(s).

3.2 CDMA TIA/EIA/IS-98B and ANSI-J-STD-008:

The measurement site and EUT shall be configured as specified in Appendix A: Test Set-up Configurations. The power radiated by the EUT shall be measured using a calibrated and accurate RF measuring instrument (e.g., *Spectrum Analyzers/Measurement Receivers/Power Meter)*. Note: see Appendix F.4 CDMA: for CDMA TIA/EIA/IS-95 power measurement considerations.

Using the parameters in Table 3.2-1 for the CDMA Pilot Channel, and related parameters for the mobile station, page the EUT and direct it to a voice/traffic channel.

Table 3.2-1: CDMA Base Station Parameters IS-95B

Parameter	Setting
Type	CDMA
Band	800
Channel (Reg.)	283 *
SID	1234*
NID	65535*
Service Option	2
Rate	Full
Pilot Channel	-7 dBm
Traffic Channel	-15.6 dBm
Power Control	Always Up
Path Loss	See table 4.1-1

Table 3.2-2: CDMA Base Station Parameters – J-STD-018

Parameter	Setting
Type	CDMA
Band	1900
Channel (Reg.)	25 *
SID	1234*
NID	65535*
Service Option	2
Rate	Full
Pilot Channel	-7 dBm
Traffic Channel	-15.6 dBm
Power Control	Always Up
Path Loss	See table 4.1-1

*Note: * Registration channel, SID/NID are service provider specific*

Tests shall be conducted for three different frequency pairs across the bands supported by the EUT (i.e., cellular and/or PCS), as defined in Table 3.2-1. Efficiency may be gained by performing handoffs to each frequency pair while the EUT is positioned at each measurement coordinate. Handoffs can be accomplished using the Base Station

Simulator thereby eliminating the need to disturb the test configuration or adjust the EUT. The test site/chamber shall be calibrated for these frequencies, and calibration data provided in the report.

Table 3.2-3 TIA/EIA/IS-95B Test Frequencies

Band	Channel Pair	Designation	Frequency (MHz)
Cellular A	1013	CH_1-TX	824.7
Cellular A	1013	CH_1-RX	869.7
Cellular B	384	CH_2-TX	836.52
Cellular B	384	CH_2-RX	881.52
Cellular B	777	CH_3-TX	848.31
Cellular B	777	CH_3-RX	893.31
PCS A	25	CH_4-TX	1851.25
PCS A	25	CH_4-RX	1931.25
PCS B	600	CH_5-TX	1880.00
PCS B	600	CH_5-RX	1960.00
PCS C	1175	CH_6-TX	1908.75
PCS C	1175	CH_6-RX	1988.75

Radiated power measurements will be recorded in the ”free-space” configuration on all applicable frequencies with the EUT antenna configurations extended and retracted, if applicable.

For handheld portable units, radiated power measurements will be repeated on all applicable frequencies, and with all antenna configurations, with the EUT placed against a simulated head/head and torso phantom to simulate the effects a human head would have on the antenna performance.

A diagram with the example procedural flow is shown in Appendix H: Example Flow Diagram for the Device Measurement Procedure for Each Cut. This diagram describes the procedure for cycling through all frequencies and all azimuthal positions for a single antenna configuration and great-circle antenna pattern cut. It must be repeated when a different cut and/or antenna configuration is required. It also must be repeated for characterizing the effects of the simulated head/head and torso.

3.2.1 Criteria – CDMA Radiated Power

Radiated RF Power shall be reported using the Figure of Merit for industry analyzes, as specified in Appendix B.2Calculating Spatially Averaged Quantities. Reports shall include results for free-space and simulated-use configurations (if applicable) across all channels measured with the EUT antenna extended and retracted.

Table 3.2.1-1: CDMA Minimum Radiated Power Level Requirements

Device Power (Class)	Free-Space Radiated Power Extended/Retracted	Simulated Head Radiated Power Extended/Retracted
Class I	TBD	TBD
Class II	TBD	TBD
Class III	TBD	TBD

Note: RF Power measured conductivity shall comply with the power levels specified in the relevant industry standard(s).

3.3 TDMA TIA/ANSI-136:

The measurement site and EUT shall be configured as specified in Appendix A: Test Set-up Configurations. The power radiated by the EUT shall be measured using a calibrated and accurate RF measuring instrument (e.g., Spectrum *Analyzers/Measurement Receivers/Power Meter capable of averaging across burst).* Note: TIA/EIA-136 is a non-constant envelope TDMA technology; as such the power must be averaged over the active time slots only (see Appendix F.1 TDMA TIA/ANSI-136:).

Using the parameters in Table 3.3-1 for the Digital Control Channel, and related parameters for the mobile station, page the EUT and direct it to a voice/traffic channel.

Table 3.3-1: ANSI-136 Base Station Parameters

Parameter	Setting
Type	Digital
Band	Cellular/PCS
System	B
Channel	700
SID	1234
DMAC	2
DVCC	128
Time Alignment	0
Time Slot	1 (or 1+4)
Rate	Full
Access Burst	1
Initial DTC	991
Base Station Power	-50 dBm

Tests shall be conducted for three different frequency pairs across the bands supported by the EUT (i.e., cellular and/or PCS), as defined in Table 3.3-2. Efficiency may be gained by performing handoffs to each frequency pair while the EUT is positioned at each measurement coordinate. Handoffs can be accomplished using the Base Station Simulator thereby eliminating the need to disturb the test configuration or adjust the EUT. The test site/chamber shall be calibrated for these frequencies, and calibration data provided in the report.

Table 3.3-2 ANSI-136 Test Frequencies

Band	Channel Pair	Designation	Frequency (MHz)
Cellular A	991	CH_1-TX	824.04
Cellular A	991	CH_1-RX	869.04
Cellular B	384	CH_2-TX	836.52
Cellular B	384	CH_2-RX	881.52
Cellular B	799	CH_3-TX	848.97
Cellular B	799	CH_3-RX	893.97
PCS A	2	CH_4-TX	1850.04
PCS A	2	CH_4-RX	1930.08
PCS B	999	CH_5-TX	1879.95
PCS B	999	CH_5-RX	1959.99
PCS C	1998	CH_6-TX	1909.92
PCS C	1998	CH_6-RX	1989.96

Radiated power measurements will be recorded in the ”free-space” configuration on all applicable frequencies with the EUT antenna configurations extended and retracted, if applicable.

For handheld portable units, radiated power measurements will be repeated on all applicable frequencies, and with all antenna configurations, with the EUT placed against a simulated head/head and torso phantom to simulate the effects a human head would have on the antenna performance.

A diagram with the example procedural flow is shown in Appendix H: Example Flow Diagram for the Device Measurement Procedure for Each Cut. This diagram describes the procedure for cycling through all frequencies and all azimuthal positions for a single antenna configuration and great-circle antenna pattern cut. It must be repeated when a different cut and/or antenna configuration is required. It also must be repeated for characterizing the effects of the simulated head/head and torso.

3.3.1 Criteria – ANSI-136 Radiated Power

Radiated RF Power shall be reported using the Figure of Merit for industry analyzes, as specified in Appendix B.2Calculating Spatially Averaged Quantities. Reports shall include results for free-space and simulated-use configurations (if applicable) across all channels measured with the EUT antenna extended and retracted.

Table 3.3.1-1: ANSI-136 Minimum Radiated Power Level Requirements

Device Power (Class)	Free-Space Radiated Power Extended/Retracted	Simulated Head Radiated Power Extended/Retracted
Class I	TBD	TBD
Class II	TBD	TBD
Class III	TBD	TBD
Class IV	TBD	TBD

Note: RF Power measured conductivity shall comply with the power levels specified in the relevant industry standard(s).

3.4 GSM-1900 J-STD-007 & ETSI PCS 11.10:

The measurement site and EUT shall be configured as specified in Appendix A: Test Set-up Configurations. The power radiated by the EUT shall be measured using a calibrated and accurate RF measuring instrument (e.g., Spectrum *Analyzers/Measurement Receivers/Power Meter capable of averaging across burst)*. Note: GSM-1900 is a constant envelope TDMA technology. See Appendix F.2GSM-1900 -- J-STD-007 for power measurement considerations.

Using the parameters in Table 3.4-1 for the Broadcast Control Channel, and related parameters for the mobile station, page the EUT and direct it to a voice/traffic channel.

Table 3.4-1: GSM-1900 Base Station Parameters

Parameter	Setting
Type	GSM
Band	1900
Channel	700
Time Slot	1
Rate	Full
Access Burst	1
Base Station Power	-50 dBm

Tests shall be conducted for three different frequency pairs across the bands supported by the EUT, as defined in Table 3.4-2. Efficiency may be gained by performing handoffs to each frequency pair while the EUT is positioned at each measurement coordinate. Handoffs can be accomplished using the Base Station Simulator thereby eliminating the need to disturb the test configuration or adjust the EUT. Test site shall be calibrated for these frequencies, and calibration data provided in the report.

Table 3.4-2 GSM-1900 Test Frequencies

Band	Channel Pair	Designation	Frequency (MHz)
PCS A	512	CH_1-TX	1850.20
PCS A	512	CH_1-RX	1930.20
PCS B	661	CH_2-TX	1880.00
PCS B	661	CH_2-RX	1960.00
PCS C	810	CH_3-TX	1909.80
PCS C	810	CH_3-RX	1989.80

Radiated power measurements will be recorded in the ”free-space” configuration on all applicable frequencies with the EUT antenna configurations extended and retracted, if applicable.

For handheld portable units, radiated power measurements will be repeated on all applicable frequencies, and with all antenna configurations, with the EUT placed against a simulated head/head and torso phantom to simulate the effects a human head would have on the antenna performance.

A diagram with the example procedural flow is shown in Appendix H: Example Flow Diagram for the Device Measurement Procedure for Each Cut. This diagram describes the procedure for cycling through all frequencies and all azimuthal positions for a single antenna configuration and great-circle antenna pattern cut. It must be repeated when a different cut and/or antenna configuration is required. It also must be repeated for characterizing the effects of the simulated head/head and torso.

3.4.1 Criteria – GSM-1900 Radiated Power

Radiated RF Power shall be reported using the Figure of Merit for industry analyzes, as specified in Appendix B.2Calculating Spatially Averaged Quantities. Reports shall include results for free-space and simulated-use configurations (if applicable) across all channels measured with the EUT antenna extended and retracted.

Table 3.4.1-1: GSM-1900 Minimum Radiated Power Level Requirements

Device Power (Class)	Free-Space Radiated Power Extended/Retracted	Simulated Head Radiated Power Extended/Retracted
Class I	TBD	TBD
Class II	TBD	TBD
Class III	TBD	TBD

Note: RF Power measured conductivity shall comply with the power levels specified in the relevant industry standard(s).

Section 4: Test Procedure -- Receiver Performance

Evaluations herein will be conducted in locations meeting the requirements specified in Appendix C: Test Site Characteristics & Quiet Zone Accuracy. Test sites shall be calibrated in accordance with the procedures specified in Appendix D: Test Site Calibration. Calibration data shall be included in the final test report of the EUT (Equipment Under Test).

Products supporting multiple air-interface technologies shall be tested in accordance with all relevant test procedures. Test results will be provided for each test performed in the format defined in Appendix B: Test Result Reporting.

Receiver Performance measurements may be made simultaneously with tests performed in Section 3: Test Procedure – Radiated Power. For measurements not made in conjunction, test setups and frequencies defined in this section should be used.

Total Isotropic Sensitivity (TIS) will be fully measured on three (3) channels (low, middle and high) as described in Section 3:Test Procedure – Radiated Power for the frequency bands supported by the EUT. All of the remaining intermediate channels must be evaluated for relative sensitivity. This is to be done by comparison of the 3 fully measured channels with the intermediate channels measured. Since some digital technologies have a very large number of intermediate channels, some channels may be omitted from actual testing provided there is no more than 500KHz between any two successive intermediate channels. All or any combination of intermediate channels may be evaluated, as long as the maximum separation rule is followed. Refer to Appendix I: Total Isotropic Sensitivity for details on TIS.

Handheld units[4] must be evaluated in the head adjacent talk position against a phantom as described in Appendix E: Simulated Head Design and Construction. Devices other than handheld units must be evaluated in the free space configuration. A base station simulator appropriate for the air-interface is required for these tests and will be used to report the digital error rate found by the EUT. The EUT will be placed in an active call on the specified test channel(s), and in the specified test conditions. The RF power level of the base station simulator will then be adjusted to achieve the desired digital error rate at each measured location on the sphere. The digital error rate from the EUT will be extracted from the base station simulator. A sufficient number of bits or frames will be sampled such that the confidence interval in digital error rate is 95% or better. Since the process of measuring effective radiated receiver sensitivity is typically less accurate than measuring transmitter radiated power, this test specification allows for a relaxation in the spatial separation to 30 degrees in the Theta (θ) and in the Phi (Φ) axes for TIS[5]; as noted in Section 2.2 Device Measurements--Receiver:.

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[4] Refer to Section 1.6EUT - The Cellular Subscriber Station: for definition of handheld units.

[5] The use of a 30 degree spatial separation increment is preliminary. An investigation is underway to determine the loss in overall accuracy vs. the 15 degree spatial separation increment used in the transmitter tests. The agreed goal of the receiver test is to find TIS with an accuracy of 2dB or better with a certainty of 95%.

4.1 Analog TIA/EIA/IS-91A:

Receiver sensitivity measurements, as recommended in this specification, are not presently supported in AMPS. Accordingly, test methods for analog receiver sensitivity are not specified. On definition of an accurate test method, this section will be revisited.

4.1.1 Criteria -- Analog

This section will be revisited on adoption of an accurate test method.

4.2 CDMA TIA/EIA/IS-98B and ANSI-J-STD-008:

Receiver Sensitivity measurements will be conducted using the *Base Station Simulator* to determine the EUT's receiver sensitivity by reporting the forward-link power[6] resulting in a Frame Error Rate (FER) of 3.0%. Refer to Appendix A: Test Set-up Configurations for set-up illustrations in the free-space configuration.

Using the set-up parameters defined in Section 3.2 CDMA TIA/EIA/IS-98B and ANSI-J-STD-008:, page the EUT and direct it to a voice/traffic channel ensuring the EUT is transmitting at maximum power. With a digital voice/traffic channel established, invoke a FER Measurement.

FER measurements shall be obtained with the RF power level of the call simulator adjusted so as to achieve the desired digital error rate (3.0% +/- 1.0%) at each measured location on the sphere. A minimum of 1000 frames should be observed. The RF level resulting in the targeted sensitivity values for each EUT test condition will be integrated pursuant to Appendix B.2 Calculating Spatially Averaged Quantities to give a single figure of merit referred to as Total Isotropic Sensitivity (TIS).

TIS will be fully measured on 3 channels (low, middle and high) as described in Section 3: Test Procedure – Radiated Power for the frequency bands supported by the EUT.

Measurements will be repeated on all or any combination of intermediate channels, provided that the maximum separation rule is followed.

Procedure for measuring relative sensitivity on intermediate channels:

a) Move the EUT and chamber positioner(s) to the location & polarization resulting in the best radiated sensitivity measured for the closest, in frequency, fully measured channel, now used as a Reference Channel.

b) Increase the RF signal level of the digital call simulator by 10dB over that used at the same spherical spatial location for the respective Reference Channel.

c) Using the digital call simulator, measure the appropriate digital error rate for this test condition. The measured digital error rate must not exceed that found on the reference channel.

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[6] Determining the precise Base Station Simulator power is critical as this is what thew EUT measures.

Handheld units[7] must be evaluated in the head adjacent talk position against a phantom as described in Appendix F: Power Measurement Considerations. Devices other than handheld units must be evaluated in the free space configuration.

4.2.1 Criteria -- CDMA Sensitivity

Receiver Sensitivity TIS shall be reported using the Figure of Merit for industry analyzes, as specified in Appendix B.2.3 Total Isotropic Sensitivity. Reports shall include results for free-space and simulated-use configurations (if applicable) across all channels measured with the EUT antenna extended and retracted.

Relative sensitivity on intermediate channels test results shall be provided in a file format equivalent to that specified in Appendix B.1Measurement Data Files Radiated Power:

Table 4.2.6-1 CDMA RX Sensitivity Requirements

Device Power (Class)	Free-Space RX Sensitivity Extended/Retracted	Simulated Head RX Sensitivity Extended/Retracted
Class I	TBD	TBD
Class II	TBD	TBD
Class III	TBD	TBD

4.3 TDMA TIA/ANSI-136:

Receiver Sensitivity procedures will utilize the same spherical measurement procedure as specified for the Transmitter power measurements in Section 3: Test Procedure – Radiated Power. Measurement however must be obtained while the EUT is in a test mode, and not in the normal call processing mode of operation. Therefore, the specific set of commands necessary to place the EUT in "loop back mode" must be obtained from the manufacturer in order to begin testing. A list of the test mode commands is specified in TIA/EIA-136-270A, section 8. To place the EUT in loop back mode for the digital RX sensitivity test, the following commands may be used in the order specified by the terminal manufacturer:

Table 4.3-1: Commands for digital loop back Bit Error Rate (BER) Test

Command	Description
TIA/EIA-136-270 SUSPEND	Terminate the normal mode and enter the test mode
TIA/EIA-136-270 INIT	Initialize the transceiver
TIA/EIA-136-270 LOAD-SYNTH (LOAD-SYNTH HYPERBAND)	Set the synthesizer to the channel (channel and band) specified by the byte(s) following the command
TIA/EIA-136-270 SET-ATTN	Set the RF power attenuation to the value specified by the byte following the command

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[7] Refer to Section 1.6EUT - The Cellular Subscriber Station: for definition of handheld units.

Command	Description
TIA/EIA-136-270 DCCH-DGTS	Switch to DCCH digital mode with slot assignment specified by one byte following the command
TIA/EIA-136-270 TDMAON	Synchronize to the forward traffic channel and set the DVCC and data format as specified by the first and second byte (respectively) following the command

There are two methods for setting up the EUT in digital loop back BER. The manufacturer and test facility shall determine the best method to use in order to minimize the test time, and maximize reproducibility. The methods are assigned in the order of preference:

a) Remote programming of test mode parameters via data cable. If available, the manufacturer shall provide the cable and application, which will allow the test facility to remotely program the EUT. Once the proper mode and channel has been selected, all equipment external to the EUT shall be removed prior to performing the RX sensitivity test.
b) Keypad programming of test mode parameters.

Using the set-up parameters defined in Section 3.3 TDMA TIA/ANSI-136: direct the EUT to a voice channel ensuring the EUT is transmitting at maximum power. With a digital voice channel established, invoke a BER Measurement.

Once the EUT is in digital loop back BER mode for the specified channel, the base station power will be lowered until a 3% BER (+/- 0.1%[8]) is measured by the base station when the number of bits measured is 100 kilo-bits. Prior to the final measurement(s) to achieve a 3% BER, the measurement device can use a minimum of 10 kilo-bits to determine if base station power is low enough.

Typically, the maximum deviation in RX level measurements from peak to null of any one channel does not exceed 30 dB. Therefore, the test facility may only raise the base station power 30 dB above the first 3% BER measurement level in order to reduce the number of BER measurements required. However, some measurements of EUTs may exceed 30 dB from peak to null when in the presence of a simulated head. If the base station power must be raised to greater than 30 dB above the last sensitivity (reference) level, then the sensitivity should be considered negligible for that location.

TIS pursuant to Appendix B.2 Calculating Spatially Averaged Quantities will be fully measured on the 3 channels (low, middle and high) as described in Section 3: Test Procedure – Radiated Power for the frequency bands supported by the EUT.

Measurements will be repeated on all or any combination of intermediate channels, provided that the maximum separation rule is followed.

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[8] Further investigation of this error margin may cause to either increase or decrease.

Procedure for measuring relative sensitivity on intermediate channels:

d) Move the EUT and chamber positioner(s) to the location & polarization of resulting in the best radiated sensitivity measured for the closest, in frequency, fully measured channel, now used as a Reference Channel.

e) Increase the RF signal level of the digital call simulator by 10dB over that used at the same spherical spatial location for the respective Reference Channel.

f) Using the digital call simulator, measure the appropriate digital error rate for this test condition. The measured digital error rate must not exceed that found on the reference channel.

Handheld units[9] must be evaluated in the head adjacent talk position against a phantom as described in Appendix F: Power Measurement Considerations. Devices other than handheld units must be evaluated in the free space configuration.

4.3.1: Criteria – ANSI-136 RX Sensitivity

Receiver Sensitivity TIS shall be reported using the Figure of Merit for industry analyzes, as specified in Appendix B.2.3 Total Isotropic Sensitivity. Reports shall include results for free-space and simulated-use configurations (if applicable) across all channels measured with the EUT antenna extended and retracted. The reported RF level that produces a 3% BER for each channel shall be less than or equal to the levels noted below.

Relative sensitivity on intermediate channels test results shall be provided in a file format specified in Appendix B.1Measurement Data Files Radiated Power:

Table 4.3.1-1 ANSI-136 RX Sensitivity Requirements

Device Power (Class)	Free-Space RX Sensitivity Extended/Retracted	Simulated Head RX Sensitivity Extended/Retracted
Class I	TBD	TBD
Class II	TBD	TBD
Class III	TBD	TBD

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[9] Refer to Section 1.6EUT - The Cellular Subscriber Station: for definition of handheld units.

4.4 GSM-1900:

Receiver Sensitivity procedures will utilize the same spherical measurement procedure as specified for the Transmitter power measurements in Section 3: Test Procedure – Radiated Power. Refer to GSM 05.05 and GSM 11.10 for procedures and criteria for the setup of loop back mode. The base station simulator shall place the EUT into Loop back mode.

Using the set-up parameters defined in Section 3.4 GSM-1900 J-STD-007 & ETSI PCS 11.10: page the EUT and direct it to a voice/traffic channel ensuring the EUT is transmitting at maximum power. With a digital voice/traffic channel established, invoke a BER Measurement.

Once in loop back mode, the base station power is lowered until a 2.44% (+/- 0.1%[1]) RBER is measured by the base station when the number of samples measured is 10 kilo-bits.

Typically, the maximum deviation in RX level measurements from peak to null of any one channel does not exceed 30 dB. Therefore, the test facility may only raise the base station power 30 dB above the first 3% BER measurement level in order to reduce the number of BER measurements required. However, some measurements of EUTs may exceed 30 dB from peak to null when in the presence of a simulated head. If the base station power must be raised to greater than 30 dB above the last sensitivity (reference) level, then the sensitivity should be considered negligible for that location.

TIS pursuant to Appendix B.2 Calculating Spatially Averaged Quantities will be fully measured on the 3 channels (low, middle and high) as described in Section 3: Test Procedure – Radiated Power for the frequency bands supported by the EUT.

Measurements will be repeated on all or any combination of intermediate channels, provided that the maximum separation rule is followed.

Procedure for measuring relative sensitivity on intermediate channels:

g) Move the EUT and chamber positioner(s) to the location & polarization resulting in the best radiated sensitivity measured for the closest, in frequency, fully measured channel, now used as a Reference Channel.

h) Increase the RF signal level of the digital call simulator by 10dB over that used at the same spherical spatial location for the respective Reference Channel.

i) Using the digital call simulator, measure the appropriate digital error rate for this test condition. The measured digital error rate must not exceed that found on the reference channel.

Handheld units[10] must be evaluated in the head adjacent talk position against a phantom as described in Appendix F: Power Measurement Considerations. Devices other than handheld units must be evaluated in the free space configuration.

4.4.1: Criteria – GSM 1900 RX Sensitivity

Receiver Sensitivity TIS shall be reported using the Figure of Merit for industry analyzes, as specified in Appendix B.2.3 Total Isotropic Sensitivity Reports shall include results for free-space and simulated-use configurations (if applicable) across all channels measured with the EUT antenna extended and retracted.

Relative sensitivity on intermediate channels test results shall be provided in a file format specified in Appendix B.1Measurement Data Files Radiated Power: The reported RF level that produces a 2.44% RBER for each channel shall be less than or equal to the levels noted below.

Table 4.4.1-1: GSM-1900 RX Sensitivity Requirements

Device Power (Class)	Free-Space RX Sensitivity Extended/Retracted	Simulated Head RX Sensitivity Extended/Retracted
Class I	TBD	TBD
Class II	TBD	TBD
Class III	TBD	TBD

---

[10] Refer to Section 1.6 EUT - The Cellular Subscriber Station: for definition of handheld units.

Appendix A: Test Set-up Configurations

A.1 Test Set-up – Free Space:

The Equipment Under Test (EUT) will be placed in a test chamber meeting the characteristics defined in Appendix C: Test Site Characteristics & Quiet Zone Accuracy and calibrated in accordance with Appendix D: Test Site Calibration.

Place the EUT atop a non-conductive turntable at a distance no less than 3 times the EUT transmitting frequency's wavelength from the measurement antenna. Adjust the elevation of the measurement antenna to be at boresight with the center of the EUT.

Using a simulated base-station, the EUT will be placed into a call and measurements performed in the E and H planes.

Figure A.1-1 Device Measurement Test Configuration – Great Circle Cut

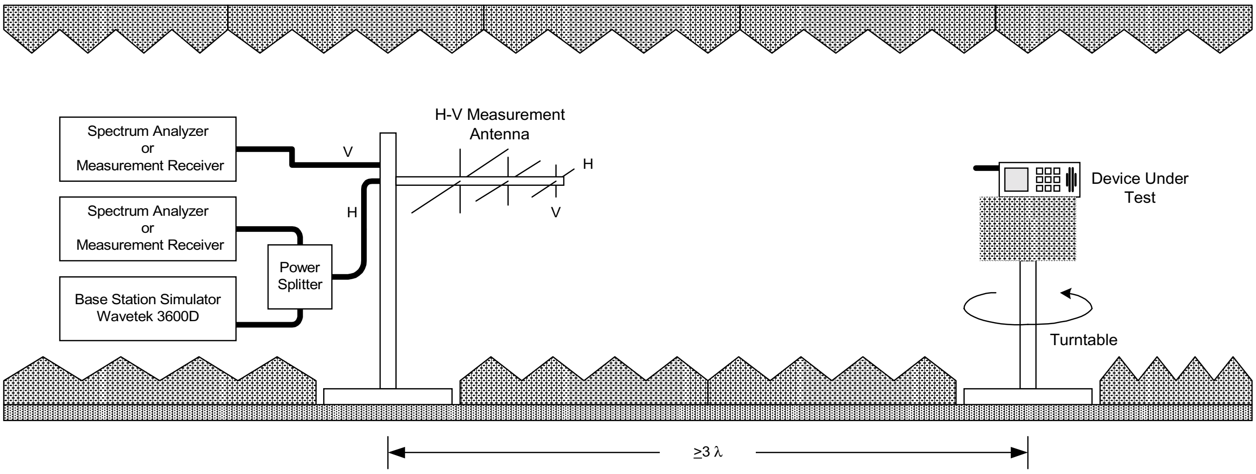


Figure A.1-2 Device Measurement Test Configuration – Traditional H0 Cut

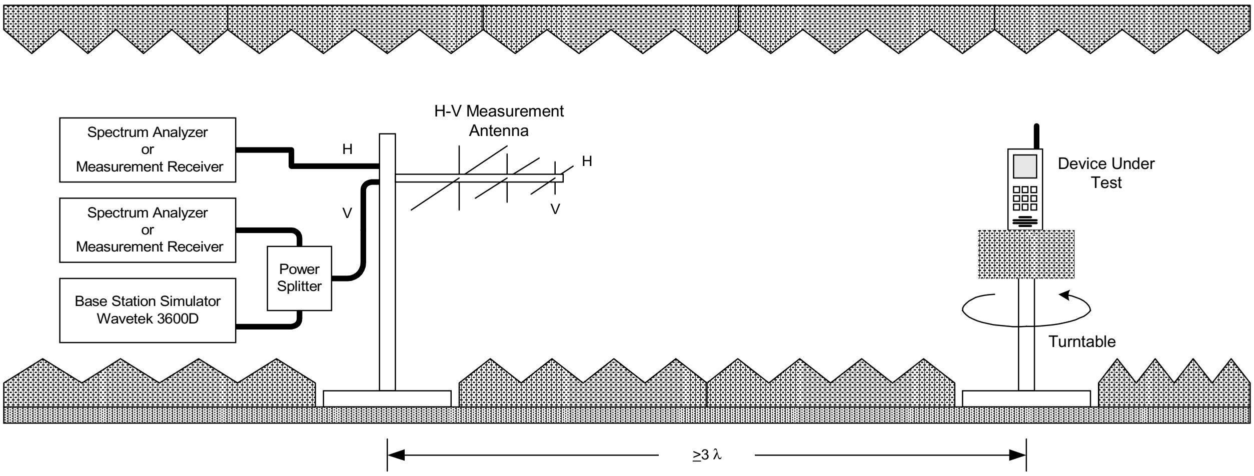
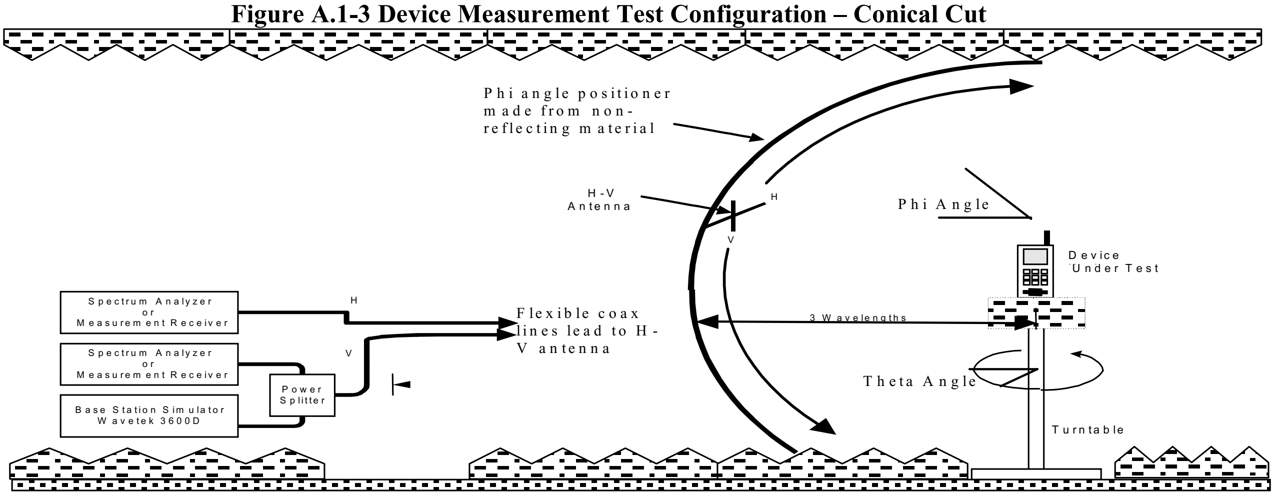


Figure A.1-3 Device Measurement Test Configuration – Conical Cut



A.2 Test Set-up -- Simulated Head/Phantom

Using the same Test Set-up procedures defined for free-space; place the EUT against a simulated head/head and torso phantom meeting the characteristics defined in Appendix E: Simulated Head Design and Construction. Position the EUT as illustrated in Figure E.1-1: Inclination Angle Statistics, with an angle of 65 degrees. The EUT position on "SAM" phantom is also illustrated in Appendix E.4 Definition of the EUT Position on "SAM" Phantom.

Place the simulated head/head and torso phantom atop a non-conductive turntable at a distance no less than 3 times the EUT transmitting frequency's wavelength from the measuring antenna. Adjust the elevation of the measurement antenna to be at boresight with the center of the EUT.

Using a simulated base-station, the EUT will be placed into a call and measurements performed in the E and H planes.

Appendix B: Test Result Reporting

Test reports and files will be provided as described in this section. Deliverables consist of a calibration file (Appendix D) and measurement data files for each EUT characterized.

Data will be reported so correlation with field performance can be determined with confidence. Pass/Fail criteria will be specified after sufficient analysis of the measured data has been conducted.

B.1 Measurement Data Files Radiated Power:

Measurements should be performed on at least three units calibrated using production level factory equipment and procedures. The mean and standard deviation in the performance levels should be assessed. Requirements for average and peak EIRP with head blockage have not been defined.

Data shall be supplied in a format accessible (i.e., readable) for additional examination and computation as outlined in Table B.1-1. For dual-band products, files shall be provided for (6 different frequency pairs) × (2 different antenna configurations, if applicable) × (2 different obstructions).

For single-band products, files shall be provided for (3 different frequency pairs) × (2 different antenna configurations, if applicable) × (2 different obstructions).

For great-circle cuts, each file shall contain measurements for 12 cuts × (2 transmit polarizations + 1 receive polarization). Based on samples measured every 15 degrees of rotation for each cut, approximately 540 measurements are recorded in each file.

Table B.1-1 Example Measurement Data File Format

Date of Measurement:	24 Aug 2000
Device Mfr/Model:	Acme 2000
TX Frequency:	CH_i-TX
RX Frequency:	CH_i-RX
Antenna [Retracted, Extended]:	Extended
Obstruction [Free Space, Simulated head/head and torso]:	Free Space

θ (degrees)	**Vertical TX EDRP (dBd)**				**Horizontal TX EDRP (dBd)**			
	ϕ=0	**ϕ=15**	**•••**	**ϕ=165**	**ϕ=0**	**ϕ=15**	**•••**	**ϕ=165**
0	28.1	28.1	•••	28.1	28.1	28.1	•••	28.1
15	28.1	28.1	•••	28.1	28.1	28.1	•••	28.1
30	28.1	28.1	•••	28.1	28.1	28.1	•••	28.1
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
345	28.1	28.1	•••	28.1	28.1	28.1	•••	28.1

θ (degrees)	**Vertical RX Sensitivity (@3% BER)**				**Horizontal RX Sensitivity (@3% BER)**			
	ϕ=0	**ϕ=30**	**•••**	**ϕ=150**	**ϕ=0**	**ϕ=30**	**•••**	**ϕ=150**
0	-112	-112	•••	-112	-112	-112	•••	-112
30	-112	-112	•••	-112	-112	-112	•••	-112
60	-112	-112	•••	-112	-112	-112	•••	-112
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
330	-112	-112	-112	-112	-112	-112	-112	-112

B.2 Calculating Spatially Averaged Quantities

Three figures of merit will be used to calculate the spatially averaged radiated EIRP and sensitivity[11]. Results from these figures of merit are for informational purposes and will not be used by the CTIA to pass or fail a device at this time. The objective is to use the following figures of merit to observe trends in performance over different products.

The spatially averaged effective radiated power and sensitivity values shall be derived from the measurement data. The spatial average is calculated as a sin-theta weighted (sin(θ)) average over all elevation angles. Uniform weighting is also used to average over all azimuths. "Sin-theta weighted average" is an averaging scheme that puts more

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[11] Certain equations (particularly the limits of summation in the near-horizon equations) maybe changed slightly once the sampling increment is finalized (e.g., 30 degrees vs. 15 degrees) since there may not be sample points at the exact border of a 45 degree or 22.5 degree window around the horizon.

emphasis on horizon data than zenith and nadir and is appropriate for use when samples are taken uniformly in theta and phi.

Note that N and M may be different for the transmit and receive measurements.

B.2.1 Total Radiated Power

Assuming that a complete sphere is measured with N theta cuts and M phi cuts, then the Total Radiated Power may be calculated as follows.

Total Radiated Power:

$$TRP = \frac{\pi}{2NM}\sum_{i=1}^{N}\sum_{j=1}^{M} EiRP(\theta_i,\phi_j)\left|\sin(\theta_i)\right| \quad \text{[Equation B.2.1-1]}$$

B.2.2 Near-Horizon Partial Radiated Power

Assuming that a complete sphere is measured with N theta cuts and M phi cuts, then the Near-Horizon Partial Radiated Power may be calculated as follows.

Power radiated over ±π/4 near the Horizon:

$$HRP_{\pm\pi/4} = \frac{\pi}{2NM}\sum_{i=\frac{N}{4}}^{\frac{3N}{4}}\sum_{j=1}^{M} EiRP(\theta_i,\phi_j)\left|\sin(\theta_i)\right| \quad \text{for conic cuts} \quad \text{[Equation B.2.2-1]}$$

$$HRP_{\pm\pi/4} = \frac{\pi}{2NM}\left[\sum_{i=\frac{N}{8}}^{\frac{3N}{8}}\sum_{j=1}^{M} EiRP(\theta_i,\phi_j)\left|\sin(\theta_i)\right| + \sum_{i=\frac{5N}{8}}^{\frac{7N}{8}}\sum_{j=1}^{M} EiRP(\theta_i,\phi_j)\left|\sin(\theta_i)\right|\right]$$

for great-circle cuts

[Equation B.2.2-2]

Power Radiated over ±π/8 near the Horizon:

$$HRP_{\pm\pi/8} = \frac{\pi}{2NM}\sum_{i=\frac{3N}{8}}^{\frac{5N}{8}}\sum_{j=1}^{M} EiRP(\theta_i,\phi_j)\left|\sin(\theta_i)\right| \quad \text{for conic cuts} \quad \text{[Equation B.2.2-3]}$$

$$HRP_{\pm\pi/8} = \frac{\pi}{2NM}\left[\sum_{i=\frac{3N}{16}}^{\frac{5N}{16}}\sum_{j=1}^{M} EiRP(\theta_i,\phi_j)\left|\sin(\theta_i)\right| + \sum_{i=\frac{11N}{16}}^{\frac{13N}{16}}\sum_{j=1}^{M} EiRP(\theta_i,\phi_j)\left|\sin(\theta_i)\right|\right] \quad \text{for great-circle cuts}$$

[Equation B.2.2-3]

B.2.3 Total Isotropic Sensitivity

Assuming that a complete sphere is measured with N theta cuts and M phi cuts, then the Total Isotropic Sensitivity may be calculated as follows.

Total Isotropic Sensitivity:

$$TIS = \frac{2NM}{\pi \sum_{i=1}^{N} \sum_{j=1}^{M} \left[\frac{1}{EIS_{\theta}(\theta,\phi)} + \frac{1}{EIS_{\phi}(\theta,\phi)} \right] \left| \sin(\theta_i) \right|} \quad \text{[Equation B.2.3-1]}$$

where EIS is the radiated effective isotropic sensitivity measured at each direction and polarization.

B.2.4 Near-Horizon Partial Isotropic Sensitivity

Assuming that a complete sphere is measured with N theta cuts and M phi cuts, then the Near-Horizon Partial Isotropic Sensitivity may be calculated as follows.

For sensitivity considered over ±π/4 near the Horizon:

$$NHPIS_{\pm \pi/4} = \frac{2NM}{\pi \sum_{i=\frac{N}{4}}^{\frac{3N}{4}} \sum_{j=1}^{M} \left[\frac{1}{EIS_{\theta}(\theta,\phi)} + \frac{1}{EIS_{\phi}(\theta,\phi)} \right] \left| \sin(\theta_i) \right|} \quad \text{for conic cuts} \quad \text{[Equation B.2.4-1]}$$

$$NHPIS_{\pm \pi/4} = \frac{2NM}{\pi \left\{ \sum_{i=\frac{N}{8}}^{\frac{3N}{8}} \sum_{j=1}^{M} \left[\frac{1}{EIS_{\theta}(\theta,\phi)} + \frac{1}{EIS_{\phi}(\theta,\phi)} \right] \left| \sin(\theta_i) \right| + \sum_{i=\frac{5N}{8}}^{\frac{7N}{8}} \sum_{j=1}^{M} \left[\frac{1}{EIS_{\theta}(\theta,\phi)} + \frac{1}{EIS_{\phi}(\theta,\phi)} \right] \left| \sin(\theta_i) \right| \right\}}$$

for great-circle cuts [Equation B.2.4-2]

For sensitivity considered over ±π/8 near the Horizon:

$$NHPIS_{\pm \pi/4} = \frac{2NM}{\pi \sum_{i=\frac{3N}{8}}^{\frac{5N}{8}} \sum_{j=1}^{M} \left[\frac{1}{EIS_{\theta}(\theta,\phi)} + \frac{1}{EIS_{\phi}(\theta,\phi)} \right] \left| \sin(\theta_i) \right|} \quad \text{for conic cuts} \quad \text{[Equation B.2.4-3]}$$

$$NHPIS_{\pm \pi/4} = \frac{2NM}{\pi \left\{ \sum_{i=\frac{3N}{16}}^{\frac{5N}{16}} \sum_{j=1}^{M} \left[\frac{1}{EIS_{\theta}(\theta,\phi)} + \frac{1}{EIS_{\phi}(\theta,\phi)} \right] \left| \sin(\theta_i) \right| + \sum_{i=\frac{11N}{16}}^{\frac{13N}{16}} \sum_{j=1}^{M} \left[\frac{1}{EIS_{\theta}(\theta,\phi)} + \frac{1}{EIS_{\phi}(\theta,\phi)} \right] \left| \sin(\theta_i) \right| \right\}}$$

for great-circle cuts [Equation B.2.4-4]

B.3 Measurement Data File –Conducted RF Power

RF Power levels shall be measured using a direct couple method for each EUT reported. Measurements should be made in accordance with the relevant CTIA test plan as specified in Section 1.4 Certification Test Plans:

Table B.3-1 Example Measurement Data File Format

Test	**Criteria (dBW)**		**Channel**		
	Min	Max	#1	#2	#3
TX Power @ Level 0 (dBW)					
•					
•					
•					
TX Power @ Level (lowest setting)					

B.4 3-D Plots

Plots shall be submitted for each EUT reported.

B.5 Calibration Data File (Quiet Zone and Path Loss)

Placeholder for quiet zone and path loss measurements. Table D.2-1 and D.3-1 illustrate the data file format.

Appendix C: Test Site Characteristics & Quiet Zone Accuracy

This section describes an efficient procedure for ensuring sufficient quiet zone accuracy of the test site by characterizing the measurement accuracy of an anechoic chamber, and the associated measurement equipment. This procedure is recommended to characterize variations in field measurements caused by reflections within an anechoic chamber.

C.1 Equipment required:

Details on the symmetry antenna can be found in Appendix J: Symmetry Pattern.

1. Anechoic chamber to be characterized. For the purpose of these tests, this chamber must be large enough to allow the measurement antenna to be at least 3λ from the EUT and the test site must be free of all interference.
2. Cellular-band sleeve dipole probe antenna with less than ±0.1 dB of asymmetry[12] in the azimuth plane pattern.
3. Cellular-band reference loop probe antenna with less than ±0.1 dB of asymmetry in the azimuth plane pattern.
4. PCS-band sleeve dipole probe antenna with less than ±0.1 dB of asymmetry[13] in the azimuth plane pattern.
5. PCS-band reference loop probe antenna with less than ±0.1 dB of asymmetry in the azimuth plane pattern

Note: It is necessary that the above antennas be optimized for the respective frequencies as indicated in C.2.

6. Low dielectric constant, low-loss column (e.g. Styrofoam) for positioning the probe antennas
7. Measurement antenna(s) (e.g. calibrated horn or dipole used during antenna measurements)
8. Network analyzer or signal generator/measurement receiver

C.2 Test Channels:

Channels to be used to test for quiet zone accuracy

1. Cellular-band: 384 (836.52 MHz)
2. PCS-band: 999 (1879.95 MHz)

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[12] The asymmetry specification for purposes of this measurement may be stated more specifically as the pattern shall not deviate from a perfect circle by more than ±0.1 dB. A sleeve dipole is recommended since the cable and feedpoint may be arranged in such a way that interactions with the measurement are minimized. The gain and efficiency of this antenna is immaterial since the measurement seeks to determine deviations in the measured antenna pattern caused by reflections within the measurement chamber.

[13] The asymmetry specification for purposes of this measurement may be stated more specifically as the pattern shall not deviate from a perfect circle by more than ±0.1 dB. A sleeve dipole is recommended since the cable and feedpoint may be arranged in such a way that interactions with the measurement are minimized. The gain and efficiency of this antenna is immaterial since the measurement seeks to determine deviations in the measured antenna pattern caused by reflections within the measurement chamber.

C.3 Measurement Procedures:

Reference Pattern Measurement

1. Place the band-appropriate vertically polarized sleeve dipole (probe antenna) at the center of the dielectric column, which is centered atop the antenna positioner located in the anechoic chamber. Center the sleeve dipole precisely on the antenna positioner's axis of rotation, and ensure that the antenna is exactly vertical. The center of the probe antenna should be at the center of the quiet zone.
2. Place the measurement antenna in the vertically polarized position a distance greater then 3 times the wavelength meters away from the probe antenna. Adjust the elevation of the measurement antenna to be at boresight with the center of the probe antenna.
3. Attach a signal source to a coaxial cable feeding the probe antenna and set the frequency to the appropriate channel. Set the amplitude to a level appropriate for the measurement receiver. Connect a measurement receiver to the measurement antenna. Ensure that all coaxial cables are dressed to minimize effects upon the measurement results.
4. Rotate the probe antenna and record the signal received by the measurement antenna at every 2 degrees of azimuth.
5. Record the measurement results to a file that can be imported into a Microsoft Excel spreadsheet.
6. Record test parameters including: (a) the distance between the measurement and probe antennas, (b) cable losses and other losses associated with the measurement setup, and (c) power of the signal source at the probe antenna connector.
7. Repeat steps 1 through 6 above using the band-appropriate horizontally polarized reference loop antenna as the probe antenna.

Note: The vertically polarized sleeve dipole and horizontally polarized reference loop antennas may be combined into one assembly, thus allowing the two data sets to be taken conjointly.

Offset Pattern Measurements

Note: the following procedure applies for both the vertically polarized sleeve dipole and horizontally polarized reference loop antenna offset pattern measurements.

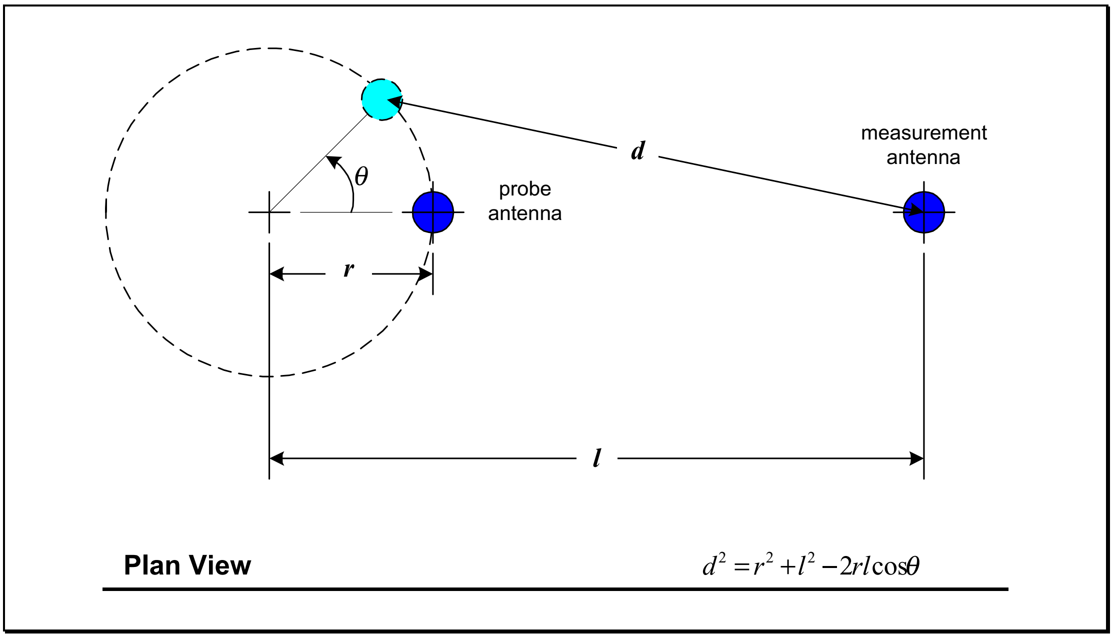
1. Offset the probe antenna from the center of the positioner's axis of rotation by 6 inches, ensuring it is exactly vertical. Repeat steps 2 through 6 described in the Reference Pattern Measurement.
2. Repeat the previous step with the probe antenna offset 3 inches from the axis of rotation.
3. Elevate the probe antenna ±6 inches and repeat steps 1 and 2.

C.4 Analysis:

1. Plot the dipole and loop antenna reference patterns using polar coordinates and having a resolution of 0.25 dB or better. These patterns should appear to be perfectly circular (less than ±0.1 dB of variation)
2. Adjust the offset pattern measurements to correct for distance variation using the equation for the Law of Cosines (see below).
3. Overlay a plot of the corrected offset patterns onto the reference pattern plot.
4. The adjusted offset patterns should not vary more than ±0.5 dB from the reference pattern.

Law of Cosines Adjustment Method

For coplanar antennas, the Law of Cosines may be used to determine the distance between antennas as one is rotated about a center axis. For minor differences in elevation, the Law of Cosines should still be of sufficient accuracy for our analysis. Refer to the following figure to aid in understanding this discussion. Note that this illustration is a view from the perspective of looking down on vertically oriented antennas from above.



- Let ***l*** be the distance measured between the axis of rotation and the measurement antenna
- Let ***r*** be the measured distance that the probe antenna is offset from the axis of rotation.
- Let θ be the rotation azimuth of the probe antenna where 0-degrees is the point where the probe antenna is closest to the measurement antenna and 180-degrees is the point where the probe antenna is farthest away from the measurement antenna

- Let ***d*** be the calculated distance between the probe antenna and the measurement antenna. Then ***d*** may be calculated from the Law of Cosines as follows:

$$d^2 = r^2 + l^2 - 2\, r\, l \cos\theta \quad \text{[Equation C.4-1]}$$

- Adjust the measured signal power to account for distance variation using the following equation:

$$P_{adj} = P_{meas} - 20 \log (d/l) \quad \text{[Equation C.4-2]}$$

  where P_{adj} and P_{meas} are in decibels.

Note that parameter ***r*** and ***l*** must be carefully measured and recorded to enable accurate application of this technique.

Appendix D: Test Site Calibration

D.1 Method:

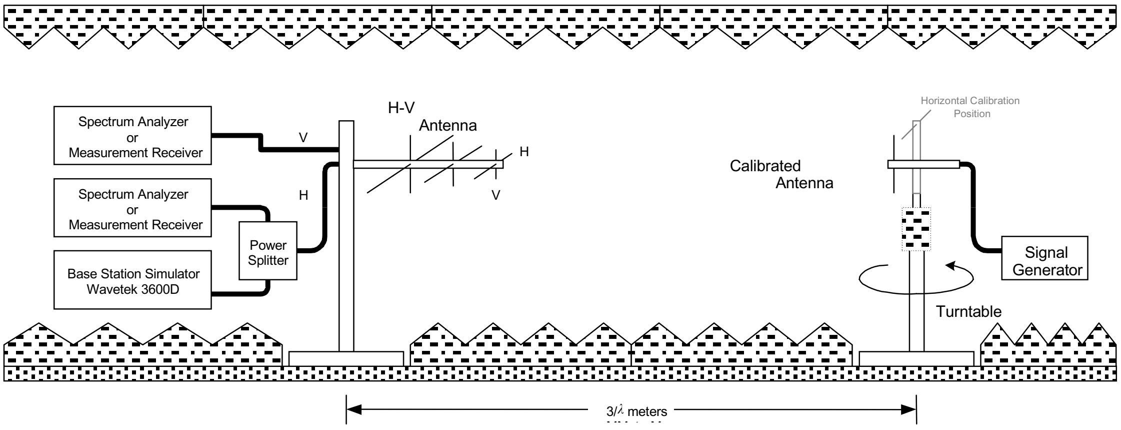
Calibration is used to determine system losses and gains so they may be normalized out of the device measurement data. A common substitution method is used for this purpose.

D.2 Calibration:

Test site Calibration uses a substitution method whereby the Equipment Under Test (EUT) is replaced by an antenna with calibrated gain/loss characteristics at the frequencies of measurement (viz. the *Calibrated Substitution Antenna*). A *Signal Generator* is used to drive the Substitution Antenna at a known power level. A *Spectrum Analyzer* or *Measurement Receiver* is used to measure the power of the radiated signal coupled out of the antenna to be used during the EUT measurement step (viz. the *Measurement Antenna*). Refer to Figure D.2-1 for the recommended test configuration for the Calibration step.

Place the band-appropriate vertically polarized sleeve dipole (measurement antenna) at the center of the dielectric column, which is centered atop the antenna positioner located in the test chamber. Center the sleeve dipole precisely on the antenna positioner's axis of rotation and ensure that the antenna is exactly vertical. The center of the probe antenna should be at the center of the quiet zone.

Figure D.2-1 Calibration Test Configuration



The *Measurement Antenna* elevation is adjusted so it is at boresight with the *Calibrated Substitution Antenna*. The power into the *Calibrated Substitution Antenna* is measured at each frequency. The power at the input terminals of the *Spectrum Analyzers* (or *Measurement Receivers*) connected to the horizontal and vertical element of the *Measurement Antenna* is recorded at each frequency.

The measurement will be repeated with the *Calibrated Substitution Antenna* polarized both vertically and horizontally at each frequency. The path loss (difference between the power into the calibrated antenna and the power received at the spectrum analyzer) will be calculated from this data for every frequency and polarization to be tested. The path loss should also be adjusted to account for the calibrated substitution antenna's gain/loss in dBd for the frequency of measurement. The table below shows how this data might be recorded.

Table D.2-1 Example Calibration Data Record

Band	Frequency (MHz)	Measured Signal Strength (dBm)		Sig Gen Power (dBm)	Substitution Antenna Gain (dBd)	Path Loss (dB)	
		Analyzer H	Analyzer V			Vert	Horz
Cellular	CH_1-TX	-90	-90	0.0	0.5	90.5	90.5
Cellular	CH_1-RX	-99	-99	0.0	0.5	99.5	99.5
Cellular	CH_2-TX	-96	-96	0.0	0.5	96.5	96.5
Cellular	CH_2-RX	-95	-95	0.0	0.5	95.5	95.5
Cellular	CH_3-TX	-89	-89	0.0	0.5	89.5	89.5
Cellular	CH_3-RX	-92	-92	0.0	0.5	92.5	92.5
PCS	CH_4-TX	-90	-90	0.0	0.5	90.5	90.5
PCS	CH_4-RX	-99	-99	0.0	0.5	99.5	99.5
PCS	CH_5-TX	-96	-96	0.0	0.5	96.5	96.5
PCS	CH_5-RX	-95	-95	0.0	0.5	95.5	95.5
PCS	CH_6-TX	-89	-89	0.0	0.5	89.5	89.5
PCS	CH_6-RX	-92	-92	0.0	0.5	92.5	92.5

Path loss may be calculated using the following equation:

$$PL = P_{sig\ gen} + G_{subst\ ant} - P_{sp\ an} \qquad \text{[Equation D.2-1]}$$

where,

$PL \equiv$ Path Loss (in dB)
$P_{sig\ gen} \equiv$ Power delivered by the Signal Generator to the Substitution Antenna (in dBm)
$G_{subst\ ant} \equiv$ Gain of the Substitution Antenna (in dBd)
$P_{sp\ an} \equiv$ Power measured by the spectrum analyzer in a 30 kHz (or greater) bandwidth (in dBm)

The losses between the *Measurement Antenna* and the *Base Station Simulator* (including cable and power splitter losses) should be matched to within ±0.1 dB so the path losses calculated from the horizontal measurements may be used directly. Otherwise, these differences should be accounted for when making downlink measurements based on mobile signal strength reports.

During the calibration process, it may be desirable to rotate the *Calibrated Substitution Antenna* and plot out the antenna pattern to ensure that the pattern looks reasonable and that the relative orientation of the two antennas is such that the peak lobe is measured for the horizontally polarized case. Cables connecting the *Calibrated Substitution Antenna* to the *Signal Generator* should be dressed in such a way that the impact upon the measurements is negligible.

The same cable configuration and equipment used during Calibration should also be used during the EUT measurement phase so that the calibrations will directly apply.

The recommended frequencies for the measurements are provided in Table 4.1-2. These have been selected to test at the band edges and near the center of each band. Significant variations in EUT performance due to antenna, filtering or circuit design should be apparent using this technique.

D.3 Calibration Data File:

Data shall be supplied in a format accessible (i.e., readable) for additional examination and computation as outlined in Table D.3-1.

Table D.3-1 Example Calibration Data File Format

Date:	24 Aug 2000
Cal Antenna:	EA-1234

Band	**Frequency (MHz)**	**Measured Signal Strength (dBm)**		**Sig Gen Power (dBm)**	**Substitution Antenna Gain (dBd)**	**Path Loss (dB)**	
		Analyzer V	**Analyzer H**			**Vert**	**Horz**
Cellular	CH$_1$-TX	-90	-90	0.0	0.5	90.5	90.5
Cellular	CH$_1$-RX	-99	-99	0.0	0.5	99.5	99.5
Cellular	CH$_2$-TX	-96	-96	0.0	0.5	96.5	96.5
Cellular	CH$_2$-RX	-95	-95	0.0	0.5	95.5	95.5
Cellular	CH$_3$-TX	-89	-89	0.0	0.5	89.5	89.5
Cellular	CH$_3$-RX	-92	-92	0.0	0.5	92.5	92.5
PCS	CH$_4$-TX	-90	-90	0.0	0.5	90.5	90.5
PCS	CH$_4$-RX	-99	-99	0.0	0.5	99.5	99.5
PCS	CH$_5$-TX	-96	-96	0.0	0.5	96.5	96.5
PCS	CH$_5$-RX	-95	-95	0.0	0.5	95.5	95.5
PCS	CH$_6$-TX	-89	-89	0.0	0.5	89.5	89.5
PCS	CH$_6$-RX	-92	-92	0.0	0.5	92.5	92.5

The *Calibration Step* shall be performed:

1. If any equipment used in the evaluation has been replaced, repaired, upgraded, or calibrated.
2. If the anechoic chamber has been repaired, or otherwise altered.
3. If the equipment within the chamber has been altered or moved from its original location.
4. If there is any question as to the whether the past calibration data is acceptable for the current measurement.

Appendix E: Simulated Head Design and Construction

E.1 Simulated Head Reference Information:

This section provides recommendations for constructing a simulated head/head and torso to be used for antenna testing. References are provided relating to typical handset usage. The book titled *Mobile Antenna Systems Handbook* by K. Fujimoto and J.R. James[14], shows data that was collected on the inclination angle at which subscribers typically hold mobile phones while in conversation (Figure B-1). The most likely angle is around 60 degrees from vertical. This is the recommended value for antenna testing using a simulated head/head and torso.

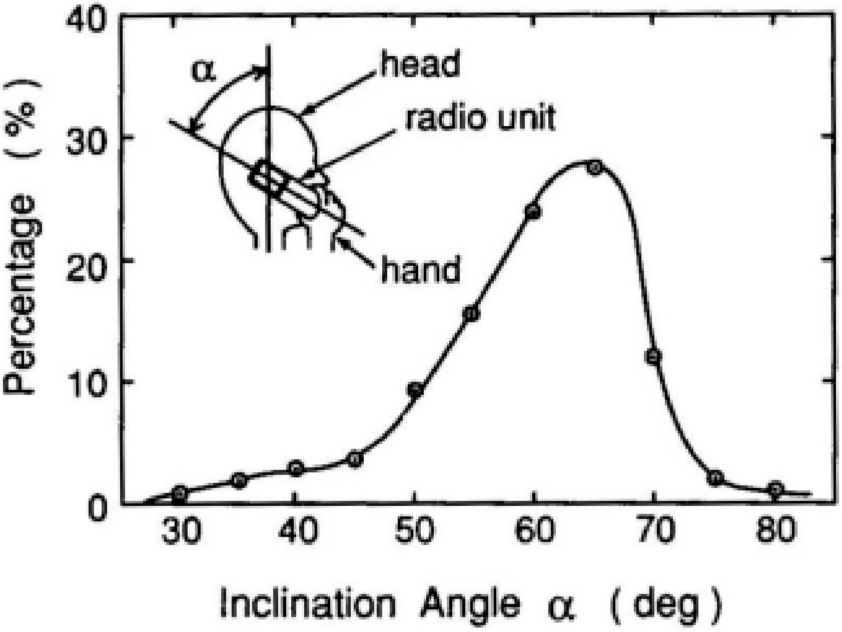


Figure E.1-1 - Inclination Angle Statistics (from K. Fujimoto and J.R. James)

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[14] K. Fujimoto and J.R. James, *Mobile Antenna Systems Handbook*, Norwood, MA: Artech House, Inc., 1994, pp. 221, 227.

E.2 IEEE SCC34 "SAM" Anthropomorphic Simulated Head Reference Information

The IEEE SCC34 "SAM" anthropomorphic head model has proven to be the standard phantom used for measuring the RF parameters of handsets and is the phantom recommended for the evaluations specified in this test plan[15]. The SAM phantom is referenced in the FCC Supplement C as the preferred simulated head/head and torso for SAR testing.

Figure E.2-1 shows the IEEE SCC34 "SAM" anthropomorphic head model. The details of its construction and EUT positioning are given in IEEE Std 1528-200X Draft 6.1 dated November 14, 2000. The IEEE document gives details on two positions, while this document requires that the EUT be tested only in the "cheek" or touch position.

In summary, it consists of a 2mm thick fiberglass shell in the shape of a 90th percentile adult male head with dimensions and shape as published by the US Army [Gorden et al., 1989]. The distance between the pinna back and the head, have been adopted as the standard for RF performance testing of handsets.

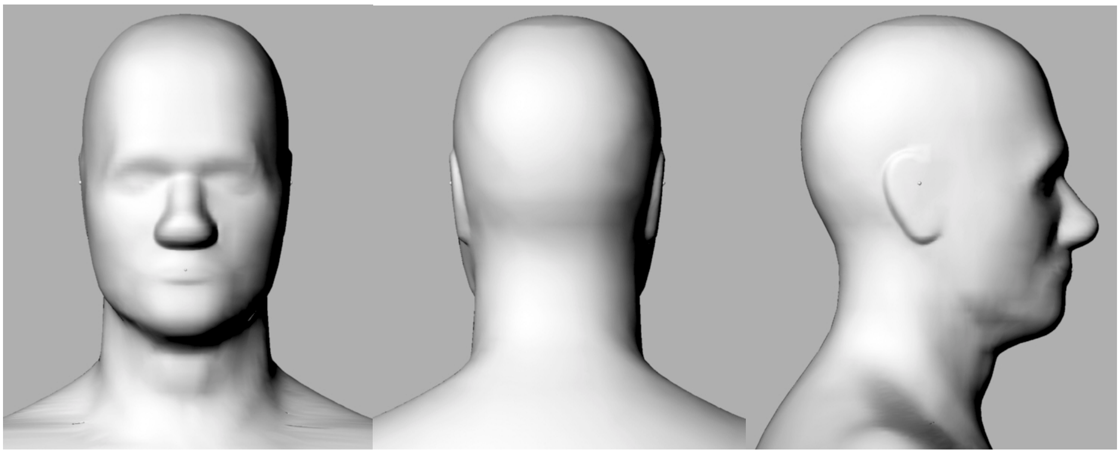

Figure E.2-1, IEEE SCC34 "SAM" anthropomorphic head model.

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[15] The availability of this phantom may be limited due to large demand and a limited number of suppliers. While not recommended, an alternative phantom may be used. Since there may be differences between phantoms, a difference in EIRP is expected and should be addressed when reporting test results. Contact CTIA for details on alternative phantoms.

E.3 Simulated Head Fluid Recipes:

Recipe I ("Head" tissue according to the data provided by C. Gabriel at 900 MHz):

Recipe II ("Head" tissue according to the data provided by C. Gabriel at 1900 MHz):

Table E.3-1: Recipe I & II, Head Tissue 900MHz & 1900 MHz

Elements	900 MHz	1900 MHz
Water	42.5%	45.0%
Sugar	55.6%	53.9%
Salt (NaCl)	0.8%	------
HEC (Hydroxyethylcellulosis)	1.0%	1.0%
Bactericide (Dowicil™ 75)	0.1%	0.1%

Note: the desired relative dielectric constant is 41.5 and desired conductivity is 0.90 S/m at 835 MHz.

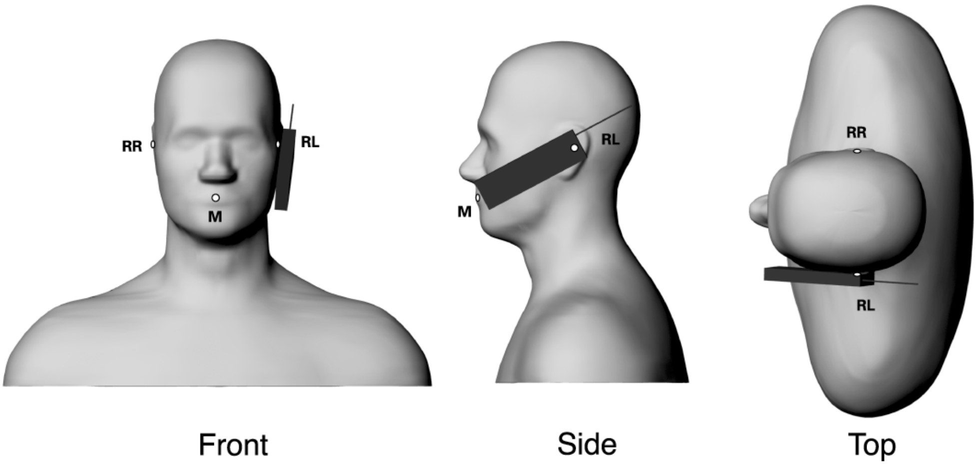
The desired relative dielectric constant is 40.0 and desired conductivity is 1.40 at 1900 MHz. The above recipe will not achieve these values, yet is the recommended recipe because other recipes that would come closer to the desire value use 2-(2-butoxyethoxy) ethanol (DGBE) which is harmful to most plastics, including fiberglass.

Companies such as Schmidt and Partners market these recipes commercially. Also, research into tissue simulation fluids is ongoing. Refer to the most recent IEEE standards and FCC requirements for SAR for the most up-to-date recommendations for tissue simulation fluids.

E.4 Definition of the EUT Position on "SAM" Phantom

1. Position the device with the vertical center line of the body of the device and the horizontal line crossing the center of the ear piece in a plane parallel to the sagittal plane of the phantom ("initial position"). While maintaining the device in this plane, align the vertical center line with the reference plane containing the three ear an mouth reference points (RE, LE and M) and align the center of the ear piece with the line RE-LE
2. Translate the mobile box towards the phantom with the earpiece aligned with the line LE-RE until the EUT touches the ear. While maintaining the device in the reference plane and maintaining the EUT contact with the ear, move the bottom of the box until any point on the front side is in contact with the cheek of the phantom or until contact with the ear is lost.

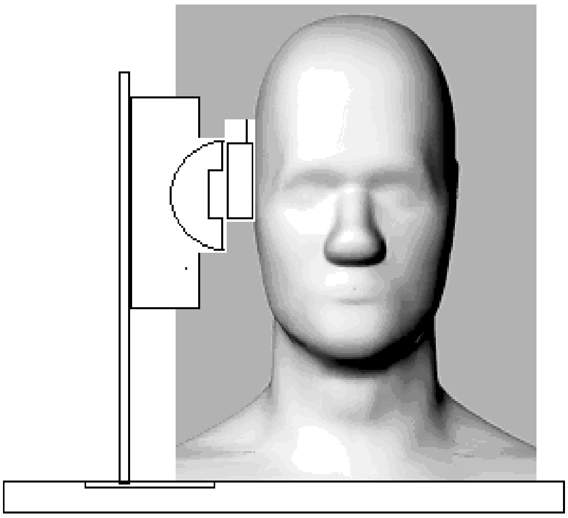
Figure E.4-1 EUT Positions on "SAM"



E.5 Definition of Handset Placement Fixture

A fixture constructed of material with minimum influence on the RF characteristics will be used to hold the EUT against the simulated head[16]. Such a fixture may be constructed as in figure E.5-1. The fixture shown is made of expanded polystyrene (Styrofoam™) and low dielectric plastics (Fiberglass™). The primary goal of the fixture is to allow the accurate positioning of the EUT, while also being transparent and non-reflective to RF. A minimum amount of plastics are used, while the material that is closest to the EUT is expanded polystyrene because of its excellent dielectric and physical properties.

Figure E.5-1 EUT Holding Fixture



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[16] Research into the use of a simulated hand is ongoing and may be included as the preferred fixture in the future.

Appendix F: Power Measurement Considerations

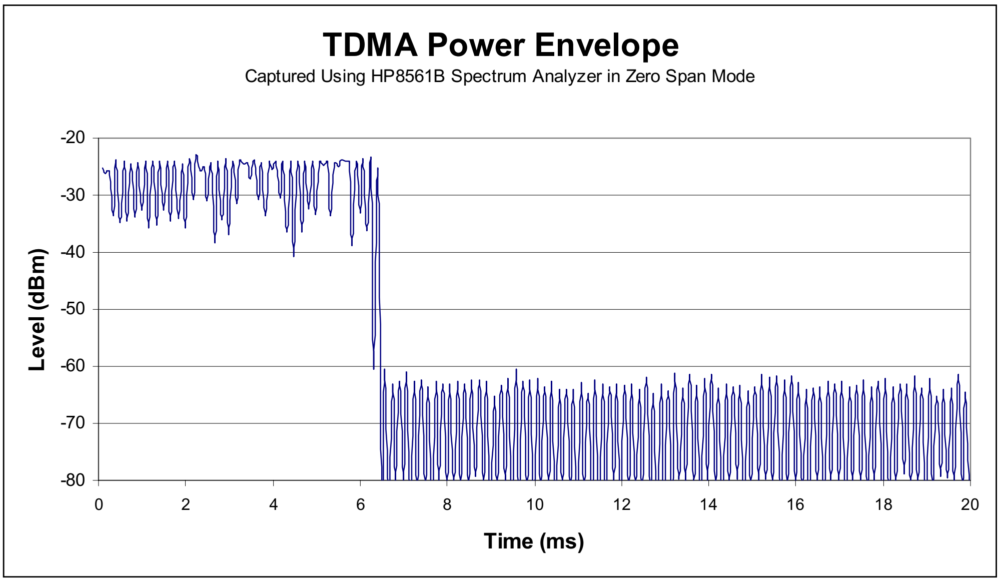
F.1 TDMA TIA/ANSI-136:

TIA/EIA-136-270-A specifies that the mean burst power shall be measured over at least 140 consecutive symbols between symbol number 6 and symbol number 162. Refer to Section 3.2.1.2.2 of TIA/EIA-136-270-A for additional information.

TIA/EIA-136 uses a non-constant envelope modulation (π/4-DQPSK) that is slotted into 6 timeslots. Two of the 6 timeslots are active during a call (e.g. 1+4, 2+5, 3+6). Each timeslot is 162 symbols long and is active for 6.67 ms. The carrier is turned off during the inactive timeslots (≅. 13.33 ms). The first 3 symbols of the active timeslot are used as guard time and the transmit carrier of the mobile station must be off. Symbols 4 through 6 are used for power ramp-up for the mobile station to come up to full transmit power. When an Abbreviated Slot Format is used, the last 22 symbols are also used for guard time and the transmit carrier for the mobile station must be off. When Normal Slot Format is used, the last 22 symbols contain data and carrier is on. Refer to Section 2 of TIA/EIA-136-121-A for further details.

For the purposes of characterizing antenna performance, it is acceptable to trigger on the rising edge of the power bursts at the measurement receiver and average over the central 85% of one or more bursts to estimate the average digital power. The chart below shows a typical spectrum analyzer trace when set to zero span and triggered on the video signal's rising edge. Resolution/Video Bandwidth was set to 300 kHz and Sweep Time was set to 50 ms. Averaging over the first 73 samples results in an average power estimate of –28 dBm.

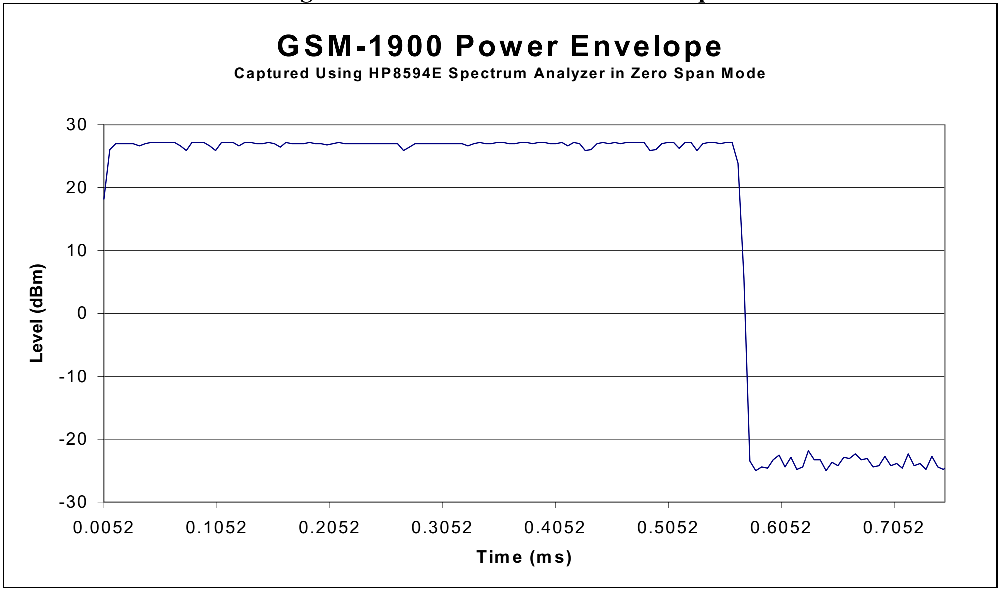
Figure F.1-1: TDMA PWR Envelope



F.2 GSM-1900 -- J-STD-007

GSM-1900 uses a constant envelope modulation (GMSK) that is slotted into 8 timeslots. For the purposes of characterizing antenna performance, it is acceptable to trigger on the rising edge of the power bursts at the measurement receiver and average over the central 85% of one or more bursts to estimate the average digital power. The chart below shows a typical spectrum analyzer trace when set to zero span, and triggered on the video signal's rising edge. Resolution/Video Bandwidth was set to 300 kHz and Sweep Time was set to 8.02 ms. Averaging over the first 73 samples results in an average power estimate of –27 dBm.

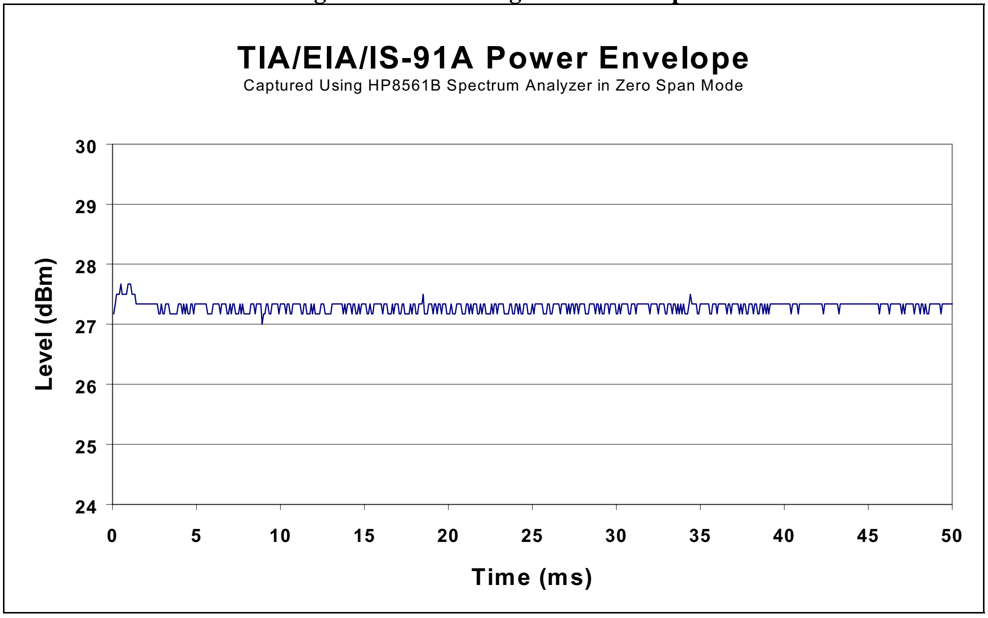
Figure F.2-1: GSM-1900 PWR Envelope



F.3 Analog -- TIA/EIA/IS-91A

TIA/EIA/IS-91A uses a constant envelope modulation (FSK). For the purposes of characterizing antenna performance, it is acceptable to trigger on the rising edge of the power transition at the measurement receiver. The chart below shows a typical spectrum analyzer trace (for 30 kHz analog channel) when set to zero span and triggered on the video signal's rising edge. Resolution/Video Bandwidth was set to 30 kHz and Sweep Time was set to 50 ms. Averaging over the entire 50 ms trace results in an average power estimate of 27.3 dBm.

Figure F.3-1: Analog PWR Envelope



F.4 CDMA:

When using the Tek CMD-80 Digital Radio Communication tester, go to "Power Control", "Max Output", this will accomplish the "always up" condition. Other pieces of test equipment (HP 8924) may be used to perform same function of sending up-bits for power control decisions.

Appendix G: Great Circle Measurement Orientation Diagrams

The following diagrams are provided to illustrate the orientation of the Device Under Test with respect to an antenna used to measure the dominant polarization. Orientations for the four E-Plane cuts specified by this document are illustrated. The EUT is rotated horizontally to characterize the E-Plane pattern across a plane intersecting the EUT faceplate at the specified angle.

Figure G-1 Device Orientation – E0 Cut

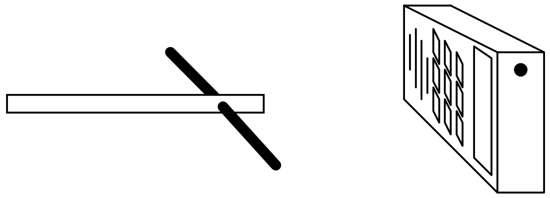


Figure G-2 Device Orientation – E45 Cut

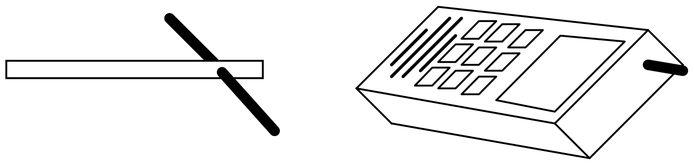


Figure G-3 Device Orientation – E90 Cut

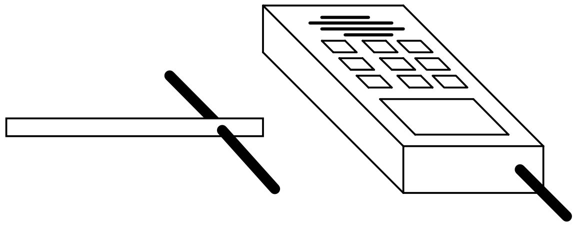
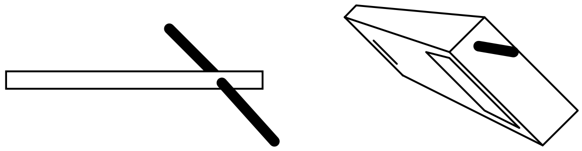
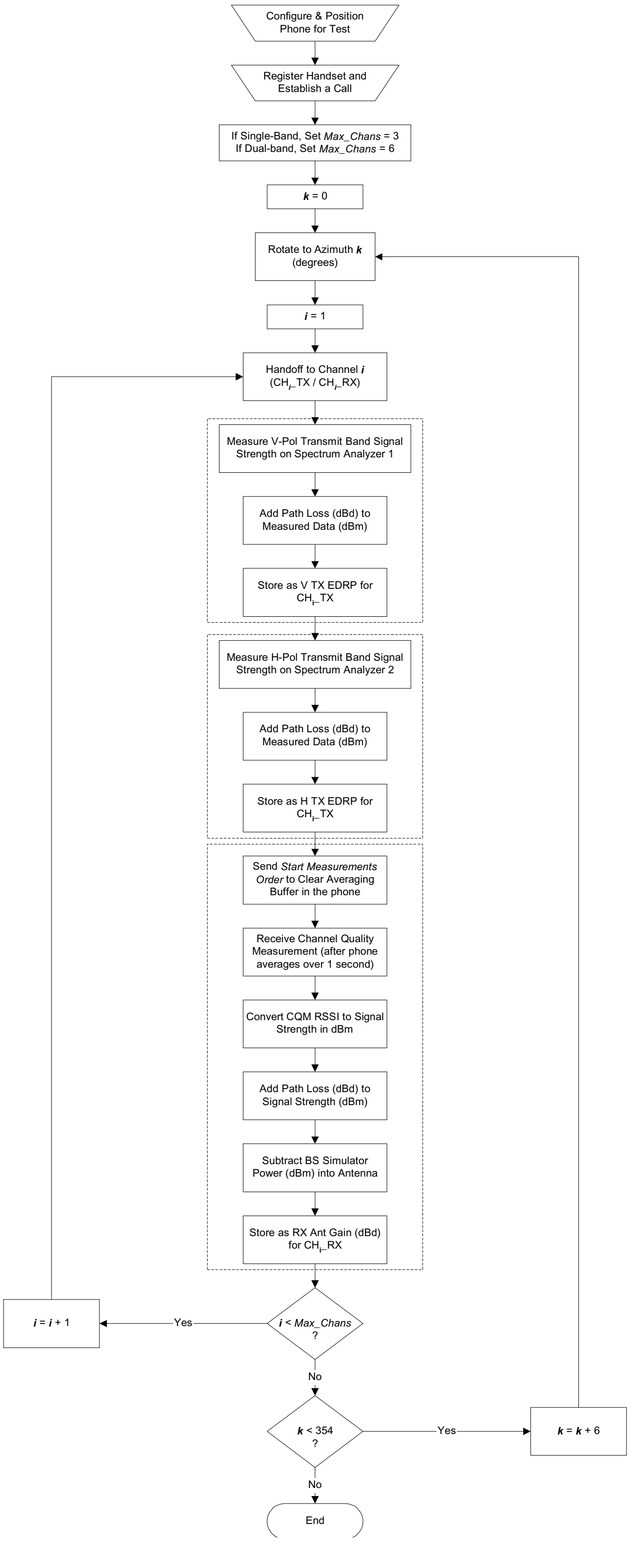


Figure G-4 Device Orientation – E135 Cut



Appendix H: Example Flow Diagram for the Device Measurement Procedure for Each Cut

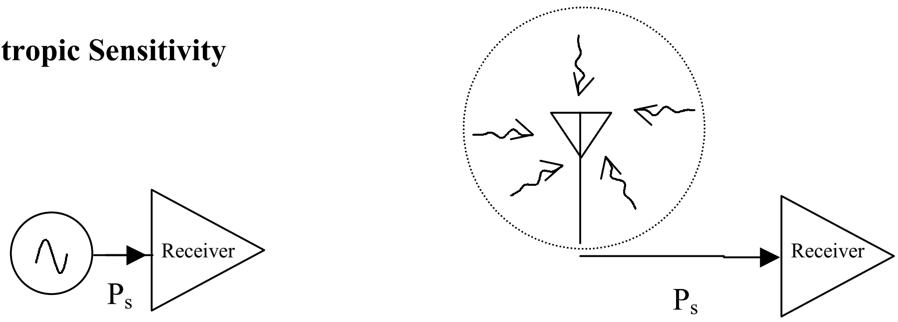


Appendix I: Total Isotropic Sensitivity (Informative)

This section specifies a way of reducing a complete spherical pattern of receive-sensitivity data to a single figure of merit, and to give some meaningful examples of this process. The basic principal applied is to compare the EUT's performance to that of a receiver with a perfect (100% efficient) antenna.

These derivation yields results to apply to real chamber measurements of receive sensitivity.

Total Isotropic Sensitivity



Conducted sensitivity measurement (left) and TIS (right)

Definitions

Assume plane waves of equal power and equal phase incident on the EUT from every direction, and further assume that at each direction, plane waves of equal power in each of the two polarizations (E_θ and E_ϕ) are incident. Now assume the uniform power in all of these waves is simultaneously adjusted so that the power available to the EUT's receiver from the EUT's antenna when immersed in them is the power required for the receiver to operate at its threshold of sensitivity (e.g., a specifiec bit error rate). If the EUT is now replaced with an ideal isotropic antenna with equal gain in each polarization in every direction, the power available from the ideal isotropic antenna from this same uniform incident field is the Total Isotropic Sensitivity[17], TIS.

Define the Effective Isotropic Sensitivities, EIS, as follows:

$EIS_\theta(\theta,\phi) =$ Power available from an ideal isotropic, theta-polarized antenna generated by the theta-polarized plane wave incident from direction (θ,ϕ) which, when incident on the EUT, yields the threshold of sensitivity performance.

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[17] This is an sensible definition because it compares the EUT's antenna/receiver system to a perfect, 100% efficient antenna that responds equally to either polarization.

$EIS_\phi(\theta,\phi) =$ Power available from an ideal isotropic, phi-polarized antenna generated by a phi-polarized plane wave incident from direction (θ,ϕ) which, when incident on the EUT, yields the threshold of sensitivity performance.

EIS is the pattern quantity that is actually measured in the chamber, by recording power required at each angle and polarization to achieve sensitivity. It is measured by including the same path-loss factor that is used in the chamber to yield EIRP for a transmitting antenna. Note that the EIS terms are defined with respect to a single-polarized ideal isotropic antenna, but the TIS is defined with respect to a dual-polarized ideal isotropic antenna. This is a convenience to make calibration in the chamber correspond with the calibration done for EIRP. That is to say, the same numerical path loss terms that are generated when calibrating a chamber to yield EIRP patterns for a transmit test will yield EIS patterns for a receive test as defined here (based on single-polarized isotropic references). TIS is based on a dual-polarized isotropic comparison, because real-world EUTs and propagation are dual-polarized. Proper choice of integration kernels will be seen to reconcile this apparent difference.

In general,

$$EIS_x(\theta,\phi) = \frac{P_S}{G_x(\theta,\phi)} \qquad (1)$$

where P_s is the conducted sensitivity of the EUT's receiver and $G_x(\theta,\phi)$ is the gain relative isotropic (in polarization x) of the EUT's antenna (in this case, including mismatch and ohmic losses) in the direction (θ,ϕ).

Calculation of Received Power

Assume a spherical surface centered on the EUT, and calculate the incoming power in the uniform spherical wave described in the definition of TIS. In general, the power flowing into any closed surface can be calculated by integrating the real part of the Poynting vector[18] over that surface:

$$P_{available} = \frac{1}{2}\oint\!\!\oint_S \mathrm{Re}(\vec{E}\times\vec{H})\cdot d\vec{s}$$

where *S* is the spherical surface on which the electric and magnetic fields are evaluated. For purposes of this discussion, the sign convention is chosen so that a positive power indicates a net power flow into the closed spherical surface.

Assume that the spherical surface *S* has a sufficiently large radius r that the far-field approximation can be applied. Then, upon separating the integration kernel into terms for each of two orthogonal linearly polarized components of incoming wave, we have[19]

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[18] See, e.g., Stutzman & Thiele, *Antenna Theory and Design*, first edition, 1981, page 9, equation 1-34; or Balanis, *Antennas*, x edition, 19xx, page 36, equation 2-9.

[19] This is an analogous development to equations 2-12 and 2-12a on page 38 of Balanis.

$$P_{available} = \frac{1}{2\eta_0} \oint\!\!\oint_S (E_\theta^2(r,\theta,\phi) + E_\phi^2(r,\theta,\phi))ds$$

where r is the radius of the spherical surface of integration, η_0 is the intrinsic impedance of free space, and $E_x(r,\theta,\phi)$ are the magnitudes of the two components of electric field on the surface *S*. Finally, substituting for the differential element of area, ds, we have

$$P_{available} = \frac{1}{2\eta_0} \oint\!\!\oint_S (E_\theta^2(r,\theta,\phi) + E_\phi^2(r,\theta,\phi))r^2 \sin(\theta)d\theta d\phi \quad (2)$$

As defined above, the TIS is the power that an ideal isotropic radiator would receive from an incoming spherical wave with equal power in each polarization from every direction, such that the same incoming wave would cause the EUT to operate at sensitivity. Define E_{TIS} to be the magnitude of each of the linearly polarized components of this wave,

$$E_\theta(r,\theta,\phi) = E_\phi(r,\theta,\phi) = E_{TIS}$$

Then equation 2 becomes, for this case,

$$P_{available} = \frac{1}{2\eta_0} \oint\!\!\oint_S 2E_{TIS}^2 r^2 \sin(\theta)d\theta d\phi = \frac{4\pi E_{TIS}^2 r^2}{\eta_0}$$

This is the total power carried in such an incoming wave. However, the power actually received from this same incoming wave by any antenna is

$$P_{received} = \frac{1}{2\eta_0} \oint\!\!\oint_S (G_\theta(\theta,\phi)E_{TIS}^2 + G_\phi(\theta,\phi)E_{TIS}^2)r^2 \sin(\theta)d\theta d\phi$$

where $G_x(\theta,\phi)$ are the antenna's component gains in each polarization as in equation 1.

This can be further simplified to

$$P_{received} = \frac{E_{TIS}^2 r^2}{2\eta_0} \oint\!\!\oint_S (G_\theta(\theta,\phi) + G_\phi(\theta,\phi))\sin(\theta)d\theta d\phi$$

The ideal isotropic dual-polarized antenna envisioned in the above definition of TIS would have a total gain in every direction of 1 (that is, 0 dBi). Therefore, its component gains in each polarization in every direction are 0.5 (that is, -3 dBi), and the power it would receive from this incoming wave (by definition, the TIS) is

$$P_{received} = TIS = \frac{E_{TIS}^2 r^2}{2\eta_0} \oiint_S (\frac{1}{2} + \frac{1}{2}) \sin(\theta) d\theta d\phi = \frac{2\pi E_{TIS}^2 r^2}{\eta_0} \quad (3)$$

For the specific case of the EUT, the power delivered by its antenna to its receiver when immersed in this incoming wave is, *by definition*, the receiver's sensitivity power, P_S, so that

$$P_S = \frac{E_{TIS}^2 r^2}{2\eta_0} \oiint_S (G_\theta(\theta,\phi) + G_\phi(\theta,\phi)) \sin(\theta) d\theta d\phi \quad (4)$$

Furthermore, we can rearrange equation 1 so that

$$G_x(\theta,\phi) = \frac{P_S}{EIS_x(\theta,\phi)}$$

Substituting into equation 4 yields

$$P_S = \frac{E_{TIS}^2 r^2}{2\eta_0} \oiint_S \left[\frac{P_S}{EIS_\theta(\theta,\phi)} + \frac{P_S}{EIS_\phi(\theta,\phi)} \right] \sin(\theta) d\theta d\phi$$

This can be rearranged to yield

$$\frac{E_{TIS}^2 r^2}{\eta_0} = \frac{2}{\oiint_S \left[\frac{1}{EIS_\theta(\theta,\phi)} + \frac{1}{EIS_\phi(\theta,\phi)} \right] \sin(\theta) d\theta d\phi}$$

Substituting this into equation 3 yields

$$TIS = \frac{4\pi}{\oiint_S \left[\frac{1}{EIS_\theta(\theta,\phi)} + \frac{1}{EIS_\phi(\theta,\phi)} \right] \sin(\theta) d\theta d\phi} \quad (5)$$

Results for a few Special Cases

Assume that the receiver, environment, and antenna are all at the same temperature, e.g., 290K.

Case 1: The EUT employs a 100% efficient, single-polarized, ideal isotropic radiator: For example, assume the EUT's antenna is an ideal, theta-polarized isotropic antenna. By definition, $EIS_\theta(\theta,\phi)$ is then P_s for every angle, and $EIS\phi(\theta,\phi)$ is infinite at every angle. Then equation 5 becomes

$$TIS = \frac{4\pi}{\oiint_S \left[\frac{1}{P_S} + \frac{1}{\infty}\right] \sin(\theta) d\theta d\phi} = \frac{4\pi}{\oiint_S \left[\frac{1}{P_S} + 0\right] \sin(\theta) d\theta d\phi} = \frac{P_S 4\pi}{\oiint_S \sin(\theta) d\theta d\phi} = P_S$$

In other words, TIS of a 100% efficient, ideal isotropic, single-polarized antenna is just the sensitivity power, P_s.

Case 2: The EUT employs a 100% efficient, dual-polarized, ideal isotropic radiator: $EIS_\theta(\theta,\phi)$ is then $2P_s$ for every angle, and $EIS\phi(\theta,\phi)$ is also $2P_s$ at every angle. (Recall that the EIS is defined with respect to a single-polarized isotropic, and a dual-polarized isotropic antenna must have half the gain in each polarization of a corresponding single-polarized isotropic antenna.) Then equation 5 becomes

$$TIS = \frac{4\pi}{\oiint_S \left[\frac{1}{2P_S} + \frac{1}{2P_S}\right] \sin(\theta) d\theta d\phi} = \frac{P_S 4\pi}{\oiint_S \sin(\theta) d\theta d\phi} = P_S$$

Again, a 100% efficient, ideal isotropic antenna has a TIS that is equal to the conducted sensitivity of the receiver, P_s.

Case 3: The EUT employs a 50% efficient but otherwise ideal, single-polarized isotropic antenna. $EIS_\theta(\theta,\phi)$ is then $2P_s$ for every angle (the antenna is a 3-dB attenuator, degrading the receiver noise figure by 3 dB, so twice the power is required to get the same performance), and $EIS\phi(\theta,\phi)$ is infinite at every angle. Then equation 5 becomes

$$TIS = \frac{4\pi}{\oiint_S \left[\frac{1}{2P_S} + \frac{1}{\infty}\right] \sin(\theta) d\theta d\phi} = \frac{4\pi}{\oiint_S \left[\frac{1}{2P_S} + 0\right] \sin(\theta) d\theta d\phi} = \frac{2P_S 4\pi}{\oiint_S \sin(\theta) d\theta d\phi} = 2P_S$$

So a 50% efficient antenna has a TIS equal to the conducted sensitivity degraded by 3 dB (i.e., twice as large).

This supports two general conclusions. First, the lower limit (best achievable value) for TIS is simply the conducted sensitivity of the EUT's receiver, P_s. This TIS is achieved with a perfectly matched, 100% efficient antenna. Second, the TIS of a real antenna will be the conducted sensitivity of its receiver degraded by the mismatch/efficiency loss of the antenna.

Conversion to Summations of Discretely Sampled Pattern Data

For simplicity, the summations will be derived separately for the two cases where the EIS data are taken using conic cuts and great-circle cuts. It is assumed in both cases that the measurement points are distributed uniformly in theta and phi.

Conic Cuts: For reference, the Z axis (theta=0 axis) is the long axis of the EUT in a free-space test or points straight up out of the top of the phantom's head in a phantom test. A conic cut is defined as a scan of phi from 0 to 360 degrees while theta is fixed at a given value. A series of conic cuts from theta = 0 (probe antenna at zenith) to 180 degrees (probe antenna at nadir) captures an entire spherical pattern.

$M =$ number of samples per conic cut
$N =$ number of conic cuts to form the spherical pattern
$i =$ index for each conic cut, i ranges from 1 to N
$j =$ index for each sample in a conic cut, j ranges from 1 to M

Then the theta and phi intervals are

$$\Delta\theta = \theta_i - \theta_{i-1} = \frac{\pi}{N}$$

$$\Delta\phi = \phi_j - \phi_{j-1} = \frac{2\pi}{M}$$

At this point, a choice must be made as to how samples taken at the edges of intervals are to correspond to the intervals themselves in approximating the integration. For simplicity, we will choose that the EIS measured at the beginning of a phi interval will represent that entire interval. This will have the effect of discarding the redundant measurement taken at phi=360 degrees. The most correct way to do this would probably be to utilize a trapezoidal rule for approximating the integration, but previous tests done with conic cut data have indicated that the difference in results is not significant.

Substituting the appropriate differentials into equation 5, the summation that approximates the TIS integration in this case is then

$$TIS = \frac{4\pi}{\sum_{i=1}^{N}\sum_{j=1}^{M}\left[\frac{1}{EIS_\theta(\theta,\phi)} + \frac{1}{EIS_\phi(\theta,\phi)}\right]\sin(\theta_i)\frac{\pi}{N}\frac{2\pi}{M}}$$

$$\text{or } TIS = \frac{2NM}{\pi\sum_{i=1}^{N}\sum_{j=1}^{M}\left[\frac{1}{EIS_\theta(\theta,\phi)} + \frac{1}{EIS_\phi(\theta,\phi)}\right]\sin(\theta_i)} \qquad (6)$$

Great-Circle Cuts: For reference, the Z axis (theta=0 axis) is the long axis of the EUT in a free-space test or points straight up out of the top of the phantom's head in a phantom test. A great-circle cut is defined here as a scan of theta from 0 to 360 degrees while phi is fixed at a given value. A series of such great-circle cuts from phi= 0 to 180 degrees captures an entire spherical pattern. Note that this coordinate system is defined with respect to the device under test (or the phantom), and may not necessarily correspond with the coordinate system of the specific positioning equipment used to obtain the pattern data.

M = number of great-circle cuts to form the spherical pattern
N = number of samples per great-circle cut

i = index for each sample in a great-circle cut, i ranges from 1 to N
j = index for each great-circle cut, j ranges from 1 to M

Then the theta and phi intervals are

$$\theta_i - \theta_{i-1} = \frac{2\pi}{N}$$

$$\phi_j - \phi_{j-1} = \frac{\pi}{M}$$

Again, a choice must be made as to how samples taken at the edges of intervals are to correspond to the intervals themselves in approximating the integration. We will choose that the EIS measured at the beginning of a theta interval will represent that entire interval. This will have the effect of discarding the redundant measurement taken at theta = 360 degrees.

The summation that approximates the TIS integration of equation 5 in this case is then

$$TIS = \frac{4\pi}{\sum_{i=1}^{N}\sum_{j=1}^{M}\left[\frac{1}{EIS_\theta(\theta,\phi)} + \frac{1}{EIS_\phi(\theta,\phi)}\right]\left|\sin(\theta_i)\right|\frac{2\pi}{N}\frac{\pi}{M}}$$

$$\text{or } TIS = \frac{2NM}{\pi\sum_{i=1}^{N}\sum_{j=1}^{M}\left[\frac{1}{EIS_\theta(\theta,\phi)} + \frac{1}{EIS_\phi(\theta,\phi)}\right]\left|\sin(\theta_i)\right|} \qquad (7)$$

The absolute value of sin(θ) must be used in this case, because we have performed the unnatural mathematical act of sweeping theta through 360 degrees. Equation 7 can be seen to apply also to the case of conic cuts (cf. equation 3), so can be used for both measurement schemes.

Appendix J: Symmetry Pattern Antenna (Informative)

The pattern symmetry requirement specified in Appendix C should not be misinterpreted as an absolute accuracy requirement. A requirement of +/-0.1 dB for antenna pattern measurements taken in the cellular and PCS bands would be very challenging to accomplish. To clarify pattern symmetry, and provide context for selecting its value, the following is provided for informational purposes only.

Symmetry Pattern vs. Absolute Accuracy:

The absolute magnitude accuracy in this specification is +/-1.0 dB for the ERP pattern measurements. Given this specification, consideration must be given to the many items in the complete error budget that contribute to this final overall accuracy. Examples of these are the ultimate accuracy of the instrument used to measure absolute power during the calibration process (e.g., a power meter), known gain accuracy of the calibration reference antenna, quiet zone accuracy (i.e., ripple or reflection in the chamber), and connector repeatability. Many of these error contributions can be made quite small at these frequency ranges. For example, connector repeatability is controlled by proper maintenance and torque of the connectors. Three-dimensional pattern integration of the calibration antenna can yield very precise directivity references. In the case of measuring highly non-directive devices, the two largest single contributors to the error budget are usually the ultimate accuracy of the power measurement instrument, and the quiet zone accuracy (ripple) in the anechoic chamber.

To obtain the +/-1.0 dB overall accuracy desired, a substantially better quiet zone uncertainty of +/-0.5 dB ripple or less (since it is one term of several in the error budget), has been specified. To quantify the quiet zone accuracy, a verification tool (i.e., the omnidirectional dipole or loop source) substantially better than the +/- 0.5 dB ripple level discerned, therefore, should be used. Thus, the omnidirectional test antennas used for chamber validation (not necessarily for chamber calibration) are required to have patterns that are symmetric to +/- 0.1 dB. This level of pattern symmetry is achieved rather easily with an electric dipole rotated about its axis, and can be achieved with some care with the uniform-current (Alford) loops described in this section. (Reference can also be made to, e.g., "Loop Antennas with Uniform Current," Proc. IRE, vol. 32, pp. 603-607, October, 1944.)

Pattern symmetry is measured with an antenna centered precisely on the axis of rotation of the positioner. An anechoic chamber with a very low reflectivity is not required to verify a nominally omnidirectional antenna's pattern symmetry. In other words, a chamber qualifying under the specified ripple/reflectivity levels is not required to prove that an omni test antenna is indeed, omni. If an antenna with a perfectly symmetric omni pattern is precisely on the center of rotation, even if there is a substantial reflector in the chamber, a perfectly uniform pattern can be observed. This is because the signals on both the direct and reflected paths remain constant as the antenna is rotated. So as long as an “omni” antenna starts out more or less omni, it can be qualified for pattern symmetry in a chamber that might not meet the +/-0.5dB quiet zone uncertainty.

It is important to note this specification calls for pattern SYMMETRY of +/-0.1 dB -- NOT absolute gain accuracy. In fact, for the chamber validation (not calibration) phase, gain is not needed at all -- only verification of the pattern symmetry. Furthermore, the +/-0.1 dB symmetry requirement is not arbitrary; it follows directly from the desire for +/-1.0 dB absolute accuracy.

To summarize, this specification does not require validation antennas with a gain accuracy of +/-0.1 dB. Rather, the antenna pattern symmetry should be +/-0.1 dB -- which is achievable and quantifiable. This specification also calls for an overall measurement accuracy level of +/-1.0 dB, which is also achievable with current chamber technology.

For additional information on the symmetry antenna, contact CTIA Certification Program staff.

Appendix K: Change History

Date:	Revision	Section(s)	Description	Changed By
10/12/00	0.1	All	Create Baseline format from EIRP Ad-Hoc contributions	T. Jeffries (CTIA)
10/17/00	0.1	All	Editorial changes and comments submitted for possible acceptance.	C. Martin (SBC)
10/18/00	0.2	All	SBC-TRI comments accepted. Global change of ERP to EIRP.	T. Jeffries (CTIA)
10/18/00	0.2	Section 2	Introduction on the need for simulated-use configuration	
		Section 3	Clarification on when to test for simulated-use	
10/18/00	0.3	All	Modified E/H plane cut methods, phantom choice primarily	P. Moller (Motorola)
10/24/00	0.3	B.2	Include equation for Spatially Averaged	S. Harbin (SBC)
10/24/00	0.3	Section 3	EIRP criteria for TDMA	S. Harbin (SBC)
10/30/00	0.4	Section 4.2	CDMA Receiver Sensitivity Test	T. Erickson (Qcomm)
10/31/00	0.4	3.4	EIRP for GSM-1900	C. Martin (SBC)
10/31/00	0.4	4.3 & 4.4	Receiver Gain procedures for ANSI-136 & GSM-1900	C. Martin (SBC)
11/1/00	0.5	Section 2	Clarification on Great Cut	P. Moller (Motorola)
11/01/00	0.5	Appendix C	Definition Loop Probe Antennas	P. Moller (Motorola)
11/01/00	0.5	Appendix E	Included E.4, EUT Position on “SAM”	P. Moller (Motorola)
11/01/00	0.5	All	General Edits	T. Jeffries (CTIA)
11/7/00	0.6	Section 3	Redefined Radiated Criteria	T. Jeffries (CTIA)
11/17/00	0.6	Section E.5	Definition of HS Placement Fixture	T. Jeffries (CTIA)
11/28/00	0.6A	All	General Edits	C. Martin (Cingular)
01/08/01	0.6A	All	General Edits	C. Martin (Cingular)
2/15/01	0.6B	Appendix E	Alternative phantom footnote and EUT fixture	P. Moller (Motorola)
3/1/01	0.7	Section 4	Added In-between Chan Test & Total Isotropic Sens	P. Moller (Motorola)
3/1/01	0.7	Appendix B	Added TIS & updated TRP equations	E. Krenz (Mototola)
3/1/01	0.7	Section 4	Revised TDMA & GSM test methods	C. Martin (Cingular)
3/1/01	0.7	All	General Edits	T. Jeffries (CTIA)
4/5/01	0.7A	Appendix C	Clarification antenna symmetry	E. Krenz, P. Molller (Motorola)
5/7/01	0.7-B	All	Editorial changes	T. Jeffries (CTIA)
5/7/01	0.7-B	Appendix I	TIS definition and information	E. Krenz (Motorola)
5/7/01	0.7-B	Appendix J	Symmetry Pattern information	E. Krenz (Motorola)
5/7/01	0.7-B	All	Technical Clarification and Edits	P. Chery, K. Bednasz, M. Isley, R. Sadler (Ericcson)
5/24/01	1.0	All	Editorial Changes – Official Release Draft Ver. 1.0	T.Jeffries (CTIA)