STATE OF CONNECTICUT
SITING COUNCIL

SBA Towers II, LLC and New Cingular Wireless, PCS, LLC Application for a Certificate of Environmental Compatibility and Public Need for a Telecommunications Facility Located at Wewaka Brood Road : Bridgewater, Connecticut.

:DOCKET #412

: MARCH 28 2011

**AFFIDAVIT OF RONALD E. GRAIFF**

I, Ronald E. Graiff the undersigned, being duly sworn, do depose and say:

1. I am over the age of eighteen and believe in the obligations of an oath.

2. A true and accurate copy of my pre-filed testimony for use before the Connecticut Siting Council attached hereto as Exhibit A.

3. I am the author of the attached pre-filed testimony and believe the facts contained therein are true and accurate to the best of my knowledge and belief.

FURTHER the deponent sayeth not.

Ronald E Graiff

Subscribed and sworn to before me this 28th day of Mar, 2011.

State of Florida, County of Lake
Notary Public
My commission expires:

Patricia D Nix

PATRICIA D. NIX
Notary Public - State of Florida
My Comm. Expires Mar 2, 2013
Commission # DD 866067
Bonded Through National Notary Assn.

# CURRICULUM VITAE
# RONALD E. GRAIFF

Bachelor of Science Degree in Electrical Engineering, The Pennsylvania State University, 1968
Licensed Professional Engineer, New York State, 1974, License # 050547
Licensed by Federal Communications Commission with First Class (General Radiotelephone)
Past Member, Association of Federal Communications Commission Consulting Engineers
Recipient of CTIA "Industry Service Award" for Advancement of Cellular Industry, 1989
Member, Institute of Electrical and Electronics Engineers

Current: Independent Radio Frequency consulting engineer engaged in evaluation, application and construction of radio, television, cellular and emerging technologies based communications systems. Providing expert guidance and advice to municipalities and companies in communication tower location, radio frequency propagation, evaluation of radio frequency radiation compliance and guidelines, and environmental impact statements for communication facilities. (A partial list of municipalities and companies are noted at the end of this document). Testified before hundreds of Zoning, Planning and Boards of Adjustment as well as the Federal Communications Commission in matters dealing with cellular, enhanced specialized mobile radio service, personal communications service and broadcast. Performed hundreds of FCC OET-65 analyses for single and complex multi emitter sites. Perform RF environmental measurements at single and multi user sites in accordance with ANSI/IEEE C95.3-1992 and NCRP Report 119.

Prior: 1975-1990, Vice President, Engineering, LIN Broadcasting Corporation. Public company engaged in radio, television, common carrier and cellular telephone. Personally responsible for the design, construction and implementation of numerous broadcasting projects ranging from 5,000 watts to 5,000,000 watts. Responsible for the specification and implementation of both guyed and self supporting towers from 250 feet tall to 2,000 feet tall. Applied for and designed cellular telephone systems in New York, Los Angeles, Philadelphia, Dallas-Ft Worth, and Houston. Prepared and provided direct testimony before the Federal Communications Commission with respect to the design of cellular telephone systems. Overall responsibility for the design and quick build of the five markets above as well as purchase responsibility for the RF and switching systems for same. Co-Chairman of the FCC/Industry interconnect committee, responsible for developing interconnection arrangements with the regional Bell operating companies and equitable use of the North American Numbering Plan. Co-Chairman of the Cellular Telecommunications Industry Association (CTIA) Advanced Technology Committee, responsible for evaluating and recommending the second generation TDMA digital systems. Chairman of the Engineering Committee of the Association of Maximum Service Telecasters and presented reports and testimony to the Federal Communications Commission on equivalent protection of television allocations and RF propagation.

Extensive experience in the measurement and evaluation of Radio Frequency (RF) fields from both a design and biological point.

1970-1975 RF(Radio Frequency) Systems and Allocations Engineer, The American Broadcasting Company. General responsibility for all facets of the RF operations of ABC's 5 television stations and 14 radio stations as well as the specialized needs of ABC news and sports in their communication requirements. Designed and implemented the radio communication systems for ABC news at the 1972 political conventions in Miami as well as the radio communication system for ABC sports at the 1976 Winter Olympics in Innsbruck, Austria. Designed specialized RF systems from 26 MHz to 13 GHz utilized in ABC's entry into Electronic News Gathering in the early 70's.

Prior to 1970 employed by Philco-Ford Corporation as a field engineer working on classified military communication systems projects in many areas of south-east Asia and Europe.

Partial list of companies and municipalities for which work has been performed:

AT&T Wireless (CT, NJ, NY) Cellular One (NJ, NY,PA); Cingular Wireless(CT); Independent Wireless One; metroPCS (NY); Nextel (CT,NJ,NY); Nextel Partners (MA,NY); Sprint Spectrum (NY); T-Mobile (NY); Verizon Wireless (CT,NJ,NY,MA,VT)

Andover Township, NJ; Township of Bedminister, NJ; Bernardsville, NJ; Danbury CT; Fairfield Township, NJ; Frankford Township, NJ; Morris Township, NJ; Town of Harrison, NY; Township of Hazlet, NJ; Township of Jefferson, NJ; Town of Kent, NY; Kinnelon, NJ; Lenox, MA; Township of Livingston, NJ; Morris Township, NJ; New Fairfield, CT; Ogdensburg, NJ; Town of Orangetown, NY; Borough of Pompton Lakes, NJ; Village of Portchester, NY; Redding, CT; Rinebeck, NY, Trumbull, CT; West Caldwell, NJ; Village of Woodstock, NY; Wesley Hills, NY

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# PREFILED TESTIMONY OF RONALD E. GRAIFF FOR CSC DOCKET 412

March 28, 2011

My name is Ronald E. Graiff and I am an independent radio frequency consulting engineer. I have been retained by The Town of Bridgewater, CT to review and provide testimony on the application of SBA Towers II, LLC and New Cingular Wireless PCS, LLC ("Applicant") to construct a proposed cellular tower facility at 48&89 Wewaka Brook Road in Bridgewater, CT, Connecticut Siting Council ("CSC") Docket 412 and the application of New Cingular Wireless PCS, ("AT&T") to construct a proposed cellular tower facility at 111 Second Hill Road, Bridgewater, CT, no CSE docket assigned.

By way of background, I have been engaged in radio frequency engineering system design and construction for over 40 years. I have a Bachelor of Science degree in electrical engineering from The Pennsylvania State University and I am a Licensed Professional Engineer in the State of New York. During my career I have designed and constructed radio frequency communications systems for military and commercial entities. In addition I participated in the rule making before the FCC, applied for, designed and built the very first non-wireline cellular radio telephone systems in New York, Philadelphia, Dallas, Houston and Los Angeles. I received the industry service award from the Cellular Telecommunications Industry Association ("CTIA") for acting as Co-Chairman of CTIA Advanced Technology Committee, responsible for evaluating and recommending the second generation (2G) TDMA digital systems. I currently have been retained and qualified as an expert witness by zoning, planning and adjustment boards in numerous municipalities in New York and New Jersey in their evaluation of wireless telecommunications facilities. A CV is attached to this document for convenience.

My review in this matter will deal with the radio frequency technical aspects of the above-mentioned application. Specifically I will critically review the accuracy of the technical aspects, the need for the facility, the location of the facility, the height of the facility and the physical aspects of the proposed construction of the antenna systems.

## DOCKET 412 APPLICATION

### RADIO FREQUENCY COVERAGE DEPICTION ANALYSIS

The Applicant claims that the proposed facility will provide wireless communications service along State Route 133 and other roads in the surrounding areas of the Town of Bridgewater so as to provide service to the public. To support that claim the Applicant has submitted two coverage plots indicating "Existing & Future Coverage," and "Existing, Future & Proposed Coverage." These two submissions depict radio frequency coverage at two signal level "bins" of (1) greater than or equal to –74 dBm and (2) less than –74 dBm and greater or equal to –82 dBm. There is no description or documentation as to how these calculated propagation studies were prepared, specifically the propagation model utilized, the frequency depicted, the technical transmission parameters, and the assumptions utilized in the propagation model's algorithm. Furthermore, the signal level bins depicted are inappropriate for a rural area such as exists in the Town of Bridgewater.

Because of this lack of information it is impossible to determine the accuracy of the plots and their applicability to the area. It is well documented (see ETSI Technical Report ETR 364, November, 1996, as one example) that there are different signal level requirements for urban, suburban and rural areas. ETSI does not specify either maximum or minimum signal strengths, but only "link budgets." Cingular Wireless has presented papers at numerous hearings where it notes that its design requirements in the NY/NJ **Metropolitan Area** (emphasis added) is –75 dBm. Areas such as rural Bridgewater with only single story wood frame homes and a very low residual base noise floor (hardly metropolitan areas) require radio frequency signal strength levels of significantly less amplitude. Even if they were, the signal level shown here is 1 dB stronger than Cingular's own paper supports. Moreover, the depiction of –82 dBm is also overreaching as, once again, it has been documented that in areas such as Bridgewater signal strengths of –84 dBm **and less** are more than sufficient to provide reliable in vehicle and in suburban building coverage.

The Applicant has provided no basis for these extremely strong signal levels. In fact, the Federal Communications Commission ("FCC") has no minimum or maximum requirement for signal levels provided by carriers except for a requirement in the criteria for comparative renewal proceedings, 47CFR, 22.940 *et.al.* that the "applicant has provided 'substantial' service during its past license term. 'Substantial' service is defined as service which is sound, favorable and **substantially above a level of mediocre service** (emphasis added) which might just minimally warrant renewal." The Applicant has not demonstrated that at signal levels of less than –82 dBm its level of service would not be substantially above mediocre service.

The Applicant's claims to these signal strength levels are unfounded, unjustified and should not be considered in determining need for the proposed facility. White papers distributed by both AT&T and T-Mobile (the other major carrier operating in the US with the GSM modulation standard) discuss the minimum signal strength required for their systems.. While both carriers attempt to justify the signal strengths (-82 dBm for AT&T and –84 dBm for T-Mobile) a review of the assumptions, calculations and expectations notes that the carriers assume a standard deviation of between 6 to 8 dB (an incredibly large variation of nearly 10% of the minimum noted) and unrealistic building attenuation needs (in this case 15 dB, which number is not justified in Bridgewater). One can only wonder what the signal strength will be after the proposed merger of AT&T and T-mobile is completed. If the AT&T level is utilized will all of the T-Mobile sites have to be redesigned? In addition, in these justification papers, both carriers claim to need 95% reliability! Such a reliability factor is nearly perfect and clearly above any expectation of being substantially above mediocre. The Applicant has overstated its needs with a safety factor that is not justified. Moreover as the Applicant has proposed installing tower mounted low noise amplifiers ("TMA") these devices act to improve the receiver sensitivity and noise floor of the system resulting in an even further reduction of signal strength required to achieve reliable system performance. At a minimum the Applicant should be directed to provide coverage plots (and even more information, as described below) at a signal strength of –84 dBm and below. This requirement is very important in considering the need and its justification. It is also important to note that a reduced signal strength, i.e. one less than –84 dBm for example, will result in an area of greater coverage with the resulting gaps "white areas" on the plots that are significantly smaller. This inverse relationship between signal strength and coverage is intuitively obvious to even the most casual observer.

As noted above, there is little if any information provided on the model utilized or the assumptions made in preparing the propagation plots. There are numerous models in existence today, all with limitations and shortcomings. See, for example, *Spectrum Planning Report*, Radiofrequency Planning Group, Australian Communications Authority, April 2001 where differences in various models are demonstrated. In light of this lack of demonstrated accuracy in the depicted coverage plots, the Applicant should be well directed to provide scan drive tests of the existing system and a continuous wave drive test of the proposed facility.

Drive testing may be considered, if performed correctly, the "Gold Standard' in determining existing and proposed coverage. Conducted with specially designed test equipment, global positioning equipment and data recorders, real time signal strength measurements are taken, recorded and depicted on maps of the area. Note, that no one has ever made a telephone call from the calculated plots as supplied, but the drive test is, in effect, a call placed on the system. Depiction of the results, however, is critical. As can be noted on the provided calculated plots one of the signal bins depicted is less than –74 dBm and greater or equal to –82 dBm. While I am not agreeing with this level as it is too strong, what the map depicts are signal strengths of only greater than –82 dBm. What if the calculated or measured signal strength was –82.1 dBm or –82.4 dBm? As depicted, these signal levels would be deemed non acceptable. These broad signal bins should be replaced with coverage plots depicting signal strengths in bins of 4 dBm. As presented, the inaccuracy and lack of the precision in demonstrating the projected signal strengths is not good engineering practice. Note that ETSI in ETR 364 notes that field strength measurements of rms values can be performed with an uncertainty of 3.5 dB and predictions can reasonably be done with an uncertainty of 10 db. (see below).

Assume, for example, that one was standing on the corner of 2$^{nd}$ Street and Main in the dark of night and needed to find a specific location. If given a map that had 2$^{nd}$ and Main on the extreme right hand side of the map, one would be able to determine where to go to the west (assuming Main ran east and west), but would be unable to determine where to go to the east as there was no map for that direction. The ideal map would have 2$^{nd}$ and Main in the center of the map. The same is true for the bins of signal strength depicted.

A bin that ends at exactly –82 dBm is useless as there is no information on any signal strength less than –82 dBm, no matter how much less. Bins should be designed to "bracket" the desired level (whatever it is). For example, signal strengths on such presentations as are evaluated herein should have bin brackets of –80 dBm to –84 dBm, and –84.1 dBm to –88dBm. Such **a** bin size not only brackets the area of interest and accounts for the inherent accuracy of the depiction, but also indicate the "roll off" of signal strength, i.e. how it actually decays with distance. The same presentation should also be utilized in drive testing. Be warned, however, notwithstanding my comment that drive testing is the Gold Standard, it, too, has limitations. The current test equipment that is routinely utilized to perform drive tests is the JDSU W1314A (formerly Aligent Technologies W1314A) This device has a stated accuracy of +or- 1.5dB. At the signal strength depicted by the applicant of –82 dBm, the actual measured signal strength could vary between –80.5 dBm and –83.5 dBm, nearly a +or- change of 30% in strength. Hardly the precision accuracy required to declare that "the system won't work at depicted levels of less than –82 dBm."

**For all of the above reasons, the evidence submitted with respect to existing coverage is deficient and incapable of a critical evaluation of need.**

Notwithstanding all of the shortcomings of the previously evaluated coverage map, now one must turn to the map that depicts "Existing, Future, and proposed Coverage." This map appears to depict the coverage provided by the proposed facility. The same inadequacies noted above continue, but the depiction of the proposed coverage is even more clouded. It is impossible to determine the extent of the proposed coverage at the height requested. Typically such presentations of proposed coverage are demonstrated with an overlay (in a contrasting color) or a cross hatched depiction of the proposed coverage. This allows the reviewer to determine the extent of new coverage, the amount of overlap and if a site with slightly less coverage and the resultant reduction of tower height would meet the applicant's needs. Furthermore, depictions of coverage, in the manner described should be presented at heights of 20 feet less and 40 feet less. Note that no model, no matter how good, will show significant differences in coverage at 10 foot increments. This lack of proper presentation also does not allow a critical review of the system as it exists today. Note, for example, that the Dinglebrook Lane site (SR1860) was recently placed into service. As carriers routinely "tune" and adjust a new site after it is placed in service, one has no idea of what the real world service provided by this new site really is and if it has had an impact on the purported gap in coverage. **For all of the above reasons, the evidence submitted with respect to existing, future and proposed coverage is deficient and incapable of a critical evaluation of need.**

## SYSTEM DESIGN

Good design practice in a cellular or PCS system, especially one operating with the GSM standard that utilized "frequency reuse" is to have the cells spaced in a regular re-use grid with inter site distances and bearings following the geometry of the transmitting antenna azimuths. In addition, it is very important to have the proposed cell near the center of the purported "white area" gap in coverage.

Examining the plot entitled Existing and Future Coverage one will note the locations of existing sites (gold color); proposed sites (magenta color) and the proposed site. One can only wonder why site CT5902 (Carmen Hill Road Site) is shown only as a one sector 1900 MHz site only, and not a full 800 MHz site. This plot also indicated the extent of the purported gap that extends around the Housatonic River, south to Route 133 (east and west) and north to Tappen Road. A casual observation of the existing and proposed sites indicates relatively uniform spacing and azimuthal separation. The proposed site, however, appears to violate the existing and proposed geometry of the system. Besides not being in the center of the gap, the site is too far east and too far south. Moreover as there appears to be no engineering department "search ring" submitted with the application, the reviewer has no idea if the site, as proposed meets the design goals of the system engineer. Such search rings are routinely issued by the engineering team and given to the site acquisition team so they know in what area to look. Such search rings are usually a part of a complete application package. The Applicant should provide a graphic representation of the search ring utilized for this site and if it did locate a site in an area that was more in line with the regular reuse grid why it rejected that site or could not utilize it with another site to result in a "two site" solution with structures that had less visual impact on the community.

As noted above, there has been no demonstration on the minimum height necessary to achieve the relief the Applicant seeks to fill in its purported gap in coverage. That said, there are issues associated with the antenna supporting structure and the antenna configuration, number of antennas and separation of co-located antennas.

## ANTENNA ARRAY CONFIGURATION

The Applicant proposes to construct a 170 foot monopole tower capable of supporting up to 4 separate carriers (the Applicant's antennas and 3 additional co-locators). It is notable that T-Mobile Northeast LLC chose not to participate in this application. With the pending acquisition of T-Mobile by AT&T Wireless and the combination of the two networks may reduce or eliminate the need for a separate antenna array at the site. Note that one of the "operating efficiencies" and "cost savings" that AT&T touts about its announced merger is the reduction of total number of tower sites required and a consolidation of existing sites.

The description of the Applicant's antenna system notes that it will consist of "up to twelve (12) panel antennas on a platform at 167 feet AGL." It goes on to note so as to maximize co-location opportunities the monopole tower will accommodate at least three additional carriers' antenna platforms. The vertical elevation drawing of the proposed monopole entitled "Tower Elevation" tends to support four (4) platforms, each platform containing 12 antennas, each platform separated by 10 feet. Such an antenna/platform is un-necessary and visually obtrusive.

Modern antenna design has substantially evolved since the first cellular installations of 25 years ago. In addition carriers now have more access to additional spectrum than they did 25 years ago. While it is not specified in the application materials (save an emissions statement) it would be safe to assume that the Applicant is proposing to install both its 850 MHz cellular system and its 1900 MHZ PCS system. In addition it is general knowledge that the Applicant has successfully acquired additional spectrum in the 700 MHz band. Notwithstanding its proposal to install up to 12 antennas on a platform at the proposed facility, there is no technical reason to do so.

There exist today, off the shelf, antennas that can transmit both the 850 MHz and 1900 MHz signals from a single antenna structure. These antennas encompass both sets of radiating elements in a single enclosure and in addition have the features of dual polarization cross polarization (so as to improve receive diversity) and individually adjustable beam tilt (beam steering) to fine tune system operation for each frequency band. An example of such an antenna would be the Powerwave P90-14-XLH-RR. As antennas such as the one noted have built in diversity, the need to space such antennas on a structure (either horizontally as on a platform or vertically on the pole itself) is not necessary. Interestingly enough, AT&T (the co-applicant here) has proposed the use of this antenna [six (6) antennas total] close mounted on a 1 foot diameter (top) monopole extension at 6 Mountain Road in Washington Ct. Furthermore each existing and proposed carrier on the monopole at 6 Mountain Road is close mounted to the monopole (no platforms or T-Arms). There is no evidence why such a less obtrusive installation technique could not be used here (if this application were approved).

Should the Applicant claim that its needs in Bridgewater include the use of the 700 MHz band and that fact would require more antennas, one need only to look at another antenna type, the CCS antenna FLG-X7CAP-465. This antenna operates not only in the 850 and 1900 Bands, but the 700 Band as well. Furthermore this antenna is specifically designed to operate within a fiberglass radome (such as is used in stealth concealment flag pole structures). This alternative antenna array type is feasible and would further ameliorate the visual impact of the monopole.

Notwithstanding that the Applicant has not demonstrated the minimum height necessary so as to fill in its purported gap in coverage, it has also failed to demonstrate why the proposed monopole has to be configured as shown in the Tower Elevation Drawing. The concept of vertically spacing competing carriers is one of convenience and not necessity. So as to minimize the work and or cost in fabricating monopole sections, it was decided that "ports" (areas where the transmission lines would exit the monopole to connect to the antennas) would be spaced every 10 feet. Such a convention allowed for mass produced sections without special order requirements. This decision was based on manufacturing needs as opposed to radio frequency technical needs. It is well known that antennas of competing carriers (either carriers operating on adjacent bands, i.e. 850 to 850 or other bands, i.e. 850 to 1900) can be located extremely close to each other without interference issues. In a paper published by Andrew Corporation, graphs representing the isolation between 850/850, 1900/1900 and 850/1900 systems are displayed with the measurement protocol. The results demonstrate that vertically separated antennas can achieve at least 53 dB of isolation with as little as 6 inch separation (head to tail) of antennas. Such an arrangement or requirement on the proposed pole could result in a significantly shorter structure, and be aware that the Applicant has **not** demonstrated the minimum height necessary for this structure, while still allowing sufficient space for co-locators.

All of the issues noted above with respect to the number of antennas required, the mounting of antennas, the separation of antennas, and the stealthing of antennas would result in an antenna structure with significantly less visual impact.

## 111 SECOND HILL APPLICATION

### RADIO FREQUENCY COVERAGE DEPICTION ANALYSIS

AT&T's coverage analysis for the proposed site is essentially similar to that submitted along with the Docket 412 application. Therefore most, if not all, of the deficiencies noted with respect to that application apply here. As a result of those deficiencies, it is once again impossible to determine the impact on the existing and proposed system that this installation would have. The proposed supporting structure is planned to be a 160 foot above ground level monopole. AT&T had previously identified an existing 110 foot above ground level Connecticut Department of Transportation tower at 96-110 Second Hill Road and considered utilizing it (with structure modifications). After consultation with local residents, the applicant proposed to place the monopole at the 111 Second Hill Road location.

A taller 170 or 180ft structure like the one at Wewaka should have been considered. AT&T has not supplied alternate propagation plots that would demonstrate the coverage of the proposed facility and if such a taller structure might have on the need for the Docket 412 site. Such a taller structure in conjunction with tuning and optimizing the site at Dinglebrook Lane (SR 1860) could result in a significantly reduced height at the Docket 412 site or, more importantly, no site at all. AT&T should be directed to present such alternate coverage plots (along with all of the coverage demonstration needs of the Docket 412 site previously noted). Such a presentation would be invaluable in determining need for the Docket 412 site.

### SYSTEM DESIGN

The issues raised with system design in the Docket 412 review appear to apply here except the fact that this site appears to be proposed in a location that meets with the regular reuse design criteria. This site location appears to be in an optimum location.

### ANTENNA ARRAY CONFIGURATION

Once again, all of the issues raised with respect to antenna array configuration, spacing and mounting in the Docket 412 review equally apply here and should be considered before this application is approved.

## FINAL CONSIDERATIONS OF BOTH APPLICTIONS

It is clear that both the applications affect one another. The facts that the sites are neighbor sites and within the same town dictate that one can not be considered with out consideration for the other.

An interesting aspect of the joint consideration of the applications is that the tower at Second Hill configured properly may obviate the need for Wewaka (Docket 412) while the opposite may not be true. A similar situation existed in Wesley Hills, New York, where I acted as an expert for the land use board. In that case, Verizon Wireless proposed a new monopole in an area that met with strong opposition from the community at large and the Village itself. Nearby the proposed site, but not a true alternate site because of distance to it (about the same distance as exists between the Docket 412 site and the 111 Second Hill Road site) an existing tower stood ready to support the Verizon Wireless antennas. In fact, Verizon Wireless proposed to locate at that very site in the "near"future, but wished to construct the Village site first. After a critical review of properly prepared coverage plots, along with drive tests, it was determined that the existing site just might meet the needs of Verizon Wireless. Interestingly, the engineer preparing the plots and coverage analysis in that application is the same one who appears to be doing such in these applications.

With the evidence of possible coverage from the existing site meeting the needs of Verizon Wireless, the land use board directed Verizon Wireless to construct antennas on the existing site first and then after drive or system test verification come back to the board for consideration of its first choice.

The situation here may very well dictate the same action. Should the 111 Second Hill site be constructed first (at a height determined necessary to provide the maximum coverage) the Applicant in the Docket 412 proceeding could then determine by drive or system test verification if indeed the Wewaka Road were needed, and if it were, at what reduced height to meet its needs. Such an order of approval would best serve the public interest and meet the non-proliferation of towers policy of the Siting Council.

Ronald E. Graiff, P.E.

# Spectrum Planning Report

# Investigation of Modified Hata Propagation Models

Spectrum Planning Team
Radiofrequency Planning Group
Australian Communications Authority

Document: SP 2/01
Date: April 2001

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## INTRODUCTION

The purpose of this paper is to review several modified Hata models. The different modified Hata models are compared against the Okumura field strength curves from which the original Hata model was derived. The models are compared for different frequencies, distances and base transmitter heights. The mobile antenna height in all cases was assumed to be 1.5m and the field strength values are calculated for a 1 kW ERP transmitter. A recommendation is made on which model most closely approximates the Okumura field strength curves.

## BACKGROUND

The original Hata model was published in 1980 by Masaharu Hata [1]. Hata took the information in the field strength curves produced by Yoshihisa Okumura [2] and produced a set of equations for path loss. Okumura carried out a number of propagation studies in and around Tokyo City and produced a set of curves of field strength against distance.

Two of the limitations of the Hata model are that it has a limited path length and a limited frequency range. A number of modified models have been produced to extend the path length and frequency range. These modified models vary slightly from each other and some of these models more closely match the Okumura curves than others do.

## EMPIRICAL HATA MODEL

The Hata empirical model uses a propagation equation split up into two terms, a term that has a logarithmic dependence on distance and a term that is independent of distance. The Hata model also includes adjustments to the basic equation to account for Urban, Suburban and Open area propagation losses. For more detail see reference [1]. The variables are described in the attachments at the end of this report.

The Hata equation for propagation loss in an urban area is given by:

$$L_p = 69.55 + 26.16\log(f) - 13.82\log(h_b) - a(h_m) + (44.9 - 6.55\log(h_b)) * \log(d)$$

Where, in the case of propagation loss in a medium to small city:

$$a(h_m) = (1.1\log(f) - 0.7) * h_m - (1.56\log(f) - 0.8)$$

The adjustment for propagation loss in a suburban area is:

$$L_{ps} = L_p(urban\ area) - 2 * (\log(f/28))^2 - 5.4$$

The adjustment for propagation loss in an open area is:

$$L_{po} = L_p(urban\,area) - 4.78(\log(f))^2 + 18.33\log(f) - 40.94$$

The model is suitable for use over the ranges:

Frequency range 150 – 1500 MHz
Base station height 30 – 200 m
Mobile height 1 – 10 m
Distance range 1 – 20 km

Figure 1 in the Attachments compares the field strength curves generated by the Hata model against the Okumura field strength curves for urban areas. At distances below 30 km the Hata curves compare very well, to within ±1dB of the Okumura curves. At distance above 30 km the Okumura curves drop below the Hata curves. At 100 km the difference varies from 7 dB to 15 dB.

## MODIFIED MODELS

The modified Hata models were produced to improve on the range limitation that the original Hata model had. The first modified model appeared in a CCIR report [6] in an attempt to extend the Hata model to cover greater distance.

An ambiguous equation in the CCIR report lead to an uncertain interpretation. In particular as to how the distance term was raised. There was uncertainty about whether the power term includes the whole log term or just the distance term. The equation in the CCIR report was written as shown below.

$$E = 69.82 - 6.16 \log f + 13.82 \log h_b + a(h_m) - (44.9 - 6.55 \log h_b) * \log d^{\,b}$$

Some later models included just the distance term raised to the power b and some included the whole log distance term raised to the power b. In general the original equation was kept with new terms added to extend the distance range. To aid comparison with the original Okumura curves all models have been converted to calculate field strength from a 1 kW ERP transmitter. Some of the modified models have been published in this form and there is some small variation in some of the constants in the different models due to rounding errors.

Three models that were compared are the ITU-R P.529-2 [4], ITU-R P.529-3 [5] and the model used in the ERC Report 68 [3].

**ITU-R P.529-2**

The equation in this model has the distance term only, raised to the power $b$. The equation is stated as:

$$E = 65.55 - 6.16\log(f) + 13.82\log(h_b) + a(h_m) - (44.9 - 6.55\log(h_b)) * \log(d^b)$$

Where:

$$a(h_m) = (1.1\log(f) - 0.7) * h_m - (1.56\log(f) - 0.8)$$

$b = 1$ for $d <= 20$ km
$b = 1 + (0.14 + 1.87 * 10^{-4} * f + 1.07 * 10^{-3} * h_b) * (\log(d/20))^{0.8}$ if $d > 20$ km

These equations are meant to be extensions of the original Hata equation. When the distance is less than 20 km, which is in the useable range of the original Hata equation, the modified equation should equal the original equation. This equation does not equal the original equation for a distance of less than 20 km. The first constant 65.55 should have been 69.82.

This model claims to be suitable for use over the ranges:

Frequency range 150 – 1500 MHz
Base station height 30 – 200 m
Mobile height 1 – 10 m
Distance range 1 – 100 km

**ITU-R P.529-3**

The equation in this model has the whole log distance term raised to the power $b$. It also includes a modification to the base height term. This equation does equate to the original Hata equation for distances less than 20km. The equation is:

$$E = 69.82 - 6.16\log(f) + 13.82\log(h_b) + a(h_m) - (44.9 - 6.55\log(h_b)) * (\log(d))^b$$

Where:

$$a(h_m) = (1.1\log(f) - 0.7) * h_m - (1.56\log(f) - 0.8)$$

$b = 1$ for $d <= 20$ km
$b = 1 + (0.14 + 1.87 * 10^{-4} * f + 1.07 * 10^{-3} * h'_b) * (\log(d/20))^{0.8}$ if $d > 20$ km

Where:

$$h'_b = h_b / (1 + 7 * 10^{-6} * h_b^2)^{½}$$

This model is suitable for use over the ranges:

Frequency range 150 – 1500 MHz
Base station height 30 – 200 m
Mobile height 1 – 10 m
Distance range1 – 100 km

**ERC REPORT 68**

In this model, there are a number of equations for different frequency ranges. The equation discussed here covers the same frequency range as the original Hata equation. This equation has only the distance term raised to the power $b$. This equation equates approximately to the original Hata equation for distances less than 20km. The first constant is equal to 69.75 instead of 69.82. The equation is:

$$E = 69.75 - 6.16\log(f) + 13.82\log(h_b) + \alpha*(44.9 - 6.55\log(h_b))*(\log(d)) + a(h_m) + b(h_b)$$

Where

$\alpha = 1$ if $d <= 20$ km
$\alpha = 1 + (0.14 + 1.87*10^{-4}*f + 1.07*10^{-3}*h_m)*(\log(d/20))^{0.8}$ if d > 20 km

$$a(h_m) = (1.1\log(f) - 0.7)*\text{ minimum}(10, h_m) - (1.56\log(f) - 0.8) + \text{maximum}(0, 20\log(h_m/20))$$

$$b(h_b) = \text{ minimum}(0, 20\log(h_b/30))$$

This model is suitable for use over the ranges:

Frequency range 150 – 1500 MHz
Base station height 1 – 200 m
Mobile height 1 – 200 m
Distance range 1 – 100 km

## COMPARISON OF MODIFIED MODELS

It is obvious that the ITU-R P.529-2 model is incorrect and can be removed from further consideration.

In the attachments, Figures 2 to 5 compare the results of the ITU-R P.529-3 and the ERC68 models against the Okumura curves. These models give similar results at low frequencies but at high frequencies the ERC68 model starts to drop well below Okumura's curves. At lower frequencies in some cases the ERC68 model comes closer to the Okumura curve than the ITU-R P.529-3 model. Overall though, the ITU-R P.529-3 model is a better match to the Okumura data than the ERC68 model.

The field strength values for the model with the $\log(d^b)$ term are very close to the field strength values for the model with the $(\log(d))^b$ term even thought the two terms are different. This is due to the $b$ term only ranging from 1 to 1.5 approximately.

## RECOMMENDATIONS

The comparison suggests that the ITU-R P.529-3 model is the most suitable for general use. At frequencies up to about 500 MHz and for distances larger than 60 km the ERC68 model more closely matches the Okumura curves and may be preferred. The ERC68 model tends to predict field strength values below the Okumura curves where as the ITU-R P.529-3 model tends to predict field strength values above the Okumura curves. For frequencies above 500 MHz the ERC68 model predicts emission levels well short of the Okumura curves so the ITU-R P.529-3 model would be preferred in this case.

## BIBLIOGRAPHY


[1] M. Hata, *Empirical Formula for Propagation Loss in Land Mobile Radio Services*, IEEE Transactions on Vehicular Technology, Vol. VT-29, no. 3, August 1980.

[2] Y. Okumura et al., *Field Strength and Its Variability in VHF and UHF Land-Mobile Radio Service*, Review of the Electrical Communications Laboratory, Vol. 16, no. 9-10, September-October 1968.

[3] ERC Report 68, *Monte Carlo Radio Simulation Methodology*, Naples, February 2000.

[4] Recommendation ITU-R P.529-2, *Prediction Methods for the Terrestrial Land Mobile Service in the VHF and UHF Bands*, 1995.

[5] Recommendation ITU-R P.529-3, *Prediction Methods for the Terrestrial Land Mobile Service in the VHF and UHF Bands*, 1999.

[6] CCIR Report, 1986-1990

# ATTACHMENTS

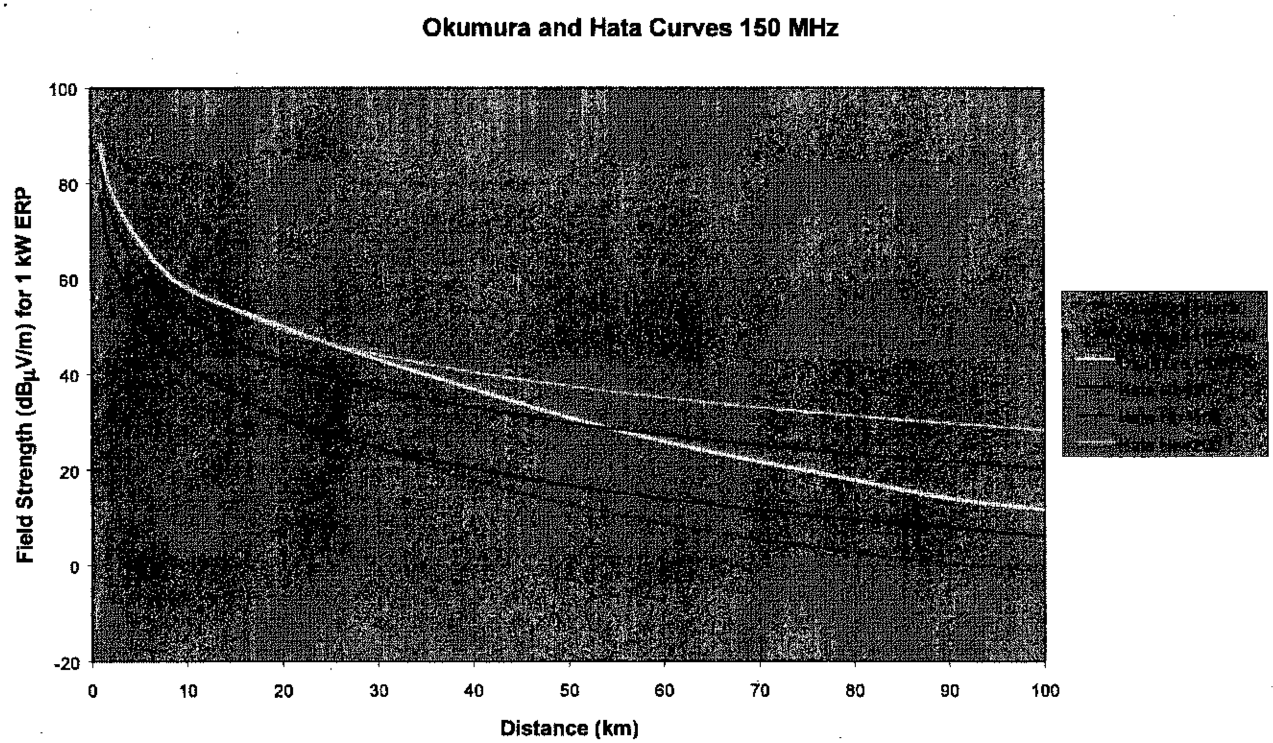


**Figure 1 Compares the Hata Model Field Strength Curves Against the Okumura Field Strength Curves for urban areas**

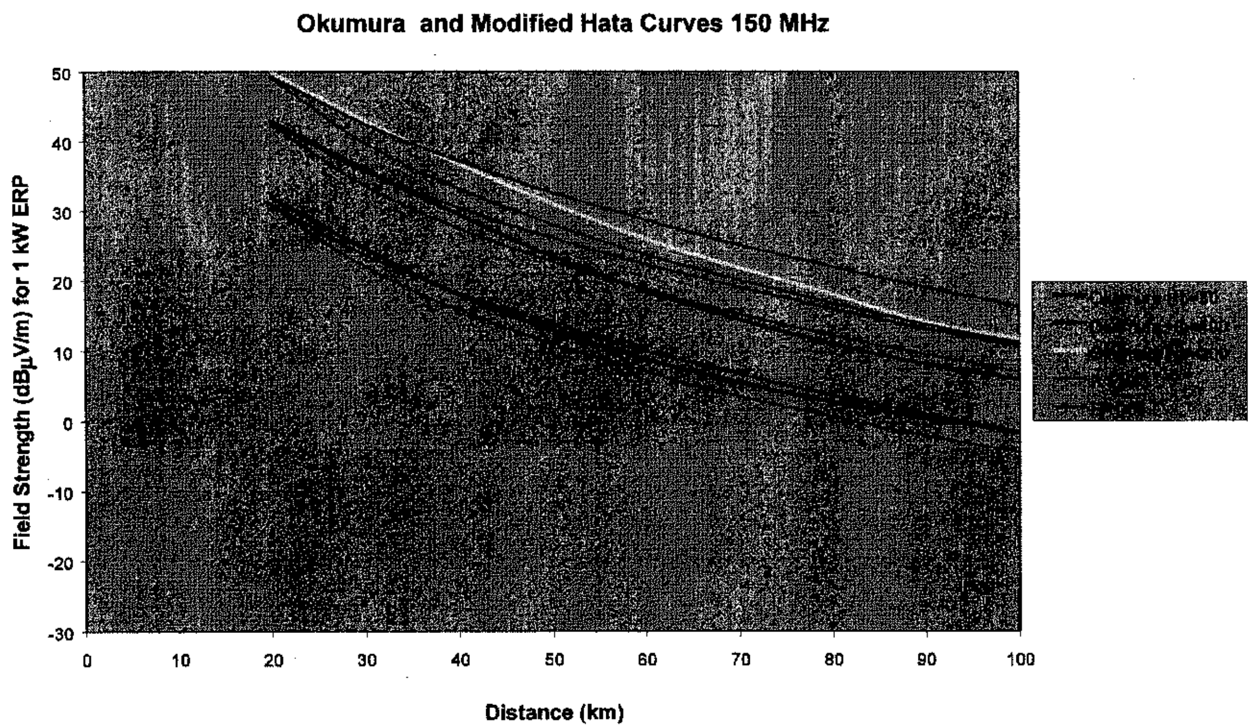


**Figure 2 Compares Modified Hata Models from ITU-R P.529-3 and ERC68 Field Strength Curves Against the Okumura Field Strength Curves.**

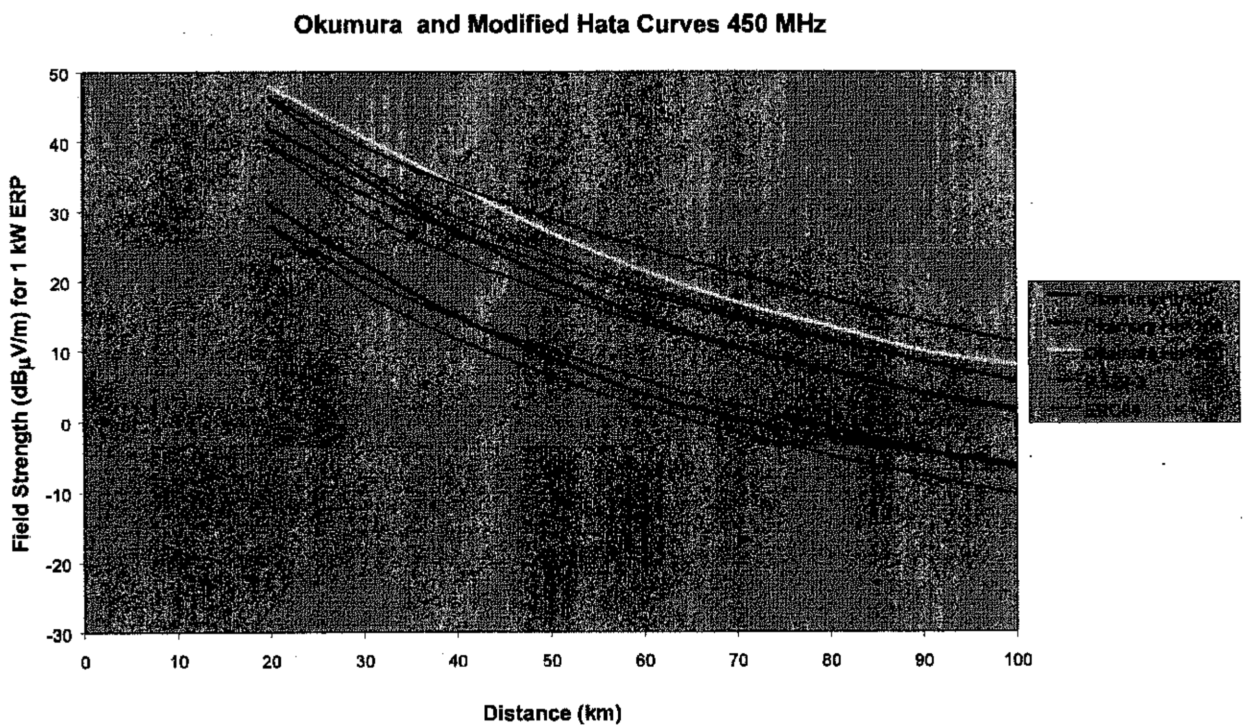


**Figure 3 Compares Modified Hata Models from ITU-R P.529-3 and ERC68 Field Strength Curves Against the Okumura Field Strength Curves.**

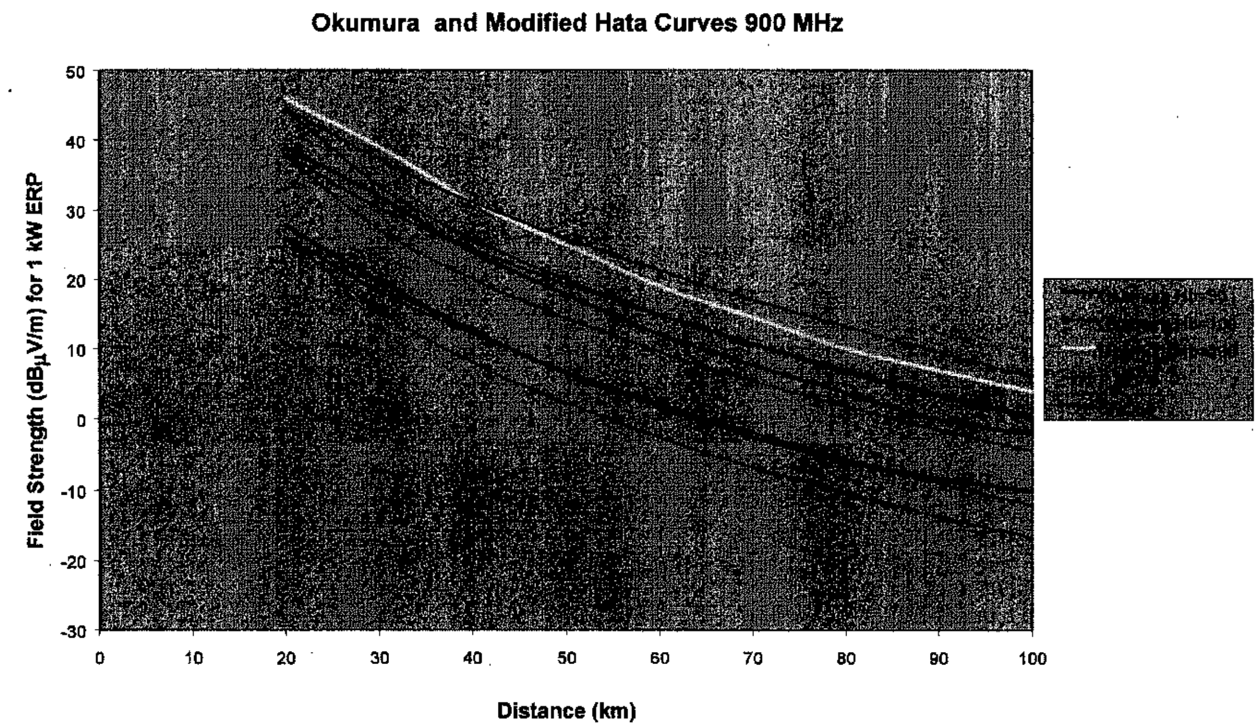


**Figure 4 Compares Modified Hata Models from ITU-R P.529-3 and ERC68 Field Strength Curves Against the Okumura Field Strength Curves.**

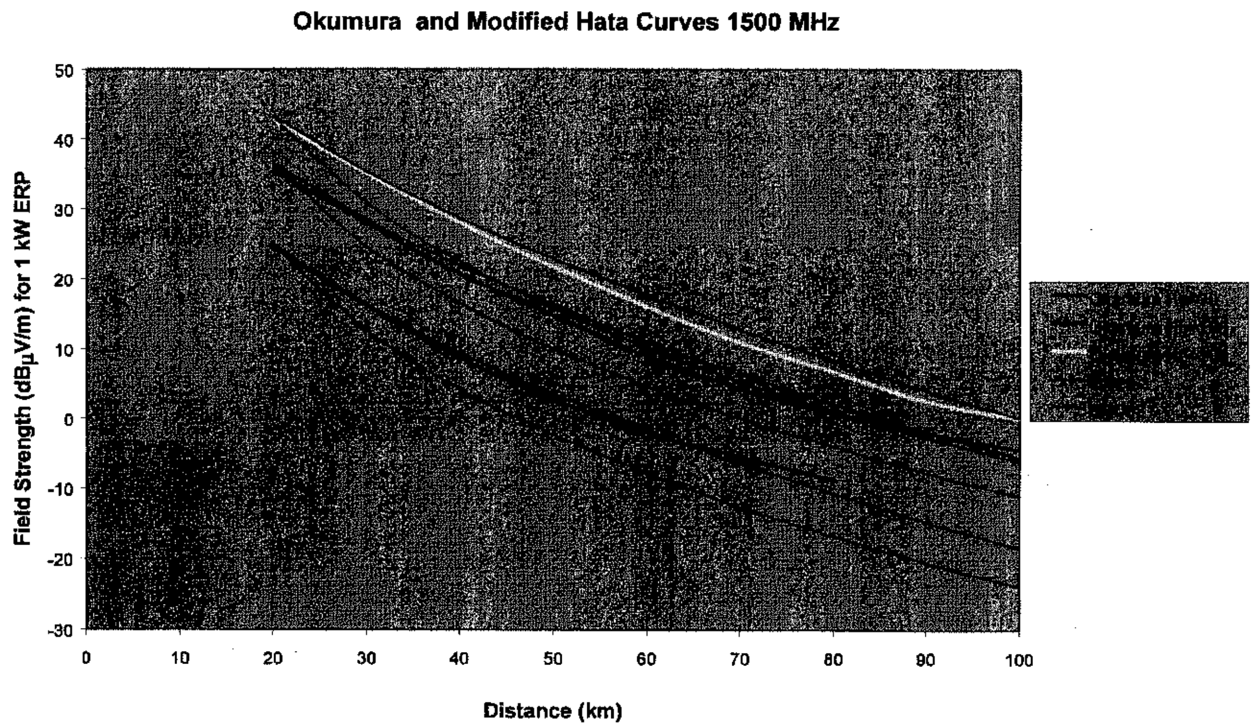


**Figure 5 Compares Modified Hata Models from ITU-R P.529-3 and ERC68 Field Strength Curves Against the Okumura Field Strength Curves.**

**Converting propagation loss to field strength at the receiver**

The original Hata equation is given in terms of a loss in dB. The Okumura curve and some modified Hata models are given in field strengths (dB (µV/m)). We need to convert the Hata equation into field strength so the different equations can be easily compared.

Original Hata equation

$$L_p = 69.55 + 26.16\log f - 13.82\log h_b - a(h_m) + (44.9 - 6.66\log h_b)\log d \quad \text{(dB)} \qquad (1)$$

The relationship between power received by an isotropic antenna and field strength at the receiving site.

$$P_r = \left(\frac{\lambda}{4\pi}\right)^2 \frac{E^2}{30} \qquad \text{W (EIRP)} \qquad (2)$$

$$P_r = \left(\frac{c}{4\pi f_{hz}}\right)^2 \frac{E^2}{30} \qquad (3)$$

Converting from a linear equation to logarithmic and with $f$ in MHz:

$$P_r = 169.537 - 120 - 21.984 - 20\log f + E - 14.771 \qquad \text{dBW (EIRP)} \qquad (4)$$

Adding all the constants together:

$$P_r = E - 20\log f + 12.782 \qquad (5)$$

The power received is also equal to the power transmitted $P_t$ minus the propagation loss $L_p$ as shown:

$$P_r = P_t - L_p \qquad (6)$$

Using equation 5 and 6 we can calculate an equation that shows the relationship between loss and field strength depending on the power transmitted.

$$E = P_t + 20\log f - 12.782 - L_p \qquad \text{dB(V/m)} \qquad (7)$$

All field strengths were measured with respect to a 1 kW ERP transmitter, which is equal to a 1.637 kW EIRP transmitter. Setting $P_t$ equal to 32.15 dB equation 7 becomes:

$$E = 19.37 + 20\log f - L_p \qquad \text{dB(V/m)} \qquad (8)$$

To convert dB(V/m) to dB(μV/m) 120 dB is added and equation 8 becomes:

$$E = 139.37 + 20\log f - L_p \qquad \text{dB}(\mu\text{V/m}) \qquad (9)$$

Replacing $L_p$ by the Hata equation for propagation loss equation 9 becomes:

$$E = 69.82 - 6.16\log f + 13.82\log h_b + a(h_m) - (44.9 - 6.66\log h_b)\log d \qquad \text{dB}(\mu\text{V/m})$$

**Variables**

| | |
|---|---|
| $L_p$ | Propagation loss in an urban area in a small to medium city in dB |
| $L_{ps}$ | Propagation loss in a suburban area in dB |
| $L_{po}$ | Propagation loss in an open area in dB |
| $E$ | The field strength at a distance from a 1 kW ERP transmitter in dBμV/m |
| $f$ | The frequency of the transmission in MHz |
| $h_b$ | The height of the base station or transmitter in metres |
| $h_m$ | The height of the mobile or receiver in metres |
| $d$ | The distance between the receiver and transmitter in kilometres |

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GLOBAL SYSTEM FOR
MOBILE COMMUNICATIONS

# Digital cellular telecommunications system; Radio network planning aspects (GSM 03.30 version 5.0.0)

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## Foreword

This ETSI Technical Report (ETR) has been produced by the Special Mobile Group (SMG) Technical Committee (TC) of the European Telecommunications Standards Institute (ETSI).

This ETR Describes the radio network planning aspects within the digital cellular telecommunications system.

This ETR is an informative document resulting from SMG studies which are related to the Digital cellular telecommunications system (Phase 2). This ETR is used to publish material which is of an informative nature, relating to the use or the application of ETSs and is not suitable for formal adoption as an ETS.

The specification from which this ETR has been derived was originally based on CEPT documentation, hence the presentation of this ETR may not be entirely in accordance with the ETSI/PNE rules.

Reference is made within this ETR to GSM Technical Specifications (GSM-TS) (NOTE).

NOTE: TC-SMG has produced documents which give the technical specifications for the implementation of the Digital cellular telecommunications system. Historically, these documents have been identified as GSM Technical Specifications (GSM-TS). These TSs may have subsequently become I-ETSs (Phase 1), or ETSs (Phase 2), whilst others may become ETSI Technical Reports (ETRs). GSM-TSs are, for editorial reasons, still referred to in current GSM ETSs.

# 1 Scope

This ETSI Technical Report (ETR) is a descriptive recommendation to be helpful in cell planning.

## 1.1 References

This ETR incorporates by dated and undated reference, provisions from other publications. These normative references are cited at the appropriate places in the text and the publications are listed hereafter. For dated references, subsequent amendments to or revisions of any of these publications apply to this ETR only when incorporated in it by amendment or revision. For undated references, the latest edition of the publication referred to applies.

[1] GSM 01.04 (ETR 350): "Digital cellular telecommunications system (Phase 2+); Abbreviations and acronyms".

[2] GSM 05.02 (ETS 300 908): "Digital cellular telecommunications system (Phase 2+); Multiplexing and multiple access on the radio path".

[3] GSM 05.05 (ETS 300 910): "Digital cellular telecommunications system (Phase 2+); Radio transmission and reception".

[4] GSM 05.08 (ETS 300 911): "Digital cellular telecommunications system (Phase 2+); Radio subsystem link control".

[5] CCIR Recommendation 370-5: "VHF and UHF propagation curves for the frequency range from 30 MHz to 1000 MHz".

[6] CCIR Report 567-3: "Methods and statistics for estimating field strength values in the land mobile services using the frequency range 30 MHz to 1 GHz".

[7] CCIR Report 842: "Spectrum-conserving terrestrial frequency assignments for given frequency-distance seperations".

[8] CCIR Report 740: "General aspects of cellular systems".

## 1.2 Abbreviations

Abbreviations used in this ETR are given clause 6 (Glossary) and in GSM 01.04 [1].

# 2 Traffic distributions

## 2.1 Uniform

A uniform traffic distribution can be considered to start with in large cells as an average over the cell area, especially in the country side.

## 2.2 Non-uniform

A non-uniform traffic distribution is the usual case, especially for urban areas. The traffic peak is usually in the city centre with local peaks in the suburban centres and motorway junctions.

A bell-shaped area traffic distribution is a good traffic density macro model for cities like London and Stockholm. The exponential decay constant is on average 15 km and 7,5 km respectively. However, the exponent varies in different directions depending on how the city is built up. Increasing handheld traffic will sharpen the peak.

Line coverage along communication routes as motorways and streets is a good micro model for car mobile traffic. For a maturing system an efficient way to increase capacity and quality is to build cells especially for covering these line concentrations with the old area covering cells working as umbrella cells.

Point coverage of shopping centres and traffic terminals is a good micro model for personal handheld traffic. For a maturing system an efficient way to increase capacity and quality is to build cells on these points as a complement to the old umbrella cells and the new line covering cells for car mobile traffic.

# 3 Cell coverage

## 3.1 Location probability

Location probability is a quality criterion for cell coverage. Due to shadowing and fading a cell edge is defined by adding margins so that the minimum service quality is fulfilled with a certain probability.

For car mobile traffic a usual measure is 90 % area coverage per cell, taking into account the minimum signal-to-noise ratio Ec/No under multipath fading conditions. For lognormal shadowing an area coverage can be translated into a location probability on cell edge (Jakes, 1974).

For the normal case of urban propagation with a standard deviation of 7 dB and a distance exponential of 3.5, 90 % area coverage corresponds to about 75 % location probability at the cell edge. Furthermore, the lognormal shadow margin in this case will be 5 dB, as described in CEPT Recommendation T/R 25-03 and CCIR Report 740.

## 3.2 Ec/No threshold

The mobile radio channel is characterized by wideband multipath propagation effects such as delay spread and Doppler shift as defined in GSM 05.05 annex C. The reference signal-to-noise ratio in the modulating bit rate bandwidth (271 kHz) is Ec/No = 8 dB including 2 dB implementation margin for the GSM system at the minimum service quality without interference. The Ec/No quality threshold is different for various logical channels and propagation conditions as described in GSM 05.05.

## 3.3 RF-budgets

The RF-link between a Base Transceiver Station (BTS) and a Mobile Station (MS) including handheld is best described by an RF-budget as in annex A which consists of 4 such budgets; A.1 for GSM 900 MS class 4; A.2 for GSM 900 MS class 2, A.3 for DCS 1800 MS classes 1 and 2, and A.4 for GSM 900 class 4 in small cells.

The antenna gain for the hand portable unit can be set to 0 dBi due to loss in the human body as described in CCIR Report 567. An explicit body loss factor is incorporated in annex A.3

At 900 MHz, the indoor loss is the field strength decrease when moving into a house on the bottom floor on 1.5 m height from the street. The indoor loss near windows ( < 1 m) is typically 12 dB. However, the building loss has been measured by the Finnish PTT to vary between 37 dB and -8 dB with an average of 18 dB taken over all floors and buildings (Kajamaa, 1985). See also CCIR Report 567.

At 1800 MHz, the indoor loss for large concrete buildings was reported in COST 231 TD(90)117 and values in the range 12 - 17 dB were measured. Since these buildings are typical of urban areas a value of 15 dB is assumed in annex A.3. In rural areas the buildings tend to be smaller and a 10 dB indoor loss is assumed.

The isotropic power is defined as the RMS value at the terminal of an antenna with 0 dBi gain. A quarter-wave monopole mounted on a suitable earth-plane (car roof) without losses has antenna gain 2 dBi. An isotropic power of -113 dBm corresponds to a field strength of 23.5 dBuV/m for 925 MHz and 29.3 dBuV/m at 1795 MHz, see CEPT Recommendation T/R 25-03 and GSM 05.05 section 5 for formulas. GSM900 BTS can be connected to the same feeders and antennas as analog 900 MHz BTS by diplexers with less than 0.5 dB loss.

## 3.4 Cell ranges

### 3.4.1 Large cells

In large cells the base station antenna is installed above the maximum height of the surrounding roof tops; the path loss is determined mainly by diffraction and scattering at roof tops in the vicinity of the mobile i.e. the main rays propagate above the roof tops; the cell radius is minimally 1 km and normally exceeds 3 km. Hata's model and its extension up to 2000 MHz (COST 231-Hata model) can be used to calculate the path loss in such cells (see COST 231 TD (90) 119 Rev 2 and annex B).

The field strength on 1.5 m reference height outdoor for MS including handheld is a value which inserted in the curves of CCIR Report 567-3 Figure 2 (Okumura) together with the BTS antenna height and effective radiated power (ERP) yields the range and re-use distance for urban areas (section 5.2).

The cell range can also be calculated by putting the maximum allowed path loss between isotropic antennas into the Figures 1 to 3 of annex C. The same path loss can be found in the RF-budgets in annex A. The figures 1 and 2 (GSM 900) in annex C are based on Hata's propagation model which fits Okumura's experimental curves up to 1500 MHz and figure 3 (DCS 1800) is based on COST 231-Hata model according to COST 231 TD (90) 119 Rev 2.

The example RF-budget shown in annex A.1 for a GSM900 MS handheld output power 2 W yields about double the range outdoors compared with indoors. This means that if the cells are dimensioned for handhelds with indoor loss 10 dB, the outdoor coverage for MS will be interference limited, see section 4.2. Still more extreme coverage can be found over open flat land of 12 km as compared with 3 km in urban areas outdoor to the same cell site.

For GSM 900 the Max EIRP of 50 W matches MS class 2 of max peak output power 8 W, see annex A.2.

An example RF budget for DCS 1800 is shown in annex A.3. Range predictions are given for 1 W and 250 mW DCS 1800 MS with BTS powers which balance the up- and down- links.

The propagation assumptions used in annex A1, A2, A3 are shown in the tables below :

For GSM 900 :

| | **Rural (Open Area)** | **Rural (Quasi-open)** | **Urban** |
|---|---|---|---|
| Base station height (m) | 100 | 100 | 50 |
| Mobile height (m) | 1.5 | 1.5 | 1.5 |
| Hata's loss formula (d in km) | 90.7+31.8log(d) | 95.7+31.8log(d) | 123.3+33.7log(d) |
| Indoor Loss (dB) | 10 | 10 | 15 |

For DCS 1800 :

| | **Rural (Open Area)** | **Rural (Quasi-Open)** | **Urban (*)** |
|---|---|---|---|
| Base station height (m) | 60 | 60 | 50 |
| Mobile height (m) | 1.5 | 1.5 | 1.5 |
| COST 231 Hata's loss formula (d in km) | 100.1+33.3log(d) | 105.1+33.3log(d) | 133.2+33.8log (d) |
| Indoor Loss (dB) | 10 | 10 | 15 |

(*) medium sized city and suburban centres (see COST 231 TD (90) 119 Rev2). For metropolitan centres add 3 dB to the path loss.

NOTE 1: The rural (Open Area) model is useful for desert areas and the rural (Quasi-Open) for countryside.

NOTE 2: The correction factors for Quasi-open and Open areas are applicable in the frequency range 100-2000 MHz (Okumura,1968).

### 3.4.2 Small cells

For small cell coverage the antenna is sited above the median but below the maximum height of the surrounding roof tops and so therefore the path loss is determined by the same mechanisms as stated in section 3.4.1. However large and small cells differ in terms of maximum range and for small cells the maximum range is typically less than 1-3 km. In the case of small cells with a radius of less than 1 km the Hata model cannot be used.

The COST 231-Walfish-Ikegami model (see annex B) gives the best approximation to the path loss experienced when small cells with a radius of less than 5 km are implemented in urban environments. It can therefore be used to estimate the BTS ERP required in order to provide a particular cell radius (typically in the range 200 m - 3 km).

The cell radius can be calculated by putting the maximum allowed path loss between the isotropic antennas into figure 4 of annex C.

The following parameters have been used to derive figure 4 :

Width of the road, w = 20 m
Height of building roof tops, Hroof = 15 m
Height of base station antenna, Hb = 17 m
Height of mobile station antenna, Hm = 1.5 m
Road orientation to direct radio path, Phi = 90°
Building separation, b = 40 m

For GSM 900 the corresponding propagation loss is given by :

Loss (dB) = 132.8 + 38log(d/km)

For DCS 1800 the corresponding propagation loss is given by :

Loss (dB) = 142,9 + 38log(d/km) for medium sized cities and suburban centres
Loss (dB) = 145,3 + 38log(d/km) for metropolitan centres

An example of RF budget for a GSM 900 Class 4 MS in a small cell is shown in annex A.4.

### 3.4.3 Microcells

COST 231 defines a microcell as being a cell in which the base station antenna is mounted generally below roof top level. Wave propagation is determined by diffraction and scattering around buildings i.e. the main rays propagate in street canyons. COST 231 proposes the following experimental model for microcell propagation when a free line of sight exists in a street canyon :

Path loss in dB (GSM 900) = 101,7 + 26log(d/km) d > 20 m
Path loss in dB (DCS 1800) = 107,7 + 26log(d/km) d > 20 m

The propagation loss in microcells increases sharply as the receiver moves out of line of sight, for example, around a street corner. This can be taken into account by adding 20 dB to the propagation loss per corner, up to two or three corners (the propagation being more of a guided type in this case). Beyond, the complete COST231-Walfish-Ikegami model as presented in annex B should be used.

Microcells have a radius in the region of 200 to 300 metres and therefore exhibit different usage patterns from large and small cells. They can be supported by generally smaller and cheaper BTS's. Since there will be many different microcell environments, a number of microcell BTS classes are defined in GSM 05.05. This allows the most appropriate microcell BTS to be chosen based upon the Minimum Coupling Loss expected between MS and the microcell BTS. The MCL dictates the close proximity working in a microcell environment and depends on the relative BTS/MS antenna heights, gains and the positioning of the BTS antenna.

In order to aid cell planning, the micro-BTS class for a particular installation should be chosen by matching the measured or predicted MCL at the chosen site with the following table.

The microcell specifications have been based on a frequency spacing of 6 MHz between the microcell channels and the channels used by any other cell in the vicinity. However, for smaller frequency spacings (down to 1.8 MHz) a larger MCL must be maintained in order to guarantee successful close proximity operation. This is due to an increase in wideband noise and a decrease in the MS blocking requirement from mobiles closer to the carrier.

| Micro-BTS class | Recommended MCL (GSM 900) | | Recommended MCL (DCS 1800) | |
|---|---|---|---|---|
| | Normal | Small freq. spacing | Normal | Small freq. spacing |
| M1 | 60 | 64 | 60 | 68 |
| M2 | 55 | 59 | 55 | 63 |
| M3 | 50 | 54 | 50 | 58 |

Operators should note that when using the smaller frequency spacing and hence larger MCL the blocking and wideband noise performance of the micro-BTS will be better than necessary.

Operators should exercise caution in choosing the microcell BTS class and transmit power. If they depart from the recommended parameters in 05.05 they risk compromising the performance of the networks operating in the same frequency band and same geographical area.

# 4 Channel re-use

## 4.1 C/Ic threshold

The C/Ic threshold is the minimum co-channel carrier-to-interference ratio in the active part of the timeslot at the minimum service quality when interference limited. The reference threshold C/Ic = 9 dB includes 2 dB implementation margin on the simulated residual BER threshold The threshold quality varies with logical channels and propagation conditions, see GSM 05.05.

## 4.2 Trade-off between Ec/No and C/Ic

For planning large cells the service range can be noise limited as defined by Ec/No plus a degradation margin of 3 dB protected by 3 dB increase of C/Ic, see annex A.

For planning small cells it can be more feasible to increase Ec/No by 6 dB corresponding to an increase of C/Ic by 1 dB to cover shadowed areas better. C/(I+N) = 9 dB represents the GSM limit performance.

To permit handheld coverage with 10 dB indoor loss, the Ec/No has to be increased by 10 dB outdoors corresponding to a negligible increase of C/Ic outdoors permitting about the same interference limited coverage for MS including handhelds. The range outdoors can also be noise limited like the range indoors as shown in section 3.4 and annex A.1.

## 4.3 Adjacent channel suppressions

Adjacent channel suppression (ACS) is the gain (Ia/Ic) in C/I when wanted and unwanted GSM RF-signals co-exist on adjacent RF channels whilst maintaining the same quality as in the co-channel case, i.e. ACS = C/Ic - C/Ia. Taking into account frequency errors and fading conditions in the product of spectrum and filter of wanted and unwanted GSM RF-signals, ACS = 18 dB is typical as can be found in GSM 05.05.

1st ACS >= 18 dB, i.e. C/Ia1 <= -9 dB for C/Ic = 9 dB in GSM 05.05, imposes constraints of excluding the 1st adjacent channel in the same cell. However, the 1st adjacent channel can be used in the 1st adjacent cell, as C/Ic <= 12 dB and ACS >= 18 dB gives an acceptable handover- margin of >= 6 dB for signalling back to the old BTS as shown in GSM 05.08. An exception might be adjacent cells using the same site due to uplink interference risks.

2nd ACS >= 50 dB, i.e. C/Ia2 <= -41 dB for C/Ic = 9 dB in GSM 05.05, implies that due to MS power control in the uplink, as well as intra-cell handover, it is possible that the 2nd adjacent channel can be used in the same cell. Switching transients are not interfering due to synchronized transmission and reception of bursts at co-located BTS.

## 4.4 Antenna patterns

Antenna patterns including surrounding masts, buildings, and terrain measured on ca 1 km distance will always look directional, even if the original antenna was non-directional. In order to achieve a front-to-back ratio F/B of greater than 20 dB from an antenna with an ideal F/B > 25 dB, backscattering from the main lobe must be suppressed by using an antenna height of at least 10 m above forward obstacles in ca 0.5 km. In order to achieve an omni-directional pattern with as few nulls as possible, the ideal non-directional antenna must be isolated from the mast by a suitable reflector. The nulls from mast scattering are usually in different angles for the duplex frequencies and should be avoided because of creating path loss imbalance.

The main lobe antenna gains are typically 12-18 dBi for BTS, and 2-5 dBi for MS. Note that a dipole has the gain 0 dBd = 2 dBi.

## 4.5 Antenna heights

The height gain under Rayleigh fading conditions is approximately 6 dB by doubling the BTS antenna height. The same height gain for MS and handheld from reference height 1.5 m to 10 m is about 9 dB, which is the correction needed for using CCIR Recommendation 370.

## 4.6 Path loss balance

Path loss balance on uplink and downlink is important for two-way communication near the cell edge. Speech as well as data transmission is dimensioned for equal quality in both directions. Balance is only achieved for a certain power class (section 3.4).

Path loss imbalance is taken care of in cell selection in idle mode and in the handover decision algorithms as found in GSM 05.08. However, a cell dimensioned for 8 W MS (GSM 900 class 2) can more or less gain balance for 2 W MS handheld (GSM 900 class 4) by implementing antenna diversity reception on the BTS.

## 4.7 Cell dimensioning

Cell dimensioning for uniform traffic distribution is optimized by at any time using the same number of channels and the same coverage area per cell.

Cell dimensioning for non-uniform traffic distribution is optimized by at any time using the same number of channels but changing the cell coverage area so that the traffic carried per cell is kept constant with the traffic density. Keeping the path loss balance by directional antennas pointing outwards from the traffic peaks the effective radiated power (ERP) per BTS can be increased rapidly out-wards. In order to make the inner cells really small the height gain can be decreased and the antenna gain can be made smaller or even negative in dB by increasing the feeder loss but keeping the antenna front-to-back ratio constant (section 4.4).

## 4.8 Channel allocation

Channel allocation is normally made on an FDMA basis. However, in synchronized networks channel allocation can be made on a TDMA basis. Note that a BCCH RF channel must always be fully allocated to one cell.

Channel allocation for uniform traffic distribution preferably follows one of the well known re-use clusters depending on C/I-distribution, e.g. a 9-cell cluster (3-cell 3-site repeat pattern) using 9 RF channel groups or cell allocations (CAs), (Stjernvall, 1985).

Channel allocation for non-uniform traffic distribution preferably follows a vortex from a BTS concentration on the traffic centre, if a bell-shaped area traffic model holds. In real life the traffic distribution is more complicated with also line and point traffic. In this case the cell areas will be rather different for various BTS locations from city centre. The channel allocation can be optimized by using graph colouring heuristics as described in CCIR Report 842.

Base transceiver station identity code (BSIC) allocation is done so that maximum re-use distance per carrier is achieved in order to exclude co-channel ambiguity.

Frequency co-ordination between countries is a matter of negotiations between countries as described in CEPT Recommendation T/R 25-04. Co-channel and 200 kHz adjacent channels need to be considered between PLMNs and other services as stated in GSM 05.05.

Frequency sharing between GSM countries is regulated in CEPT Recommendation T/R 20-08 concerning frequency planning and frequency co-ordination for the GSM service.

### 4.9 Frequency hopping

Frequency hopping (FH) can easily be implemented if the re-use is based on RF channel groups (CAs). It is also possible to change allocation by demand as described in GSM 05.02.

In synchronized networks the synchronization bursts (SB) on the BCCH will occur at the same time on different BTS. This will increase the time to decode the BSIC of adjacent BTS, see GSM 05.08. The SACCH on the TCH or SDCCH will also occur at the same time on different BTS. This will decrease the advantage of discontinuous transmission (DTX). In order to avoid this an offset in the time base (FN) between BTS may be used.

If channel allocation is made on a TDMA basis and frequency hopping is used, the same hop sequence must be used on all BTS. Therefore the same time base and the same hopping sequence number (HSN) shall be used.

### 4.10 Cells with extra long propagation delay

Cells with anticipated traffic with ranges more than 35 km corresponding to maximum MS timing advance can work properly if the timeslot after the CCCH and the timeslot after the allocated timeslot are not used by the BTS corresponding to a maximum total range of 120 km.

## 5 Propagation models

### 5.1 Terrain obstacles

Terrain obstacles introduce diffraction loss, which can be estimated from the path profile between transmitter and receiver antennas. The profile can preferably be derived from a digital topographic data bank delivered from the national map survey or from a land resource satellite system, e.g. Spot. The resolution is usually 500*500 m2 down to 50*50 m2 in side and 20 m down to 5 m in height. This resolution is not sufficient to describe the situation in cities for microcells, where streets and buildings must be recognized.

### 5.2 Environment factors

Environment factors for the nearest 200 m radius from the mobile play an important role in both the 900 MHz and 1800 MHz bands. For the Nordic cellular planning for NMT there is taken into account 10 categories for land, urban and wood. Further studies are done within COST 231.

Coarse estimations of cell coverage can be done on pocket computers with programs adding these environment factors to propagation curves of CCIR Recommendation 370-5 figure 9 and CCIR Report 567-3 figure 2 (Okumura, 1968).

### 5.3 Field strength measurements

Field strength measurements of the local mean of the lognormal distribution are preferably done by digital averaging over the typical Rayleigh fading. It can be shown that the local average power can be estimated over 20 to 40 wavelengths with at least 36 uncorrelated samples within 1 dB error for 90 % confidence (Lee, 1985).

### 5.4 Cell adjustments

Cell adjustments from field strength measurements of coverage and re-use are recommended after coarse predictions have been done. Field strength measurements of rms values can be performed with an uncertainty of 3.5 dB due to sampling and different propagation between Rayleigh fading and line-of-sight. Predictions can reasonably be done with an uncertainty of about 10 dB. Therefore cell adjustments are preferably done from field strength measurements by changing BTS output power, ERP, and antenna pattern in direction and shape.

## 6 Glossary

| | |
|---|---|
| ACS | Adjacent Channel Suppression (section 4.3) |
| BCCH | Broadcast Control Channel (section 4.8) |
| BTS | Base Transceiver Station (section 3.3) |
| BSIC | Base Transceiver Station Identity Code (section 4.8) |
| CA | Cell Allocation of radio frequency channels (section 4.8) |
| CCCH | Common Control Channel (section 4.10) |
| COST | European Co-operation in the field of Scientific and Technical Research |
| DTX | Discontinuous Transmission (section 4.9) |
| Ec/No | Signal-to-Noise ratio in modulating bit rate bandwidth (section3.2) |
| FH | Frequency Hopping (section 4.9) |
| FN | TDMA Frame Number (section 4.9) |
| F/B | Front-to-Back ratio (section 4.4) |
| HSN | Hopping Sequence Number (section 4.9) |
| MS | Mobile Station (section 3.3) |
| PLMN | Public Land Mobile Network |
| Ps | Location (site) Probability (section 3.1) |
| SACCH | Slow Associated Control Channel (section 4.9) |
| SB | Synchronization Burst (section 4.9) |
| SDCCH | Stand-alone Dedicated Control Channel (section 4.9) |
| TCH | Traffic Channel (section 4.9) |

# 7 Bibliography

CEPT Recommendation T/R 20-08 Frequency planning and frequency co-ordination for the GSM service;

CEPT Recommendation T/R 25-03 Co-ordination of frequencies for the land mobile service in the 80, 160 and 460 MHz bands and the methods to be used for assessing interference;

CEPT Recommendation T/R 25-04 Co-ordination in frontier regions of frequencies for the land mobile service in the bands between 862 and 960 MHz;

CEPT Liaison office, P.O. Box 1283, CH-3001 Berne.

1 Jakes, W.C., Jr.(Ed.) (1974) Microwave mobile communications. John Wiley, New York, NY, USA.

2 Kajamaa, Timo (1985) 900 MHz propagation measurements in Finland in 1983-85 (PTT Report 27.8.1985.) Proc NRS 86, Nordic Radio Symposium, ISBN 91-7056-072-2.

3 Lee, W.C.Y. (Feb., 1985) Estimate of local average power of a mobile radio signal. IEEE Trans. Vehic. Tech., Vol. VT-34, 1.

4 Okumura, Y. et al (Sep.-Oct., 1968) Field strength and its variability in VHF and UHF land-mobile radio service. Rev. Elec. Comm. Lab., NTT, Vol. 16, 9-10.

5 Stjernvall, J-E (Feb. 1985) Calculation of capacity and co-channel interference in a cellular system. Nordic Seminar on Digital Land Mobile Radio Communication (DMR I), Espoo, Finland.

6 A.M.D. Turkmani, J.D. Parsons and A.F. de Toledo "Radio Propagation into Buildings at 1.8 GHz". COST 231 TD (90) 117

7 COST 231 "Urban transmission loss models for mobile radio in the 900- and 1800- MHz bands (Revision 2)" COST 231 TD (90) 119 Rev 2.

8 Hata, M. (1980) Empirical Formula for Propagation Loss in Land Mobile Radio Services, IEEE Trans. on Vehicular Technology VT-29.

# Annex A.1: (class 4) Example of RF-budget for GSM MS handheld RF-output peak power 2 W

| Propagation over land in urban and rural areas | | | | | |
|---|---|---|---|---|---|
| Receiving end: | | | BTS | MS | Eq. |
| TX: | | | MS | BTS | (dB) |
| Noise figure (multicoupl.input) | | dB | 8 | 10 | A |
| Multipath profile | 1) | | TU50 | TU50 | (no FH) |
| Ec/No min. fading | 1) | dB | 8 | 8 | B |
| RX RF-input sensitivity | | dBm | -104 | -102 | C=A+B+W-174 |
| Interference degrad. margin | | dB | 3 | 3 | D |
| RX-antenna cable type | | | 1-5/8" | 0 | |
| Specific cable loss | | dB/100m | 2 | 0 | |
| Antenna cable length | | m | 120 | 0 | |
| Cable loss + connector | | dB | 4 | 0 | E |
| RX-antenna gain | | dBi | 12 | 0 | F |
| Isotropic power, 50 % Ps | | dBm | -109 | -99 | G=C+D+E-F |
| Lognormal margin 50 % -> 75 % Ps | | dB | 5 | 5 | H |
| Isotropic power, 75 % Ps | | dBm | -104 | -94 | I=G+H |
| Field strength, 75 % Ps | | dBuV/m | 33 | 43 | J=I+137 |
| C/Ic min.fading, 50 % Ps | 1) | dB | 9 | 9 | |
| C/Ic prot. at 3 dB degrad. | | dB | 12 | 12 | |
| C/Ic protection, 75 % Ps | 2) | dB | 19 | 19 | |
| Transmitting end: | | | MS | BTS | Eq. |
| RX: | | | BTS | MS | (dB) |
| TX RF-output peak power | | W | 2 | 6 | |
| (mean power over burst) | | dBm | 33 | 38 | K |
| Isolator + combiner + filter | | dB | 0 | 3 | L |
| RF peak power, combiner output | | dBm | 33 | 35 | M=K-L |
| TX-antenna cable type | | | 0 | 1-5/8" | |
| Specific cable loss | | dB/100m | 0 | 2 | |
| Antenna cable length | | m | 0 | 120 | |
| Cable loss + connector | | dB | 0 | 4 | N |
| TX-antenna gain | | dBi | 0 | 12 | O |
| Peak EIRP | | W | 2 | 20 | |
| (EIRP = ERP + 2 dB) | | dBm | 33 | 43 | P=M-N+O |
| Isotropic path loss, 50 % Ps | 3) | dB | 139 | 139 | Q=P-G-3 |
| Isotropic path loss, 75 % Ps | | dB | 134 | 134 | R=P-I-3 |
| Range, outdoor, 75 % Ps | 4) | km | 2.0 | 2.0 | |
| Range, indoor, 75 % Ps | 4) | km | 0.7 | 0.7 | |

1) Ec/No and C/Ic for residual BER = 0.4 %, TCH/FS (class Ib) and multi-path profiles as defined in GSM 05.05 annex 3. Bandwidth W = 54 dBHz.

2) Uncorrelated C and I with 75 % location probability (Ps). lognormal distribution of shadowing with standard deviation 7 dB. Ps = 75 % corresponds to ca 90 % area coverage, see Jakes, pp.126-127.

3) 3 dB of path loss is assumed to be due to the antenna/body loss

4) Max. range based on Hata. Antenna heights for BTS = 50 m and MS = 1.5 m. Indoor loss = 15 dB.

# Annex A.2: (class 2) Example of RF-budget for GSM MS RF-output peak power 8 W

| | | | | | |
|---|---|---|---|---|---|
| Propagation over land in urban and rural areas | | | | | |
| Receiving end:<br>TX: | | | BTS<br>MS | MS<br>BTS | Eq.<br>(dB) |
| Noise figure (multicoupl.input) | | dB | 8 | 8 | A |
| Multipath profile | 1) | | RA250 | RA250 | (no FH) |
| Ec/No min. fading | 1) | dB | 8 | 8 | B |
| RX RF-input sensitivity | | dBm | -104 | -104 | C=A+B+W-174 |
| Interference degrad. margin | | dB | 3 | 3 | D |
| RX-antenna cable type | | | 1-5/8" | RG-58 | |
| Specific cable loss | | dB/100m | 2 | 50 | |
| Antenna cable length | | m | 120 | 4 | |
| Cable loss + connector | | dB | 4 | 2 | E |
| RX-antenna gain | | dBi | 12 | 2 | F |
| Isotropic power, 50 % Ps | | dBm | -109 | -101 | G=C+D+E-F |
| Lognormal margin 50 % -> 75 % Ps | | dB | 5 | 5 | H |
| Isotropic power, 75 % Ps | | dBm | -104 | -96 | I=G+H |
| Field strength, 75 % Ps | | dBuV/m | 33 | 41 | J=I+137 |
| C/Ic min.fading, 50 % Ps | 1) | dB | 9 | 9 | |
| C/Ic prot. at 3 dB degrad. | | dB | 12 | 12 | |
| C/Ic protection, 75 % Ps | 2) | dB | 19 | 19 | |
| Transmitting end:<br>RX: | | | MS<br>BTS | BTS<br>MS | Eq.<br>(dB) |
| TX RF-output peak power | | W | 8 | 16 | |
| (mean power over burst) | | dBm | 39 | 42 | K |
| Isolator + combiner + filter | | dB | 0 | 3 | L |
| RF peak power, combiner output | | dBm | 39 | 39 | M=K-L |
| TX-antenna cable type | | | RG-58 | 1-5/8" | |
| Specific cable loss | | dB/100m | 50 | 2 | |
| Antenna cable length | | m | 4 | 120 | |
| Cable loss + connector | | dB | 2 | 4 | N |
| TX-antenna gain | | dBi | 2 | 12 | O |
| Peak EIRP | | W | 20 | 50 | |
| (EIRP = ERP + 2 dB) | | dBm | 39 | 47 | P=M-N+O |
| Isotropic path loss, 50 % Ps | | dB | 148 | 148 | Q=P-G |
| Isotropic path loss, 75 % Ps | | dB | 143 | 143 | R=P-I |
| Range, outdoor, 75 % Ps | 3) | km | 30.7 | 30.7 | |

1) Ec/No and C/Ic for residual BER = 0.2 %, TCH/FS (class Ib) and multi-path profiles as defined in GSM 05.05 annex 3. Bandwidth W = 54 dBHz.

2) Uncorrelated C and I with 75 % location probability (Ps). Lognormal distribution of shadowing with standard deviation 7 dB. Ps = 75 % corresponds to ca 90 % area coverage, see Jakes, pp.126-127.

3) Max. range in quasi-open areas based on Hata. Antenna heights for BTS = 100 m and MS = 1.5 m.

## Annex A.3: (DCS1800 classes 1&2): Example of RF-budget for DCS 1800 MS RF-output peak power 1 W & 250 mW

| | | | | |
|---|---|---|---|---|
| Propagation over land in urban and rural areas | | | | |
| Receiving end: | | BTS | MS | Eq. |
| TX: | | MS | BTS | (dB) |
| Noise figure(multicoupl.input) | dB | 8 | 12 | A |
| Multipath profile | | TU50 or | RA130 | |
| Ec/No min. fading | dB | 8 | 8 | B |
| RX RF-input sensitivity | dBm | -104 | -100 | C=A+B+W-174 |
| Interference degrad. margin | dB | 3 | 3 | D (W=54.3 dBHz) |
| Cable loss + connector | dB | 2 | 0 | E |
| RX-antenna gain | dBi | 18 | 0 | F |
| Diversity gain | dB | 5 | 0 | F1 |
| Isotropic power, 50 % Ps | dBm | -122 | -97 | G=C+D+E-F-F1 |
| Lognormal margin 50 % ->75 % Ps | dB | 6 | 6 | H |
| Isotropic power, 75 % Ps | dBm | -116 | -91 | I=G+H |
| Field Strength 75 % Ps | | 27 | 51 | J=I+142.4 at 1.8 GHz |
| Transmitting end: | | MS | BTS | Eq. |
| RX: | | BTS | MS | (dB) |
| TX PA output peak power | W | - | 15.8/3.98 | |
| (mean power over burst) | dBm | - | 42/36 | K |
| Isolator + combiner + filter | dB | - | 3 | L |
| RF Peak power,(ant.connector) | dBm | 30/24 | 39/33 | M=K-L |
| 1) | W | 1.0/0.25 | 7.9/2.0 | |
| Cable loss + connector | dB | 0 | 2 | N |
| TX-antenna gain | dBi | 0 | 18 | O |
| Peak EIRP | W | 1.0/0.25 | 316/79.4 | |
| | dBm | 30/24 | 55/49 | P=M-N+O |
| Isotropic path loss,50 % Ps | 2) | dB | 149/143 | 149/143 Q=P-G-3 |
| Isotropic path loss, 75 % Ps | dB | 143/137 | 143/137 | R=P-I-3 |
| Range km - 75 % Ps | | | | |
| Urban, out of doors | | 1.91/1.27 | | |
| Urban, indoors | | 0.69/0.46 | | |
| Rural (Open area), out of doors | | 19.0/12.6 | | |
| Rural (Open area), indoors | | 9.52/6.28 | | |

1) The MS peak power is defined as:

a) If the radio has an antenna connector, it shall be measured into a 50 Ohm resistive load.
b) If the radio has an integral antenna, a reference antenna with 0 dBi gain shall be assumed.

2) 3 dB of the path loss is assumed to be due to antenna/body loss.

## Annex A.4: Example of RF-budget for GSM 900 Class4 (peak power 2 W) in a small cell

| | | | | |
|---|---|---|---|---|
| Propagation over land in urban and rural areas | | | | |
| Receiving end:<br>TX : | | BTS<br>MS | MS<br>BTS | Eq.<br>(dB) |
| Noise figure(multicoupl.input) | dB | 8 | 10 | A |
| Multipath profile | | TU50 | TU50 | |
| Ec/No min. fading | dB | 8 | 8 | B |
| RX RF-input sensitivity | dBm | -104 | -102 | C=A+B+W-174 |
| Interference degrad. margin | dB | 3 | 3 | D (W=54.3 dBHz) |
| Cable loss + connector | dB | 2 | 0 | E |
| RX-antenna gain | dBi | 16 | 0 | F |
| Diversity gain | dB | 3 | 0 | F1 |
| Isotropic power, 50 % Ps | dBm | -118 | -99 | G=C+D+E-F-F1 |
| Lognormal margin 50 % ->75 % Ps | dB | 5 | 5 | H |
| Isotropic power, 75 % Ps | dBm | -113 | -94 | I=G+H |
| Field Strength 75 % Ps | | 24 | 43 | J=I+137 at 900 MHz |
| Transmitting end:<br>RX: | | MS<br>BTS | BTS<br>MS | Eq.<br>(dB) |
| TX PA output peak power | W | - | 12.6 | |
| (mean power over burst) | dBm | - | 41 | K |
| Isolator + combiner + filter | dB | - | 3 | L |
| RF Peak power,(ant.connector) | dBm | 33 | 38 | M=K-L |
| 1) | W | 2 | 6.3 | |
| Cable loss + connector | dB | 0 | 2 | N |
| TX-antenna gain | dBi | 0 | 16 | O |
| Peak EIRP | W | 2 | 158 | |
| | dBm | 33 | 52 | P=M-N+O |
| Isotropic path loss,50 % Ps 2) | dB | 148 | 148 | Q=P-G-3 |
| Isotropic path loss, 75 % Ps | dB | 143 | 143 | R=P-I-3 |
| Range km - 75 % Ps | | | | |
| Urban, out of doors | | 1.86 | | |
| Urban, indoors | | 0.75 | | |

1) The MS peak power is defined as:

a) If the radio has an antenna connector, it shall be measured into a 50 Ohm resistive load.
b) If the radio has an integral antenna, a reference antenna with 0 dBi gain shall be assumed.

2) 3 dB of the path loss is assumed to be due to antenna/body loss.

# Annex B: Propagation loss formulas for mobile radiocommunications

## 1 Hata Model [4], [8]

| | |
|---|---|
| Frequency f: | 150 - 1000 MHz |
| Base station height Hb: | 30 - 200 m |
| Mobile height Hm: | 1 - 10 m |
| Distance d: | 1 - 20 km |

Large and small cells (i.e. base station antenna heights above roof-top levels of buildings adjacent to the base station)

### 1.1 Urban

Lu (dB) = 69.55 + 26.16*log(f) - 13.82*log(Hb) - a(Hm) + [44.9 - 6.55*log(Hb)]*log(d)

a(Hm) correction factor for vehicular station antenna height.

For a medium-small city :

a (Hm) = [1.1*log(f) - 0.7]*Hm - [1.56*log(f) - 0.8]

For a large city :

a (Hm) = 8.29*[log(1.54*Hm)]$^2$ - 1.1 for f <= 200 MHz
a (Hm) = 3.2*[log(11.75*Hm)]$^2$ - 4.97 for f >= 400 MHz

### 1.2 Suburban

Lsu (dB) = Lu - 2*[log(f/28)]$^2$ - 5.4

### 1.3 Rural (Quasi-open)

Lrqo (dB) = Lu - 4.78*[log(f)]$^2$ + 18.33*log(f) - 35.94

### 1.4 Rural (Open Area)

Lro (dB) = Lu - 4.78*[log(f)]$^2$ + 18.33*log(f) - 40.94

## 2 COST 231-Hata Model [7]

| | |
|---|---|
| Frequency f: | 1500 - 2000 MHz |
| Base station height Hb: | 30 - 200 m |
| Mobile height Hm: | 1 - 10 m |
| Distance d: | 1 - 20 km |

Large and small cells (i.e. base station antenna heights above roof-top levels of buildings adjacent to the base station).

Urban areas (for rural areas the correction factors given in subparagraph 1.3 and 1.4 can be used up to 2000 MHz).

Lu (dB) = 46.3 + 33.9*log(f) - 13.82*log(Hb) - a(Hm) + [44.9 - 6.55*log(Hb)]*log(d) + Cm

with :

a(Hm) = [1.1*log(f) - 0.7]*Hm - [1.56*log(f) - 0.8]
Cm = 0 dB for medium sized city and suburban centres with moderate tree density
Cm = 3 dB for metropolitan centres

# 3 COST 231 Walfish-Ikegami Model [7]

| | |
|---|---|
| Frequency f: | 800 - 2000 MHz |
| Base station height Hb: | 4 - 50 m |
| Mobile height Hm: | 1 - 3 m |
| Distance d: | 0.02 - 5 km |

Height of buildings Hroof (m)
Width of road w (m)
Building separation b (m)
Road orientation with respect to the direct radio path Phi (°)
Urban areas

## 3.1 Without free line-of-sight between base and mobile (small cells)

Lb = Lo + Lrts + Lmsd (or Lb = Lo for Lrts + Lmsd <= 0)

with :

### 3.1.1 Lo free-space loss

Lo = 32.4 + 20*log(d) + 20*log(f)

### 3.1.2 Lrts roof-top-to-street diffraction and scatter loss

Lrts = -16.9 - 10*log(w) + 10 log(f) + 20*log(Hr - Hm) + Lcri

with Lcri = -10 + 0.354*Phi for 0<= Phi < 35°
Lcri = 2.5 + 0.075*(Phi-35) for 35<= Phi < 55°
Lcri = 4.0 - 0.114*(Phi-55) for 55<= Phi <90°

### 3.1.3 Lmsd multiscreen diffraction loss

Lmsd = Lbsh + ka + kd*log(d) + kf*log(f) - 9*log(b)

| | | | |
|---|---|---|---|
| with | Lbsh | = -18*log(1 +Hb - Hroof) | for Hb > Hroof |
| | | = 0 | for Hb <= Hroof |
| | ka | = 54 | for Hb > Hroof |
| | | = 54 - 0.8*(Hb - Hroof) | for d >= 0.5 and Hb <=Hroof |
| | | = 54 - 0.8*(Hb - Hroof)*(d/0.5) | for d<0.5 and Hb<=Hroof |
| | kd | = 18 | for Hb > Hroof |
| | | = 18 - 15*(Hb - Hroof)/Hroof | for Hb <= Hroof |
| | kf | = -4 + 0.7*(f/925 - 1) | for medium sized cities and suburban centres with moderate tree density |
| | | = -4 + 1.5*(f/925 - 1) | for metropolitan centres |

## 3.2 With a free line-of-sight between base and mobile (Street Canyon)

Microcells (Base station antennas below roof top level)

Lb = 42.6 + 26*log(d) + 20*log(f) for d >= 0.020 km

# Annex C: Path Loss vs Cell Radius

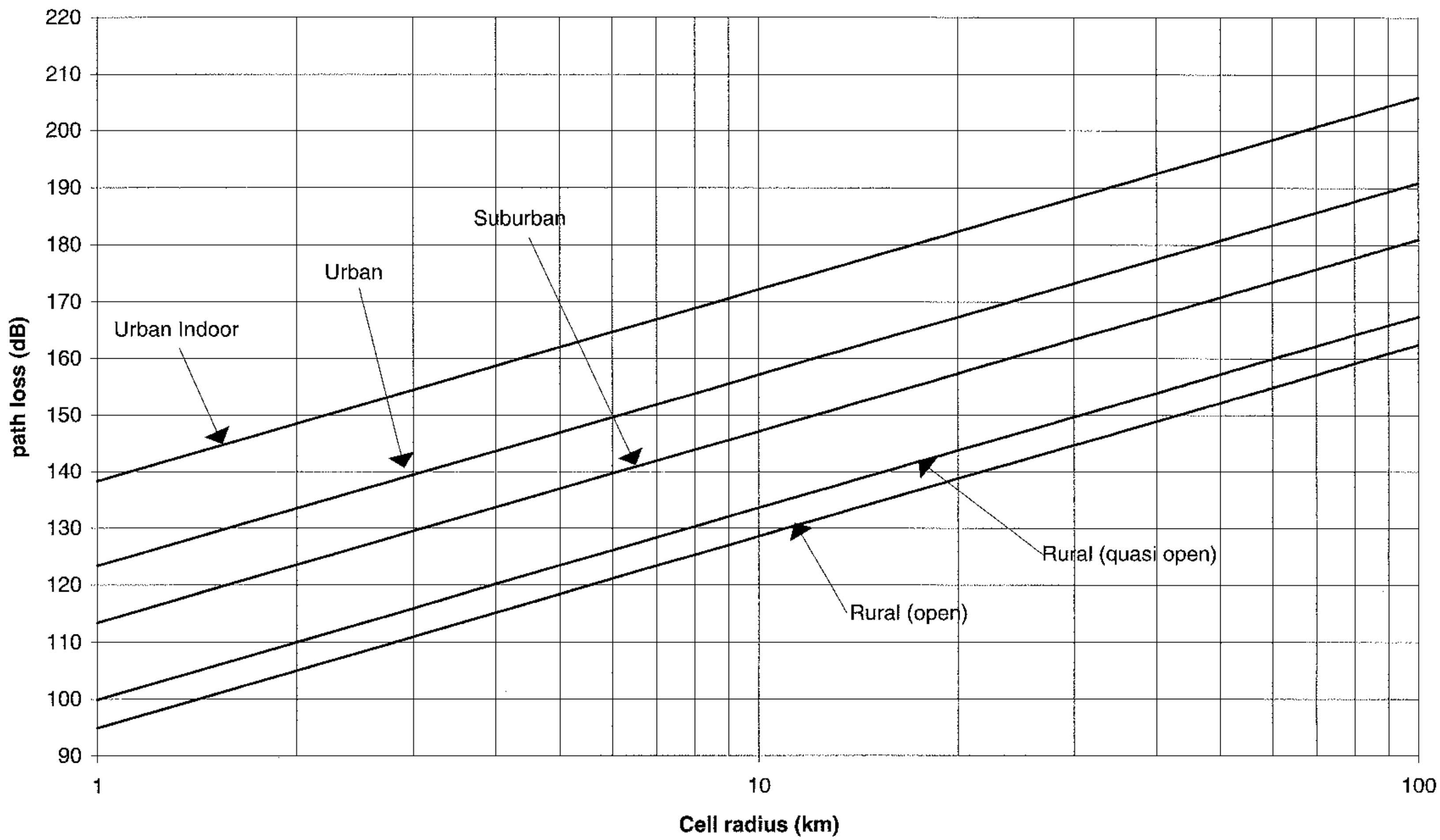


Figure1: Path loss vs Cell Radius, BS height = 50 m, MS height = 1.5 m (GSM 900)

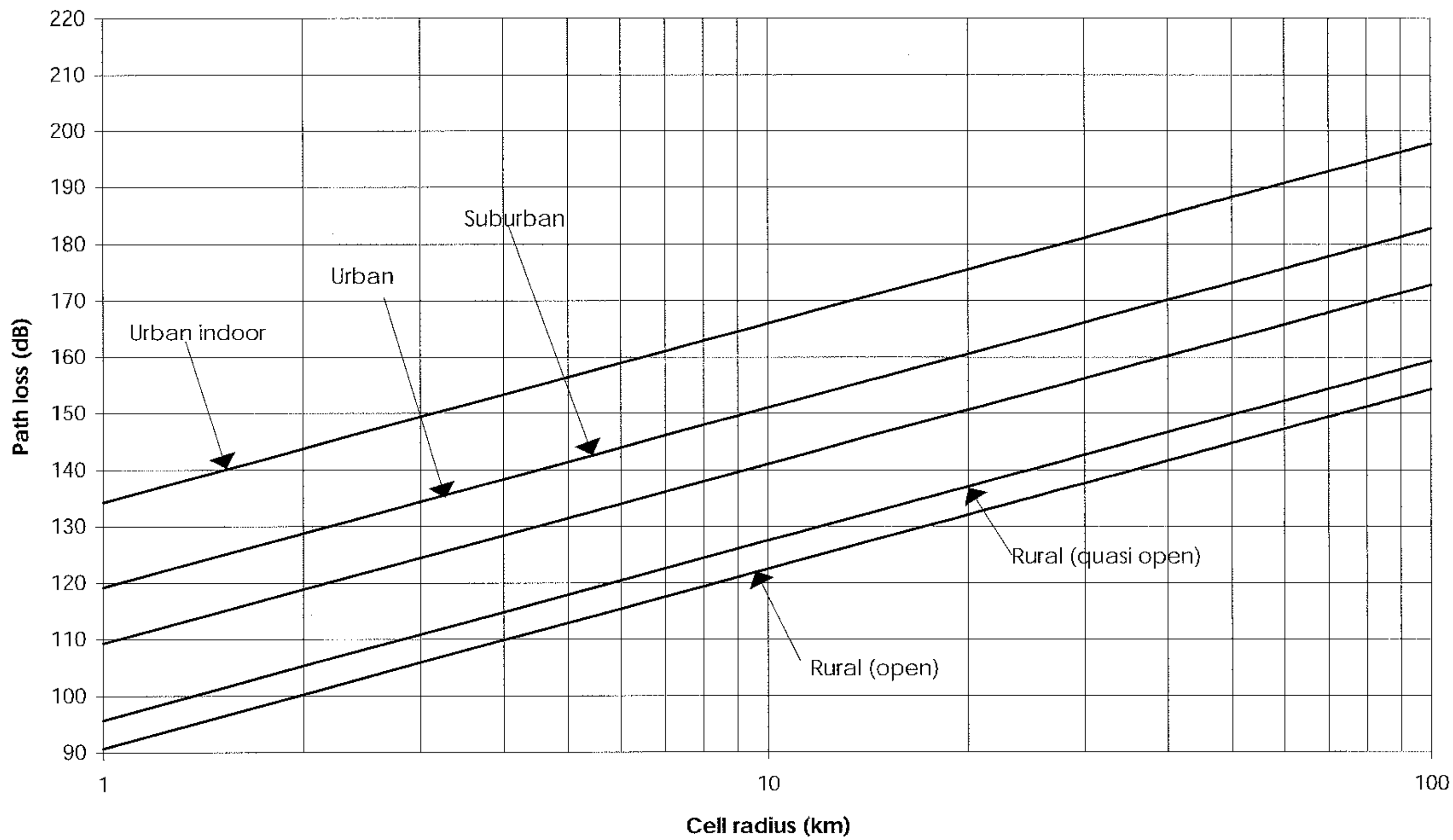


**Figure 2: Path loss vs Cell Radius, BS height = 100 m, MS height = 1.5 m (GSM 900)**

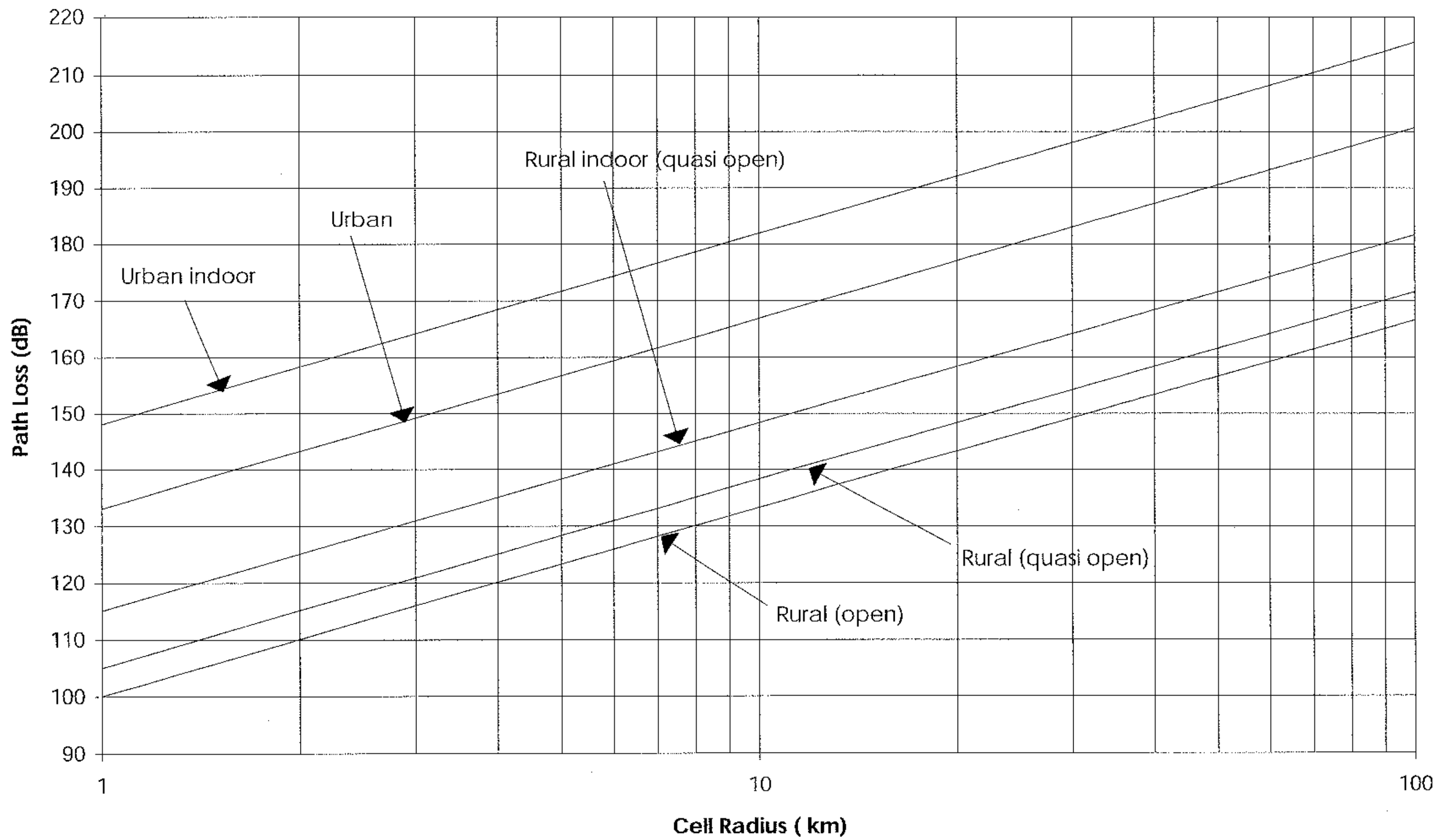


**Figure 3: Path loss vs Cell Radius, Urban BS height = 50 m, Rural BS height = 60 m, MS height = 1.5 m (DCS 1800)**

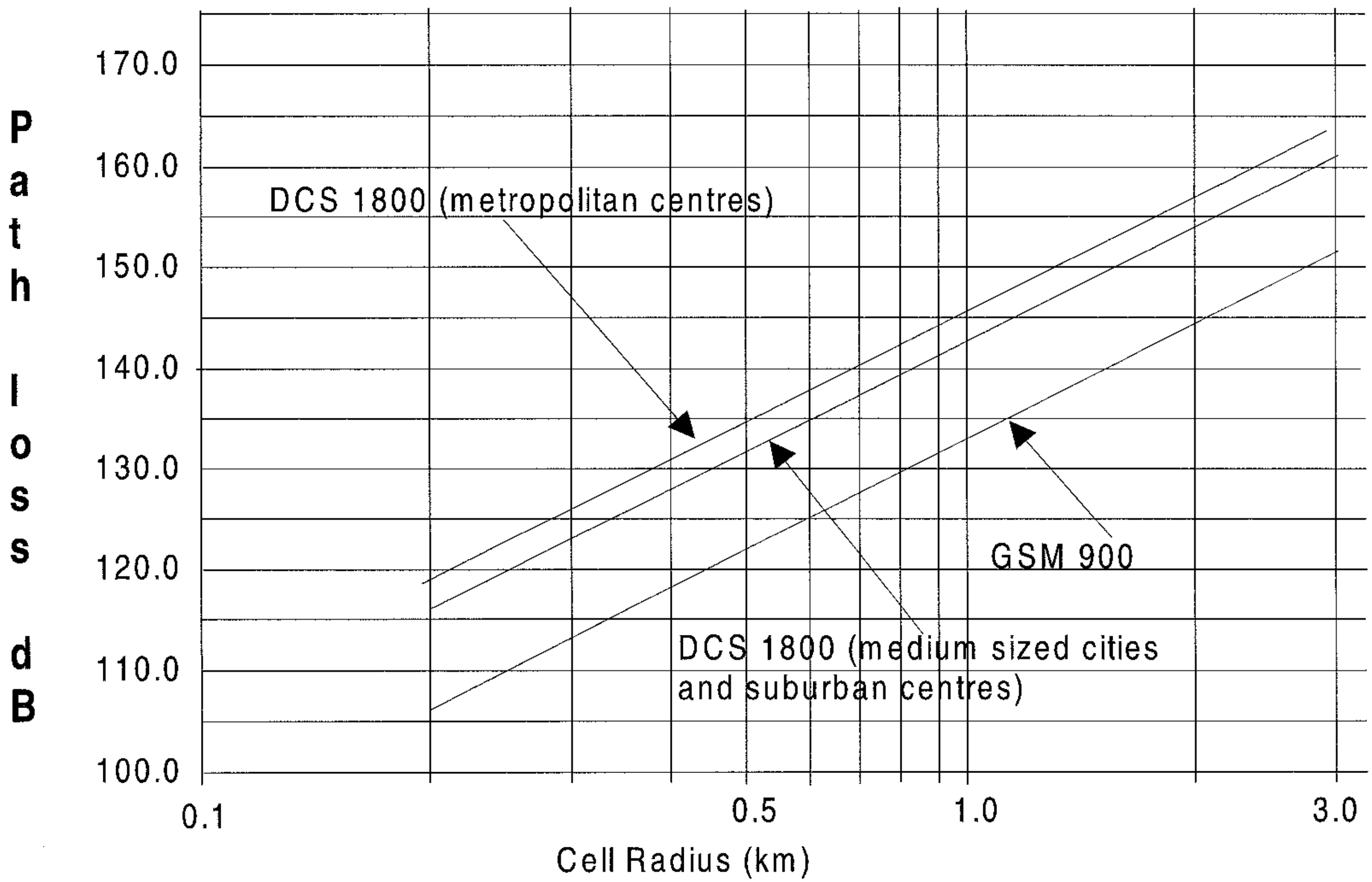


**Figure 4: Path loss vs Cell Radius for small cells (see section 3.4.2)**

# Annex D: Planning Guidelines for Repeaters

## D.1 Introduction

Repeaters can be used to enhance network coverage in certain locations. This annex provides guidelines for the design and installation of repeaters as network infrastructure elements. It covers both in building and outdoor applications. The principles within it may also form a basis for the design of repeaters for other applications within the system.

## D.2 Definition of Terms

The situation where two BTSs and two MSs are in the vicinity of a repeater is shown in figure 5 below. BTSA and MSA belong to operator A and BTSB and MSB belong to a different operator, operator B.

When planning repeaters, operators should consider the effects of the installation on both co-ordinated and uncoordinated operators. In the following sections, it is assumed that in the uncoordinated scenario, the repeater is planned and installed only for the benefit of operator A. Operator A is therefore, co-ordinated and operator B uncoordinated.

In certain situations, operators may agree to share repeaters. Under these conditions, the repeater is planned and installed to provide benefit to all co-ordinated operators. If all operators within the GSM or DCS bands share a repeater, only the co-ordinated scenario exists.

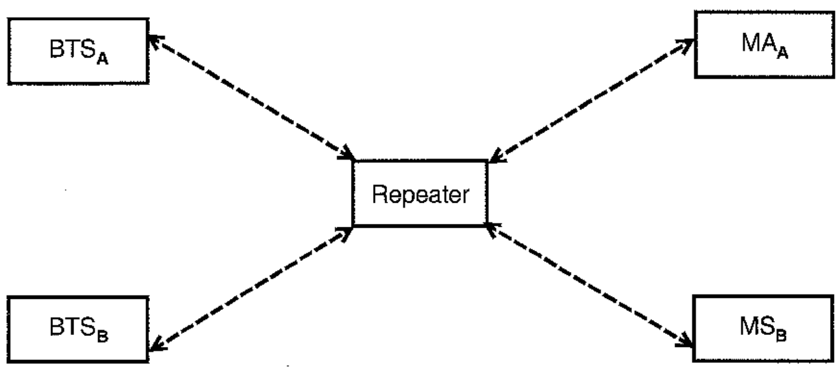


**Figure 5: Repeater Scenario for two BTSs and two MSs**

The following abbreviations are used in this annex:

| | |
|---|---|
| G | Repeater Gain |
| PBTS | BTS Output Power (in dBm) |
| PMS | MS Output Power (in dBm) |
| PmaxDL | Maximum Repeater Downlink Output Power (in dBm) |
| PmaxUL | Maximum Repeater Uplink Output Power (in dBm) |
| NDL | Repeater Downlink Noise Output in RX bandwidth (in dBm) |
| NUL | Repeater Uplink Noise Output in RX bandwidth (in dBm) |
| SMS | MS Reference Sensitivity (in dBm) |
| SBTS | BTS Reference Sensitivity (in dBm) |
| C/Ic | Carrier to Interference ratio for cochannel interference |
| CL1 | BTS to Repeater Coupling Loss (terminal to terminal) |
| CL2 | Repeater to MS Coupling Loss (terminal to terminal) |
| CL3 | The measured or estimated out of band coupling loss between a close coupled communication system and the repeater (terminal to terminal) |
| M | Number of carriers amplified by repeater |
| Gsys | The out of band repeater gain plus the gain of the external repeater antenna less the cable loss to that antenna. |
| Gcom_3 | The antenna gain of a close coupled communications system. |
| Ms | A safety margin for equipment used inside public buildings which should include the height gain of the external repeater antenna plus, if appropriate, the out of band building penetration loss. |

## D.3 Gain Requirements

The uplink and downlink gains should be such as to maintain a balanced link. The loss of diversity gain in the uplink direction may need to be considered.

The gain of the repeater within its operating band should be as flat as possible to ensure that calls set up on a BCCH at one frequency can be maintained when the TCH is on a different frequency.

The gain should be at least 15 dB smaller than the isolation between the antenna directed towards the BTS and the antenna directed towards the MSs, in order to prevent self oscillation. It is recommended to measure the isolation before installation of the repeater.

Within the GSM/DCS1800 bands, but outside of the repeater operating range of frequencies, the installation of the repeater should not significantly alter the cellular design of uncoordinated operators. In the uncoordinated scenario, the repeater should not:

i) amplify downlink signals from another operator such that MSs of that operator within a reasonable distance of the repeater select a remote cell amplified by the repeater as opposed to the local cell of that operator.

ii) amplify uplink signals from other operators' MSs within a reasonable distance of that repeater and transmit them in such a direction as to cause more interference to other BTSs of that operator than other MSs in the area.

For equipment used in public buildings where other communications systems could operate in very close vicinity (less than [5]m) of the repeater antennas, special care must be taken such that out of band signals are not re-radiated from within the building to the outside via the repeater system and vice versa. When using repeaters with an antenna mounted on the outside of the building, the effect of any additional height should be considered. If the close coupled communication system is usually constrained within the building, it may be necessary to consider the negation of building penetration loss when planning the installation. It is the operators responsibility to ensure that the out of band gain of the repeater does not cause disruption to other existing and future co-located radio communication equipment. This can be done by careful choice of the repeater antennas and siting or if necessary, the inclusion of in-line filters to attenuate the out of band signals from other systems operating in the close vicinity of the repeater.

The following equation can be used to ensure an adequate safety margin in these cases:

$$Gsys < Gcom\_3 + CL3 - Ms \qquad (D.3.1)$$

Where Gcom_3 is not known, a value of 2 dBi should be used.

Where Ms is not known a value of 15 dB should be used.

## D.4 Spurious/Intermodulation Products

When planning repeaters, operators should ensure that during operation, the spurious and intermodulation products generated by the repeater at uncoordinated frequencies are less than the limits specified in GSM 05.05.

At co-ordinated frequencies, the intermodulation attenuation of the repeater in the GSM/DCS bands should be greater than the following limits:

$$IM3\ attenuationDL \geq C/Ic + BTS\ power\ control\ range \qquad (D.4.1)$$

$$IM3\ attenuationUL \geq PmaxUL - SBTS + C/Ic - CL1 \qquad (D.4.2)$$

These limits apply in all cases except for initial random access bursts amplified by a repeater.

## D.5 Output Power/Automatic Level Control (ALC)

The maximum repeater output power per carrier will be limited by the number of carriers to be enhanced and the third order intermodulation performance of the repeater. Operators should ensure that the requirements of section D.4 are met for the planned number of active carriers, the output power per carrier, and the repeater implementation.

The number of simultaneously active carriers to be enhanced may be different in the uplink and downlink directions.

When designing ALC systems, the following should be considered:

i) When the ALC is active because of the close proximity of a particular MS, the gain is reduced for all MSs being served by the repeater, thereby leading to a possible loss of service for some of them. The operating region of the ALC needs to be minimized to reduce the probability of this occurrence.

ii) The response of the ALC loop needs careful design. The ALC should not result in a significant distortion of the power/time profile of multiple bursts.

iii) The ALC design should handle the TDMA nature of GSM signal so that it shall be effective for SDCCH and TCH transmissions with and without DTX.

iv) The ALC may not operate quickly enough to cover the initial random access bursts sent by MSs. The intermodulation product requirement listed in section D.4 need not apply for these transient bursts.

v) The ALC must have sufficient dynamic range to ensure that it maintains an undistorted output at the specified maximum power level when a fully powered-up MS is at the CL2min coupling loss.

vi) In a non-channelized repeater the ALC will limit the total output power (i.e. peak of the sum of powers in each carrier). In most cases, the maximum ALC limit should be 3 dB above the power per carrier for two carriers whose third order intermodulation products just meet the requirements of section 4. When more than two carriers are simultaneously amplified, a higher limit may be employed provided the operator ensures that worst case intermodulation products meet the requirements of section D.4.

## D.6 Local oscillator sideband noise attenuation

A local oscillator of a heterodyne type repeater with high sideband noise can cause a problem in uncoordinated scenarios. If the receive level from an uncoordinated MS is significantly higher than the receive level from the co-ordinated MS, both signals can be mixed with approximately the same level into the same IF, degrading the performance of the wanted signal.

To avoid this, an IF type repeater equipped with a local oscillator should have a sideband noise attenuation at an offset of 600 kHz from the local oscillator frequency given by the equation:

Sideband noise attenuation = CL2max - CL2min + C/Ic (D.6.1)

## D.7 Delay Requirements

The ability of the MS to handle step changes in the time of arrival of the wanted signal is specified in GSM 05.05. When planning repeaters for contiguous coverage with other infrastructure elements, it is recommended that the additional delay through the repeater does not exceed the performance of the MS.

The additional delay through the repeater should not cause a problem except in extreme multipath propagation conditions.

The delay of the repeater will reduce the range of the cell in the area enhanced by the repeater. A delay of 8 microseconds is equivalent to a range reduction of 2.4 km.

## D.8 Wideband Noise

Wideband noise is a problem for uncoordinated scenarios. The noise level at the uncoordinated operators' frequencies needs to be such that an uncoordinated MS or BTS in the vicinity of the repeater is not desensitized as a result. The following equations provide the maximum noise output by the repeater in the receiver bandwidth for the downlink and uplink:

NDL <= SMS - C/Ic + CL2Bmin (D.8.1)

NUL <= SBTS - C/Ic + CL1Bmin (D.8.2)

In co-ordinated scenarios, the maximum noise output by the repeater in the receiver bandwidth for the downlink direction is:

NDL <= PmaxDL - BTS power control range - C/Ic (D.8.3)

## D.9 Outdoor Rural Repeater Example

### D.9.1 Rural repeater example for GSM 900

Rural repeaters are used to enhance areas of poor coverage due to terrain limitations. The repeater is located where a suitable signal strength can be received from the donor BTS. Typical signal levels received from the BTS at the input port to the repeater are in the range -50 to -70 dBm. This figure includes the height advantage and the gain of the antenna directed towards the BTS. The received signal is amplified and retransmitted towards the area of poor coverage.

Figure 6 shows typical signal levels in the uplink and downlink directions. Two limiting cases for the MS to repeater coupling loss are shown. A diversity gain of 3 dB is assumed at the BTS making the effective reference sensitivity level -107 dBm.

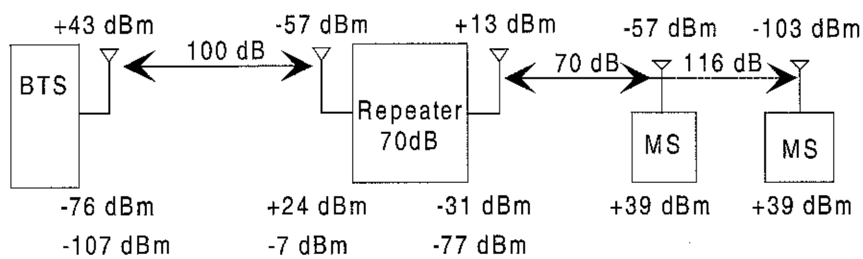


**Figure 6: Uplink and downlink signal levels for a rural repeater**

The minimum coupling loss between the MS and the repeater is assumed to be 70 dB.

#### D.9.1.1 Intermodulation products/ALC setting

In this example an amplifier with a third order intercept ($P_{TOI}$) of +50 dBm is assumed.

The setting of the ALC for the two tone case is governed by the following equation (in dB):

$$P_{ALC} = (2\,P_{TOI} + IM_3)/3 + 3 \qquad \text{(D.9.1.1)}$$

where $IM_3$ is the limit specified in GSM 05.05. The inclusion of factor of 3 dB is described in section D.5.

$$P_{ALC} = 24.3 \text{ dBm}.$$

Dependent on manufacturer guide-lines, the ALC setting may need to be reduced if many carriers are passing through the repeater.

In this example, the ALC is unlikely to be activated on the downlink. It could do so in applications with smaller BTS to repeater coupling loss.

On the uplink, the ALC is activated when the MS is transmitting at full power, at the minimum coupling loss. The repeater gain is reduced so that the output power is limited to 24 dBm. This gain reduction may degrade the service given to other MSs served by the repeater until the BTS power control algorithm has reduced the MS output power.

#### D.9.1.2 Wideband noise

Wideband noise needs to be considered for both the uplink and the downlink for uncoordinated scenarios.

A 70 dB coupling loss is assumed between the repeater and the uncoordinated MS and the repeater and the uncoordinated BTS. Then, using equations D.8.1 and D.8.2, the maximum noise power output is given by:

$$N_{DL} = N_{UL} = -104 - 9 + 70 = -43 \text{ dBm}$$

The maximum noise figure required to achieve this noise level in both the uplink and down link directions is given by the following equation:

$$F <= N - G - kT - B$$

$$<= -43 - 70 - (-174) -53$$

$$<= 8 \text{ dB}$$

where F is the noise figure, N is the maximum noise level, G is the gain, kT is equal -174 dBm/Hz and B is the bandwidth conversion factor equal to 53 dB.

## D.10 Indoor Low Power Repeater Example

### D.10.1 Indoor repeater example for DCS 1800

Indoor repeaters are used to compensate for the losses associated with building attenuation.

The signal level received from the BTS at the input port to the repeater is typically in the range -60 to -80 dBm. This figure includes the height advantage of placing an antenna on the roof of the building and the gain of the antenna directed towards the BTS.

Figure 7 shows typical signal levels in the uplink and downlink directions. Two limiting cases for the MS to repeater coupling losses are shown.

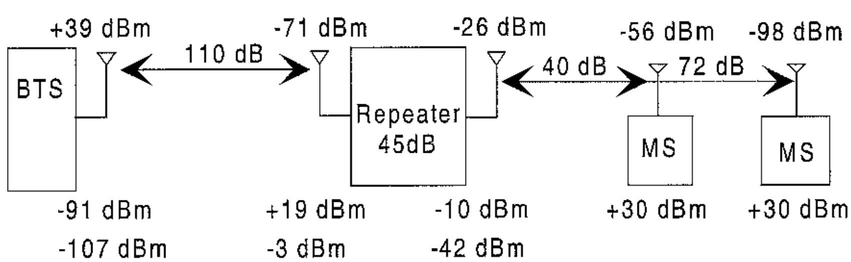


**Figure 7: Uplink and downlink signal levels for indoor repeater**

The minimum coupling loss between the MS and the repeater is assumed to be 40 dB.

#### D.10.1.1 Intermodulation products/ALC setting.

Indoor repeaters are likely to be small low cost devices. Consequently, for indoor repeaters, the intermodulation performance is not as good as a rural repeater. In this example, an amplifier with a third order intercept ($P_{TOI}$) of +40 dBm is assumed.

For $P_{TOI}$ equal to 40 dBm and $IM_3$ equal to -30 dBm, then using equation D.9.1.1:

$P_{ALC}$ = 19.7 dBm.

On the uplink, the ALC is activated when the MS is transmitting at full power, at the minimum coupling loss. The repeater gain is reduced so that the output power is limited to 19 dBm. The received signal level at the BTS of -91 dBm is likely to be below the desired level which the MS power control algorithm seeks to maintain. Therefore, the MS is likely to remain powered up and the ALC will remain in operation continuously. Since, there is likely to be only one simultaneous user of this type of repeater, this is normally acceptable.

### D.10.1.2 Wideband noise

Assuming a minimum coupling loss between the repeater and an unco-ordinated BTS of 65 dB, and between the repeater and an uncoordinated MS of 40 dBm, the following maximum noise levels are obtained using equations D.8.1 and D.8.2.

$N_{DL}$ = -100 - 9 + 40 = -69 dBm

$N_{UL}$ = -104 - 9 + 65 = -48 dBm

The uplink noise level is easy to achieve in view of the low gain. The maximum noise figure required to achieve this noise level in down link directions is given by the following equation:

$$F \le N - G - kT - B$$

$$\le -69 - 40 - (-174) - 53$$

$$\le 12 \text{ dB}$$

where F is the noise figure, N is the maximum noise level, G is the gain, kT is equal -174 dBm/Hz and B is the bandwidth conversion factor equal to 53 dB.

## History

| Document history | |
|---|---|
| November 1996 | First Edition |
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ISBN 2-7437-1178-7
Dépôt légal : Novembre 1996

(4) The terms of any oral agreement related to the withdrawal or dismissal of the application.

(b) In addition, within 5 days of the filing date of the applicant or petitioner's request for approval, each remaining party to any written or oral agreement must submit an affidavit setting forth:

(1) A certification that neither the applicant nor its principals has paid or will pay money or other consideration in excess of the legitimate and prudent expenses of the petitioner in exchange for withdrawing or dismissing the application; and

(2) The terms of any oral agreement relating to the withdrawal or dismissal of the application.

(c) For the purposes of this section:

(1) Affidavits filed pursuant to this section must be executed by the filing party, if an individual, a partner having personal knowledge of the facts, if a partnership, or an officer having personal knowledge of the facts, if a corporation or association.

(2) Applications are deemed to be pending before the FCC from the time the application is filed with the FCC until such time as an order of the FCC granting, denying or dismissing the application is no longer subject to reconsideration by the FCC or to review by any court.

(3) "Legitimate and prudent expenses" are those expenses reasonably incurred by a party in preparing to file, filing, prosecuting and/or settling its application for which reimbursement is sought.

(4) "Other consideration" consists of financial concessions, including, but not limited to, the transfer of assets or the provision of tangible pecuniary benefit, as well as non-financial concessions that confer any type of benefit on the recipient.

[59 FR 59507, Nov. 17, 1994, as amended at 63 FR 68951, Dec. 14, 1998]

### § 22.939 Site availability requirements for applications competing with cellular renewal applications.

In addition to the other requirements set forth in this part for initial cellular applications, any application competing against a cellular renewal application must contain, when initially filed, appropriate documentation demonstrating that its proposed antenna site(s) will be available. Competing applications that do not include such documentation will be dismissed. If the competing applicant does not own a particular site, it must, at a minimum demonstrate that the site is available to it by providing a letter from the owner of the proposed antenna site expressing the owner's intent to sell or lease the proposed site to the applicant. If any proposed antenna site is under U.S. Government control, the applicant must submit written confirmation of the site's availability from the appropriate Government agency. Applicants which file competing applications against incumbent cellular licensees may not rely on the assumption that an incumbent licensee's antenna sites are available for their use.

### § 22.940 Criteria for comparative cellular renewal proceedings.

This section sets forth criteria to be used in comparative cellular renewal proceedings. The ultimate issue in comparative renewal proceedings will be to determine, in light of the evidence adduced in the proceeding, what disposition of the applications would best serve the public interest, convenience and necessity.

(a) *Renewal expectancies.* The most important comparative factor to be considered in a comparative cellular renewal proceeding is a major preference, commonly referred to as a "renewal expectancy."

(1) The cellular renewal applicant involved in a comparative renewal proceeding will receive a renewal expectancy, if its past record for the relevant license period demonstrates that:

(i) The renewal applicant has provided "substantial" service during its past license term. "Substantial" service is defined as service which is sound, favorable, and substantially above a level of mediocre service which just might minimally warrant renewal; and

(ii) The renewal applicant has substantially compiled with applicable FCC rules, policies and the Communications Act of 1934, as amended.

(2) In order to establish its right to a renewal expectancy, a cellular renewal

# P90-14-XLH-RR | Dual Broadband Antennas

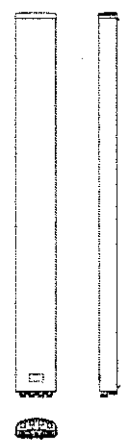
POLARIZATION: Dual Linear ±45°
FREQUENCY (MHz): 698-894, 1710-2170
HORIZONTAL BEAM WIDTH (°): 85,85
GAIN (dBi/dBd): 13.7/11.6 15.7/13.6
TILT: 0-13, 0-8
LENGTH: 48"

## ELECTRICAL SPECIFICATIONS*

| ELECTRICAL SPECIFICATIONS* | | | | | |
|---|---|---|---|---|---|
| Frequency range (MHz) | 698-894 | | 1710-2170 | | |
| Frequency band (MHz) | 698-806 | 806-894 | 1710-1880 | 1850-1990 | 1900-2170 |
| Gain (dBi/dBd) | 13.0/10.9 | 13.7/11.6 | 15.1/13.0 | 15.4/13.3 | 15.7/13.6 |
| Polarization | Dual Linear +/- 45 | | Dual Linear +/- 45 | | |
| Nominal Impedance (Ω) | 50 | | 50 | | |
| VSWR | < 1.5:1 | | < 1.5:1 | | |
| Horizontal beam width, -3 dB (°) | 86 | 83 | 85 | 84 | 85 |
| Vertical beam width, -3 dB (°) | 15.0 | | 7.0 | | |
| Electrical down tilt (°) | 0-13 | | 0-8 | | |
| Side lobe suppression, vertical 1st upper (dB) | > 12 | | > 16 | | |
| Isolation between inputs (dB) | > 30 | | > 28 | | |
| Inter band Isolation (dB) | > 40 | | | | |
| Tracking, horizontal plane ±60° (dB) | < 2 | | < 2 | | |
| Vertical beam squint (°) | < 1.25 | | < 0.5 | | |
| Front to back ratio (dB) 180°±30° copolar | > 25 | | > 25 | | |
| Front to back ratio (dB) 180°±30° total power | > 22 | | > 22 | | |
| Cross polar discrimination (XPD) 0° (dB) | > 10 | | > 15 | | |
| Cross polar discrimination (XPD) ±60° (dB) | > 10 | | > 10 | | |
| IM3, 2xTx@43dBm (dBc) | <-153 | | <-153 | | |
| Power handling, average per input (W) | 500 | | 300 | | |
| Power handling, average total (W) | 1000 | | 600 | | |

## MECHANICAL SPECIFICATIONS*

| MECHANICAL SPECIFICATIONS* | |
|---|---|
| Connector | 4 x 7/16 DIN Female, IP67 |
| Connector position | Bottom |
| Dimensions, HxWxD, in (mm) | 48" x 12" x 7.3" (1219 x 305 x 186) |
| Mounting | Pre-mounted Tilt Brackets |
| Weight, with brackets, lbs (kg) | 41 (19) |
| Weight, without brackets, lbs (kg) | 30 (14) |
| Wind load, frontal/lateral/rear side 42 m/s Cd=1.0 (N) | 920 |
| Maximum operational wind speed, mph (m/s) | 100 (45) |
| Survival wind speed, mph (m/s) | 150 (67) |
| Lightning protection | DC Ground |
| Operating Temperature | -40C to +60C |
| Radome material | PVC, IP55 |
| Packet size, HxWxD, in (mm) | 60" x 16" x 10" (1524 x 400 x 255) |
| Radome colour | Light Grey |
| Shipping weight, lbs (kg) | 52 (24) |
| RET | IRET AISGv1.1, MET and AISGv2.0 Available |
| Brackets | 7256.00, 7454.00 |



*All specifications subject to change without notice. Please contact your Powerwave representative for complete performance data.

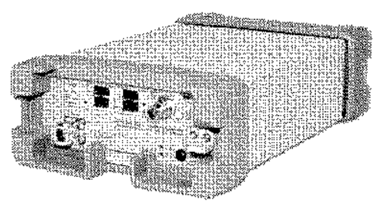
## ANTENNA PATTERNS*

For detailed patterns visit http://www.powerwave.com/rpa/.

Updated: 2010-12-05

# E6474A Drive Test

## W1314A Multi-band Wireless Measurement Receiver



**Key Features**

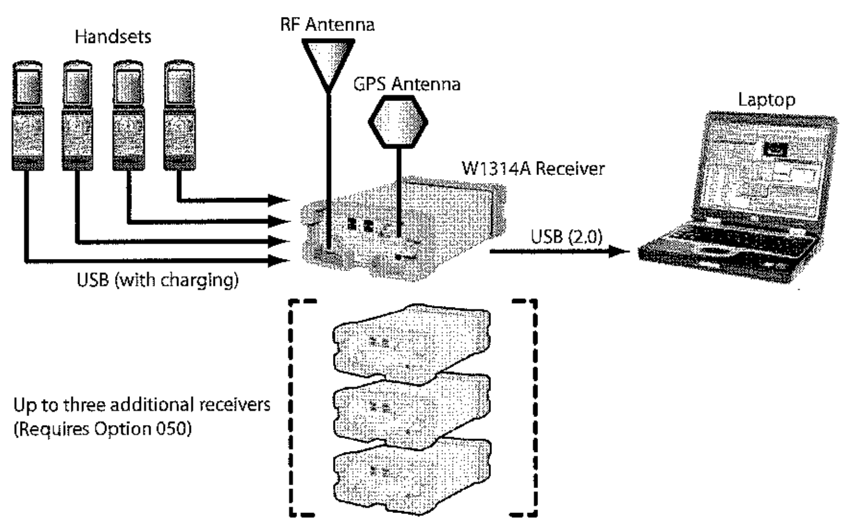
- Perform simultaneous multi-technology measurements during a single drive-test or indoor survey
- Supports LTE, UMTS, GSM, Mobile WiMAX™, 1xEVDO, cdma2000, iDEN, CW and Spectrum Analysis
- All measurement collection and analysis performed within the receiver hardware minimizing laptop processing requirements
- Designed to last for years of daily drive testing
- Solid, RF shielded housing
- Integrated 12 channel GPS or 50 channel high-sensitivity GPS with a USB 2.0 High-Speed USB hub, reducing the need for additional hardware cabling

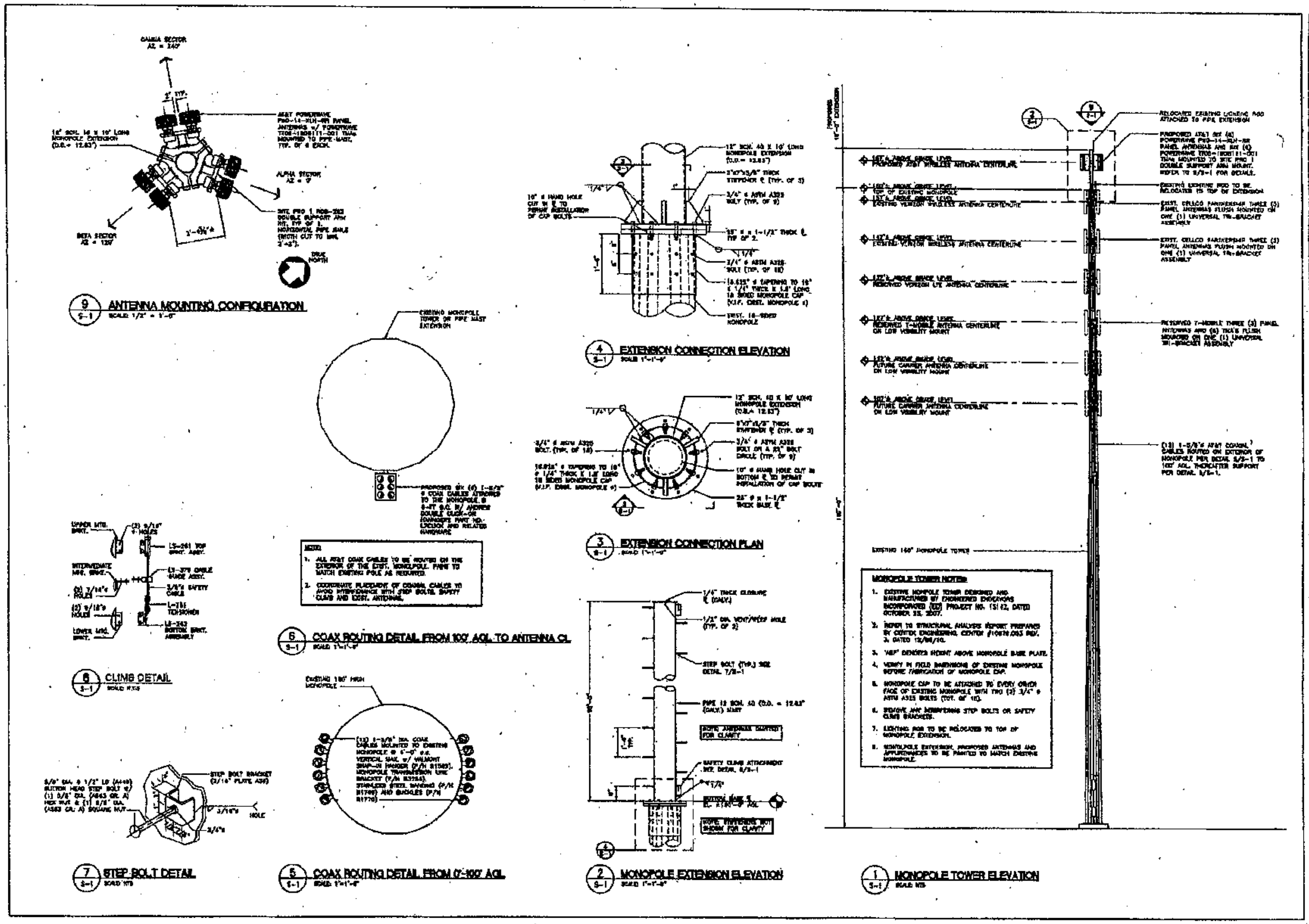
**Key Benefits**

- **Add up to four handsets with USB charging, without impacting specified receiver measurement performance**
- **Improve measurement performance, add new technologies as they become available by automatic software upgrades for extended product life**
- **Low weight and power consumption**
- **Drive test or indoor use**

The W1314A RF receiver is an integral part of the Drive Test system. With easy configuration and robust connections, you can get quick and accurate measurements from the receiver when it is combined with the E6474A Wireless Network Optimization Platform.

Easy connections and configuration mean that you can analyze and optimize your networks no matter where they are, or on what technology they are based. With the right receiver or receivers you get fast high-quality measurements.






CENTEK engineering

AT&T MOBILITY

CT2245

DATE: 7/12/16

JOB NO. 10079.053

MAST EXTENSION DETAILS

S-1

Sheet No. 1 of 2

- Verizon (Reserved):
  Antennas: Three (3) 5-ft panel antennas flush mounted with a RAD center elevation of 137-ft above grade level.
  Coax Cables: Six (6) 1-5/8" Ø coax cables running on the inside of the existing monopole.
- T-Mobile (Reserved):
  Antennas: Three (3) RFS APX16DWV-16DWVS-E-ACU panel antennas and six (6) TMAs flush mounted with a RAD center elevation of 127-ft above grade level.
  Coax Cables: Twelve (12) 1-5/8" Ø coax cables running on the inside of the existing monopole.
- Future Carrier (Reserved):
  Antennas: Three (3) 5-ft panel antennas flush mounted with a RAD center elevation of 117-ft above grade level.
  Coax Cables: Six (6) 1-5/8" Ø coax cables running on the inside of the existing tower.
- Future Carrier (Reserved):
  Antennas: Three (3) 5-ft panel antennas flush mounted with a RAD center elevation of 107-ft above grade level.
  Coax Cables: Six (6) 1-5/8" Ø coax cables running on the inside of the existing tower.
- **AT&T (proposed):**
  **Antennas: Six (6) Powerwave P90-14-XLH-RR panel antennas and six (6) Powerwave TT08-19DB111-001 TMA's flush mounted on a proposed 10-ft monopole extension with a RAD center elevation of 167-ft above grade level.**
  **Coax Cables: Twelve (12) 1-5/8" Ø coax cables running on the exterior of the existing tower.**

If there are any questions regarding this matter, please feel free to call.

Respectfully Submitted by:

STATE OF CONNECTICUT
CARLO F. CENTORE
No. 19364
LICENSED
PROFESSIONAL ENGINEER

Carlo F. Centore, PE
Principal ~ Structural Engineer

# P90-14-XLH-RR | Dual Broadband Antennas

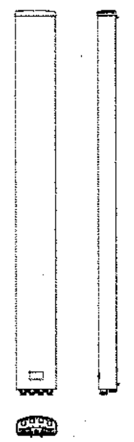
POLARIZATION: Dual Linear ±45°
FREQUENCY (MHz): 698-894, 1710-2170
HORIZONTAL BEAM WIDTH (°): 85,85
GAIN (dBi/dBd): 13.7/11.6 15.7/13.6
TILT: 0-13, 0-8
LENGTH: 48"

## ELECTRICAL SPECIFICATIONS*

| | | | | | |
|---|---|---|---|---|---|
| Frequency range (MHz) | 698-894 | | 1710-2170 | | |
| Frequency band (MHz) | 698-806 | 806-894 | 1710-1880 | 1850-1990 | 1900-2170 |
| Gain (dBi/dBd) | 13.0/10.9 | 13.7/11.6 | 15.1/13.0 | 15.4/13.3 | 15.7/13.6 |
| Polarization | Dual Linear +/- 45 | | Dual Linear +/- 45 | | |
| Nominal Impedance (Ω) | 50 | | 50 | | |
| VSWR | < 1.5:1 | | < 1.5:1 | | |
| Horizontal beam width, -3 dB (°) | 86 | 83 | 85 | 84 | 85 |
| Vertical beam width, -3 dB (°) | 15.0 | | 7.0 | | |
| Electrical down tilt (°) | 0-13 | | 0-8 | | |
| Side lobe suppression, vertical 1st upper (dB) | > 12 | | > 16 | | |
| Isolation between inputs (dB) | > 30 | | > 28 | | |
| Inter band Isolation (dB) | > 40 | | | | |
| Tracking, horizontal plane ±60° (dB) | < 2 | | < 2 | | |
| Vertical beam squint (°) | < 1.25 | | < 0.5 | | |
| Front to back ratio (dB) 180°±30° copolar | > 25 | | > 25 | | |
| Front to back ratio (dB) 180°±30° total power | > 22 | | > 22 | | |
| Cross polar discrimination (XPD) 0° (dB) | > 10 | | > 15 | | |
| Cross polar discrimination (XPD) ±60° (dB) | > 10 | | > 10 | | |
| IM3, 2xTx@43dBm (dBc) | <-153 | | <-153 | | |
| Power handling, average per input (W) | 500 | | 300 | | |
| Power handling, average total (W) | 1000 | | 600 | | |

## MECHANICAL SPECIFICATIONS*

| | |
|---|---|
| Connector | 4 x 7/16 DIN Female, IP67 |
| Connector position | Bottom |
| Dimensions, HxWxD, in (mm) | 48" x 12" x 7.3" (1219 x 305 x 186) |
| Mounting | Pre-mounted Tilt Brackets |
| Weight, with brackets, lbs (kg) | 41 (19) |
| Weight, without brackets, lbs (kg) | 30 (14) |
| Wind load, frontal/lateral/rear side 42 m/s Cd=1.0 (N) | 920 |
| Maximum operational wind speed, mph (m/s) | 100 (45) |
| Survival wind speed, mph (m/s) | 150 (67) |
| Lightning protection | DC Ground |
| Operating Temperature | -40C to +60C |
| Radome material | PVC, IP55 |
| Packet size, HxWxD, in (mm) | 60" x 16" x 10" (1524 x 400 x 255) |
| Radome colour | Light Grey |
| Shipping weight, lbs (kg) | 52 (24) |
| RET | IRET AISGv1.1, MET and AISGv2.0 Available |
| Brackets | 7256.00, 7454.00 |



*All specifications subject to change without notice. Please contact your Powerwave representative for complete performance data.

## ANTENNA PATTERNS*

For detailed patterns visit http://www.powerwave.com/rpa/.

Updated: 2010-12-05

ANDREW®

# BSA Technical Information

## Electrical Isolation of Co-Located Horizontally and Vertically Stacked Antennas

### Introduction:

Service providers are facing rapidly increasing pressure from zoning boards to co-locate their base station antennas on the same tower structure as other providers. Traditionally, these antenna installations have been vertically spaced about 15 to 20 feet apart to ensure adequate antenna electrical isolation, intermodulation and harmonic signal rejection, and resistance to receiver noise desensitization. This note addresses the electrical coupling between horizontally and vertically spaced antennas. For in-band carriers (i.e. co-located A and B band 800 MHz carriers), a minimum of 50 dB isolation between the stacked antennas is frequently required. Measurement data presented in this note concludes that this required isolation can be achieved easily with just a few inches of vertical spacing. This is true even for small, low gain antennas with wide beamwidths. This allows the antennas to be stacked more closely together, thus conserving expensive tower space, reducing total tower count, and allowing higher center lines for providers who are not located on the top position on the monopole. Also, horizontal antenna spacing is sometimes used to achieve co-location as well as greater transmit channel capacity by installing additional antennas. Data presented here concludes that >35 dB electrical isolation is easily achieved with horizontal spacings of just 12 inches or less (for azimuth beamwidths <105 degrees). This allows packing the antennas quite tightly together, thus further conserving expensive tower space.

### Coupling Test Procedure and Results:

*A.) In-Band Measurements:* A variety of electrical isolation tests were run at both 800 and 1900 MHz. A pair of like antennas was placed at various distances from each other, either end-to-end, or side-to-side, to simulate co-located antennas on a tower or monopole. A network analyzer was used to inject a signal into one antenna. Then, transmission loss (S21) at the other antenna port was swept and plotted for the appropriate band (806—896 MHz or 1850—1990 MHz). These tests were run mostly in an anechoic chamber to avoid extraneous reflections. When the antenna spacing was too large to fit in the chamber, the antennas were placed on their backs, outdoors on the ground, so the environment was essentially reflectionless.

Vertical antenna separation distance was defined as shown in Figure 1, and horizontal separation distance was defined as shown in Figure 2. Then, for each frequency band, the antenna azimuth beamwidth and gain were varied to sample typical coupling values. Also, during the vertical separation test, the top antenna was mechanically downtilted 10 degrees, and the coupling test was repeated.

The 800 MHz cellular tests and results are detailed in Table 1. These results are plotted in Figures 3, 4, and 5.

1900 MHz PCS tests and results are shown in Table 2. These results are plotted in Figures 6 and 7.

*B.) Cross-Band Measurements:* In these tests, an FV105-12-00DA2 800 MHz antenna and an RV90-17-00DP 1900 MHz antenna were stacked horizontally and vertically, as shown in Figures 8 and 9. Two network analyzer insertion loss sweeps were performed: One at 806—896 MHz, and another at 1850—1990 MHz. Results were tabulated in Table 3, and plotted in Figures 10 and 11.

Only vertically polarized antennas were used in this experiment. It was expected that the worst case isolation results would be found using vertically polarized antennas throughout so that the antenna pairs would be co-polarized relative to each other. Slant 45 dual polarized models could also be tested, but the results should be similar to those presented here.

**Conclusions:**

**A.) In-Band Isolation of Horizontally Spaced Antennas:**

1. In every measured case, isolation of horizontally spaced 90 or 65 degree antennas was greater than 30 dB with as little as six inches spacing between the antennas.
2. In every measured case, isolation of 105 degree antennas was greater than 30 dB with as little as 18 inches of spacing between the antennas.
3. Isolation of horizontally spaced antennas was driven most strongly by the antenna's azimuth beamwidth. Broad beamwidth models (105 degrees) had the worst isolation.

**B.) In-Band Isolation of Vertically Spaced Antennas:**

1. In every measured case, isolation was greater than 50 dB with as little as six inches of spacing between the antennas. Overall, isolation was excellent regardless of gain or frequency band.
2. A moderate amount of mechanical downtilt did not appreciably degrade the isolation.
3. Vertically spaced isolation was not driven by the antenna's gain (and, therefore, the antenna's elevation beamwidth).

**C.) Cross-Band Isolation:**

1. With Cellular and PCS antennas stacked vertically, isolation was typically 60-70 dB, and varied little with spacing.
2. With Cellular and PCS antennas stacked horizontally, the isolation was quite different, depending on whether the test was run at 800 or 1900 MHz. However, even a worst case result of 40 dB was easily achieved with only 18 inches spacing between the antennas.

It should be noted that these results may vary if the antennas are located behind architectural screening material for "stealth" applications. The scattering environment for these types of set-ups can be quite complex, and requires analysis of the particular site layout to be confident with the results.

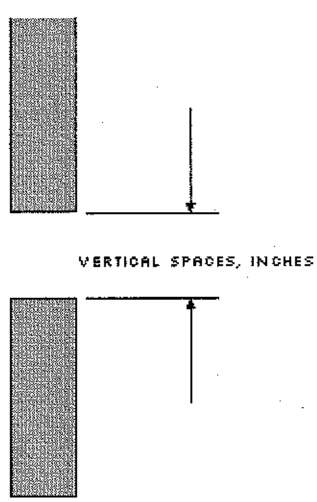



Figure 1: Antenna Vertical Spacing Definition

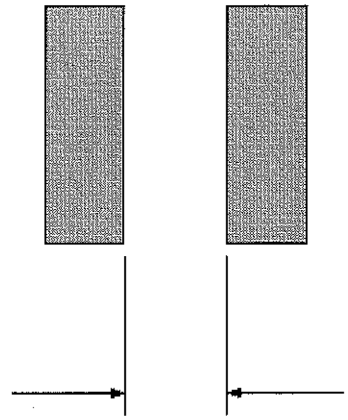



Figure 2: Antenna horizontal spacing definition

**Table 1: Cell Band Coupling Tests:**

1.) Broad beamwidth, Low gain antennas (2 x FV90-09-00DA2):

| | Vertical Spacing | | Horizontal Spacing |
|---|---|---|---|
| Spacing | 0 deg d/t | 10 deg d/t | 0 deg d/t |
| 0 | -56.3 | -69.8 | -38.3 |
| 6 | -59.5 | -77.9 | -41.0 |
| 12 | -65.8 | -78.9 | -43.7 |
| 18 | -68.6 | -81.8 | -45.2 |
| 24 | -66.0 | -86.6 | -47.9 |
| 30 | -68.8 | -89.9 | -48.9 |
| 36 | -69.9 | -85.0 | -48.6 |

2.) Broad beamwidth, High gain antennas (2 x FV105-12-00DA2):

| | Vertical Spacing | | Horizontal Spacing |
|---|---|---|---|
| Spacing | 0 deg d/t | 10 deg d/t | 0 deg d/t |
| 0 | -60.7 | -56.9 | -23.9 |
| 6 | -62.1 | -64.2 | -26.0 |
| 12 | -62.1 | -61.8 | -27.6 |
| 18 | -62.7 | -63.1 | -30.0 |
| 24 | -64.0 | -66.3 | -29.8 |
| 30 | -65.1 | -65.7 | -31.2 |
| 36 | -67.3 | -68.0 | -31.7 |

3.) Narrow beamwidth, Low gain antennas (2 x FV65-11-00DA2):

| | Vertical Spacing | | Horizontal Spacing |
|---|---|---|---|
| Spacing | 0 deg d/t | 10 deg d/t | 0 deg d/t |
| 0 | -44.8 | -45.3 | -30.5 |
| 6 | -57.3 | -52.9 | -35.3 |
| 12 | -57.3 | -52.8 | -37.7 |
| 18 | -61.8 | -57.0 | -39.9 |
| 24 | -62.3 | -60.0 | -46.0 |
| 30 | -64.6 | -62.2 | -49.0 |
| 36 | -61.9 | -57.4 | -47.3 |

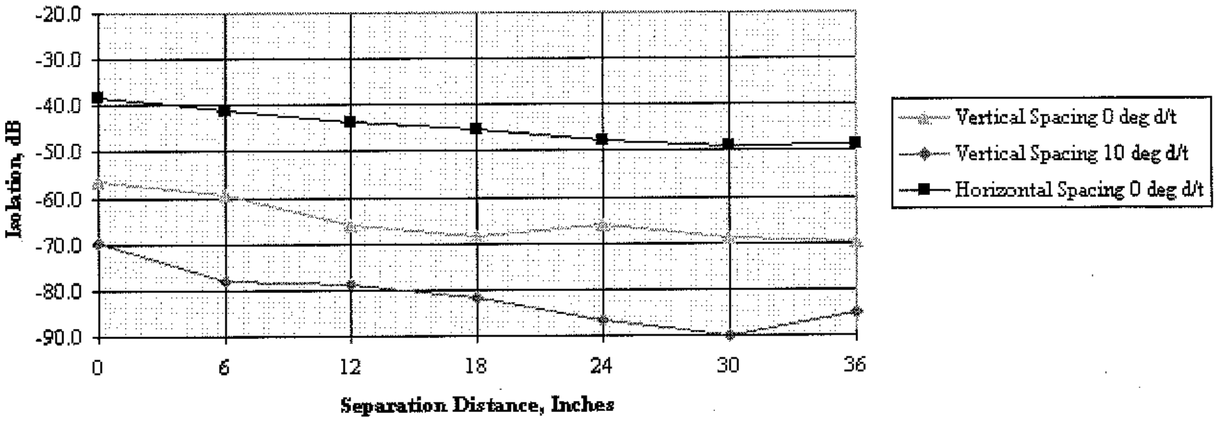



Figure 3: Broad Azimuth Beamwidth, Low Gain Isolation Test 800 Mhz (2 x FV90-09-00DA2)

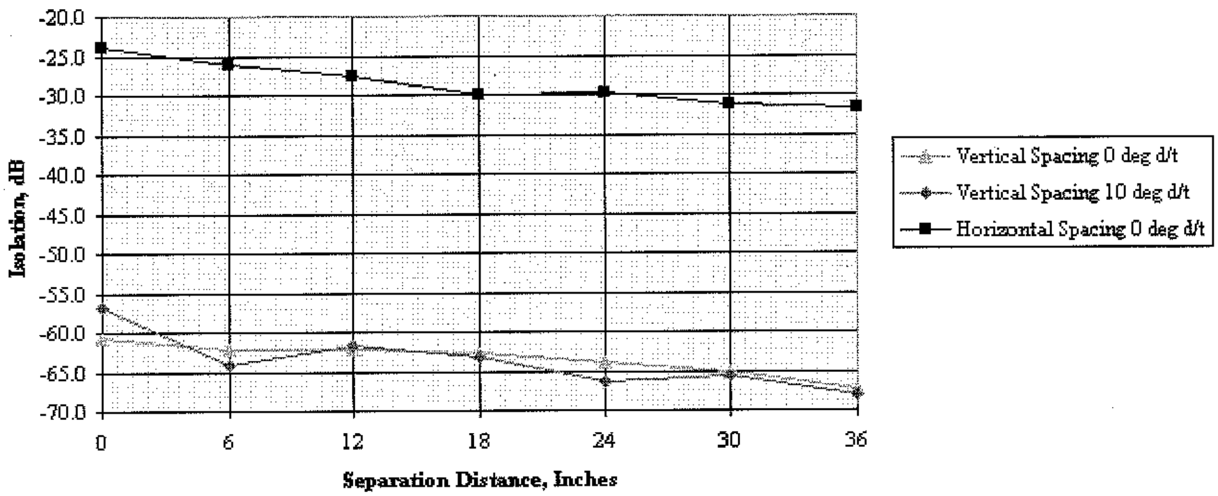



Figure 4: Broad Azimuth Beamwidth, High Gain Isolation Test 800 Mhz (2 x FV105-12-00DA2)

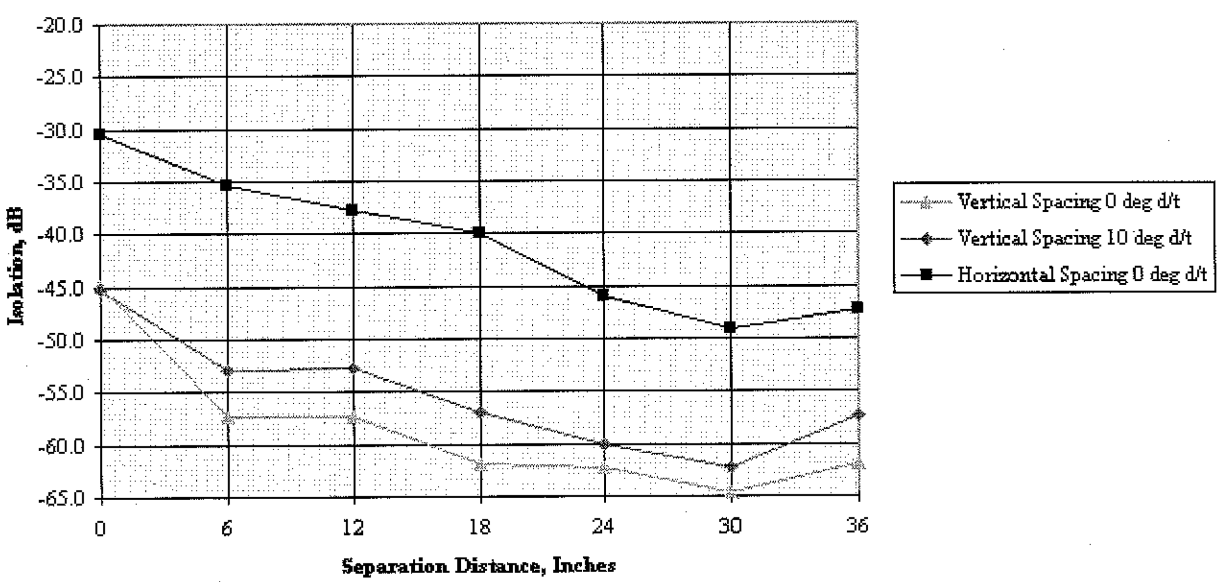



Figure 5: Narrow Azimuth Beamwidth, Low Gain Isolation Test 800 Mhz (2 x FV65-11-00DA2)

## Table 2: PCS Band Coupling Tests

| | | | |
|---|---|---|---|
| 1.) Broad beamwidth, High gain (2 x RV90-17-00DP) | | | |
| | Vertical Spacing | | Horizontal Spacing |
| Spacing inches | 0 deg d/t | 10 deg d/t | 0 deg d/t |
| 0 | -64.0 | -63.5 | -27.2 |
| 6 | -71.7 | -71.5 | -30.2 |
| 12 | -71.9 | -73.8 | -35.9 |
| 18 | -74.1 | -74.5 | -39.1 |
| 24 | -73.9 | -75.6 | -39.2 |
| 30 | -76.4 | -75.6 | -38.8 |
| 36 | -76.8 | -72.8 | -40.3 |
| 2.) Narrow beamwidth, High gain (2 x RV65-18-00DP) | | | |
| | Vertical Spacing | | Horizontal Spacing |
| Spacing inches | 0 deg d/t | 10 deg d/t | 0 deg d/t |
| 0 | -62.2 | -64.2 | -32.5 |
| 6 | -71.1 | -71.6 | -37.1 |
| 12 | -74.6 | -73.1 | -40.1 |
| 18 | -74.6 | -77.8 | -40.1 |
| 24 | -76.4 | -77.0 | -42.5 |
| 30 | -77.7 | -77.5 | -42.9 |
| 36 | -79.1 | -77.5 | -43.9 |

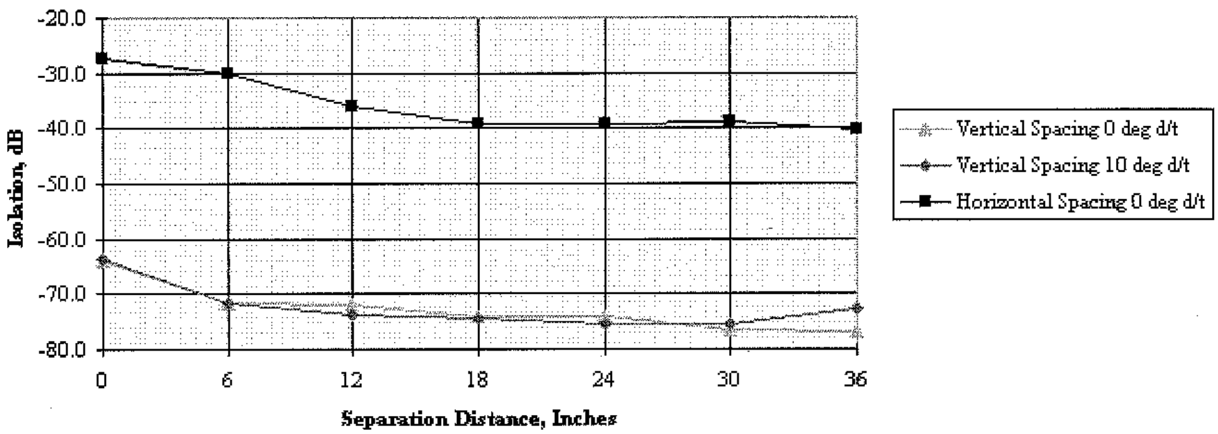



Figure 6: Broad Azimuth Beamwidth, High Gain Isolation Test 1900 Mhz (2 x RV90-17-00DP)

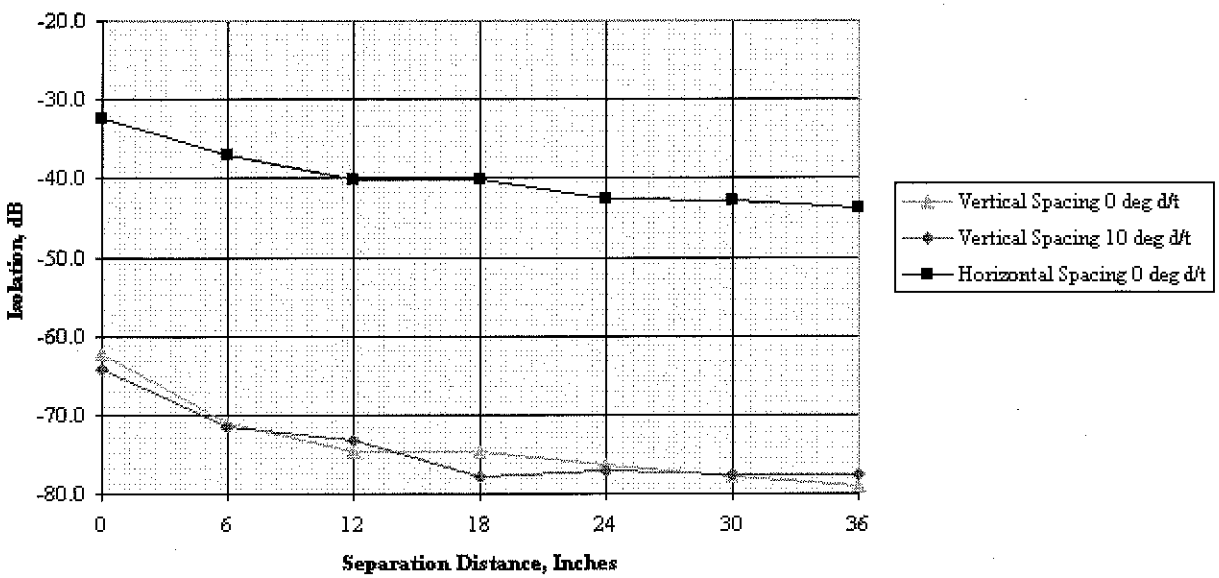



Figure 7: Narrow Azimuth Beamwidth, High Gain Isolation Test 1900 Mhz (2 x RV65-18-00DP)

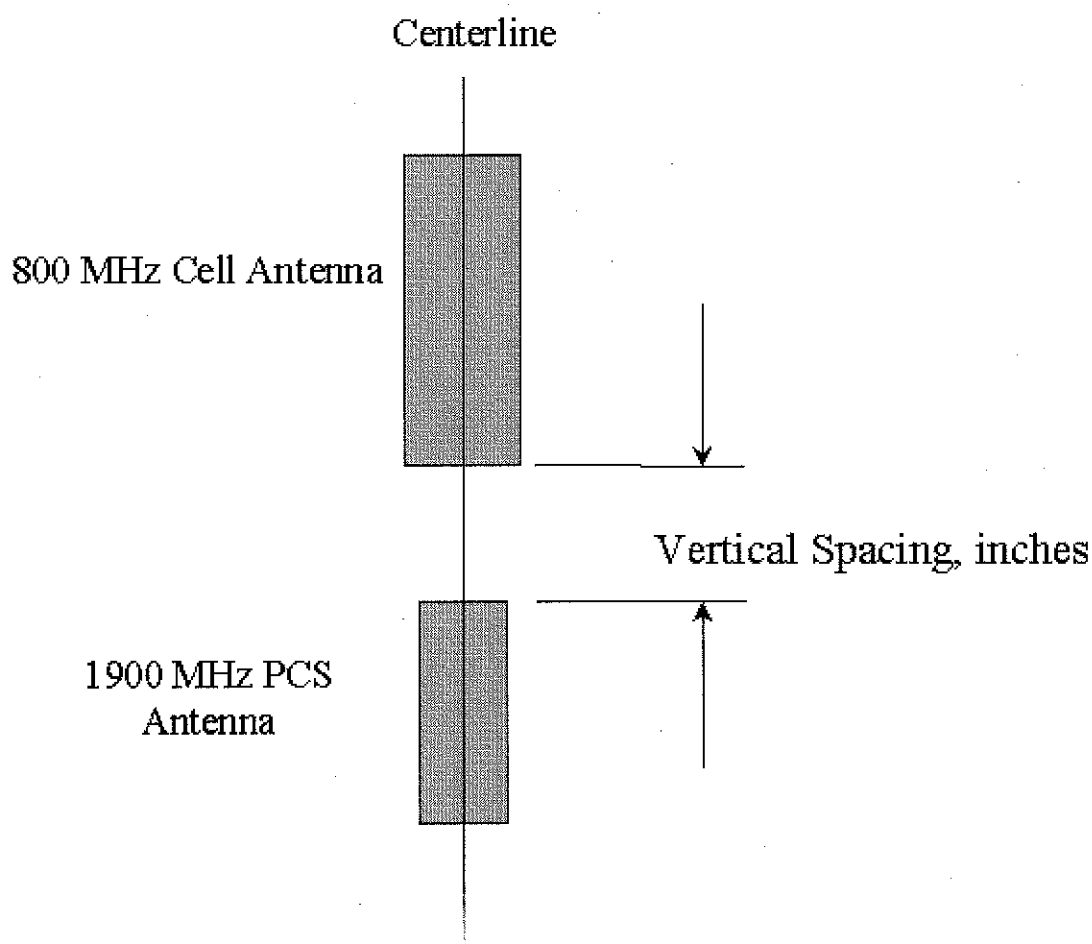



Figure 8: Cross-Band Isolation Test, Vertical Stacking

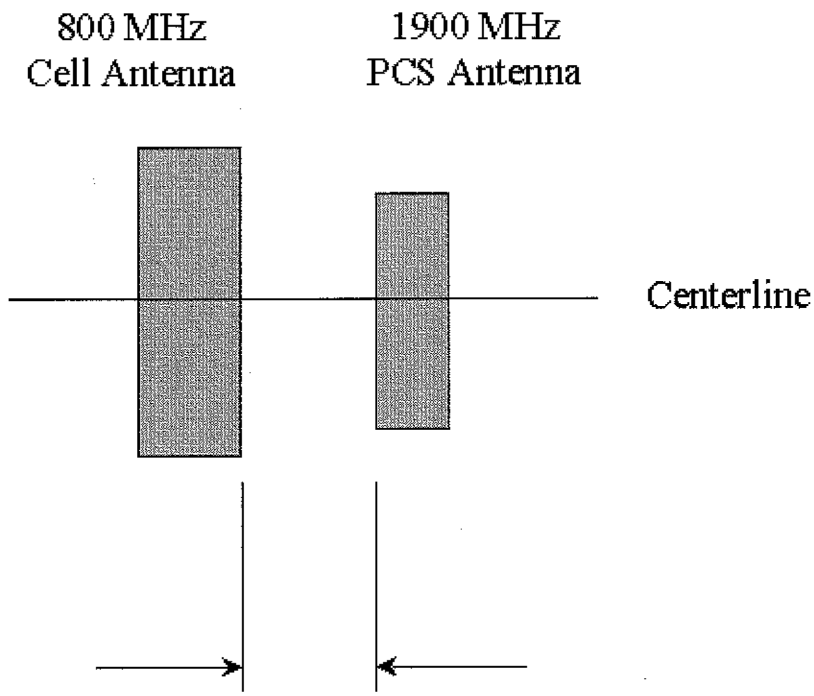



Figure 9: Cross-Band Isolation Test, Horizontal Stacking

## Horizontal Spacing, inches

1.) Swept at 800 MHz:

| Spacing | Vertical Spacing | Horizontal Spacing |
|---|---|---|
| 0 | -68.9 | -53.3 |
| 6 | -69.5 | -56.5 |
| 12 | -71.0 | -57.3 |
| 18 | -72.0 | -58.9 |
| 24 | -73.0 | -61.5 |
| 30 | -73.5 | -62.4 |
| 36 | -74.0 | -60.5 |

2.) Swept at 1900 MHz:

| Spacing | Vertical Spacing | Horizontal Spacing |
|---|---|---|
| 0 | -63.5 | -33.5 |
| 6 | -65.8 | -36.4 |
| 12 | -66.1 | -38.6 |
| 18 | -67.6 | -40.3 |
| 24 | -65.4 | -41.6 |
| 30 | -67.2 | -42.2 |
| 36 | -67.2 | -42.4 |

Table 3: Cross-Band Coupling Tests

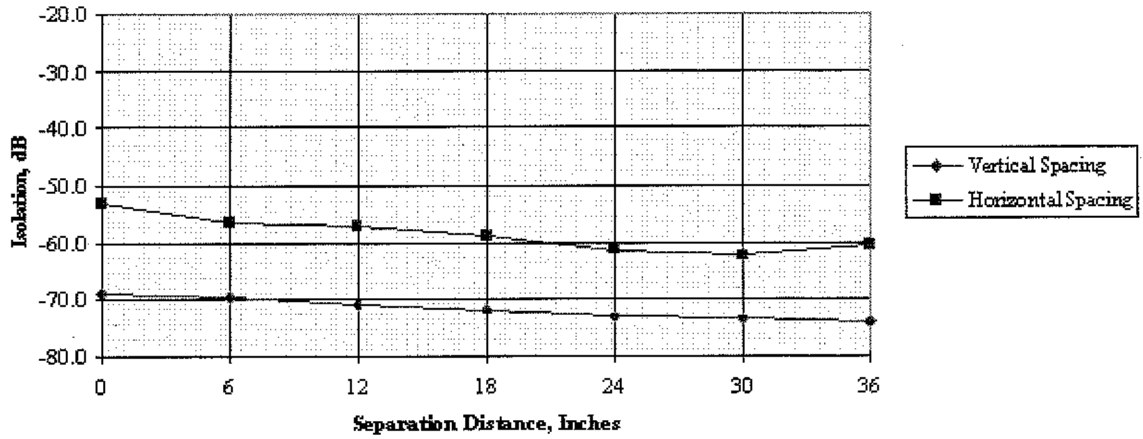



Figure 10: Cross Band Coupling Tests - 800 MHz Sweeps

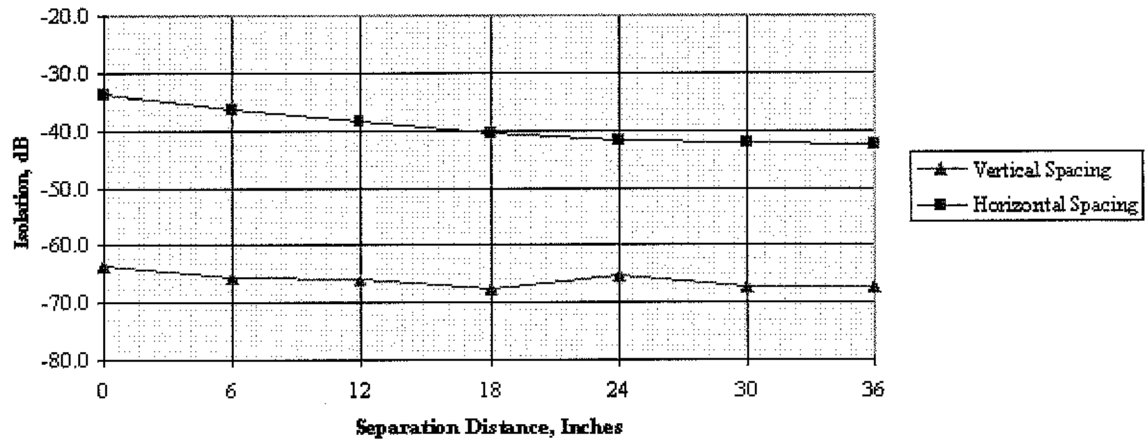



Figure 11: Cross Band Coupling Tests - 1900 MHz Sweeps

# Cingular Coverage Design Requirements for voice and data communications in GSM networks

In the NY/NJ Metropolitan area, Cingular Wireless has established design criteria for their subscribers that are consistent with industry standards. A "Link Budget", which is a summary of the network gains and losses, defines the maximum allowable path loss and establishes the design baseline. The link budget on the downlink path (from Base station to mobile unit) consists of 4 main parameters;

A. Mobile handset receive parameters
B. Environmental Losses/Statistical Reliability
C. Propagation Losses
D. Base station transmit power

Focusing on parameters A (Mobile Phone Specifications) and B (Environmental Losses/Statistical Reliability), one can define a minimum design signal level that is needed by the network to provide reliable communications, this minimum signal level will be the design baseline for the network.

## A) Receiver sensitivity = -102 dBm:

Receiver sensitivity (Rx Sens) is the minimum signal level required at the mobile antenna that will permit a mobile phone used by Cingular customers to operate. All manufacturers of cellular phones have to meet minimum design specifications that are established by the GSM standards committee in order to facilitate interoperability of equipment between different wireless operators, and to insure product quality. Receiver sensitivity is a very necessary design specification, and has been set by the GSM Standards committee to be -102 dBm. This value is actually derived from the following calculation based on the GSM standard 03.30.

Rx Sens for GSM = Noise Floor + Wb Noise + GSM Phone Noise Figure +Ec/Io
Rx Sens for GSM = -174 dBm + 53 dB + 10 dB + 8 dB = **-102 dBm**

Where:

GSM Phone Noise Fig = 10 dB
Ec/No (signal to noise) = 8 dB required for 2% BER.
Noise floor (Boltzman constant)= -174 dB in 1 Hz
Wb ( Noise environment: KTB)= 54.3 dBhz for 200Khz GSM BW.

* Rx Sens for TDMA is –104 dBm (Ec/No = 18, Wb = 42.3 for 30 Khz)

B) Environmental Losses / Statistical Reliability – 27 dB

Since it has been established that the phone sensitivity is set at –102dBm, this is the minimum signal level at the phone antenna that must be achieved to originate and maintain a phone call. If this is not met, then the mobile subscriber will experience degradation of the call and most likely a dropped call. The RF Design expert must account for all environmental and statistical parameters that will affect the signal level actually getting to the mobile phone, these factors include;

1. **Building Attenuation Loss – 15 dB**

   Most of today's wireless applications are geared towards in-building usage, for residential home use and office environment applications. Wireless frequencies are attenuated when passing though man-made or natural obstructions such as concrete block, plaster, wood and corrugated metal, and therefore the signal levels inside the building suffers substantially. This phenomenon can be easily observed everyday by watching someone with a cell phone walk into their office and drop their call in the building, or attempt to stay near a window when making a call, or dropping their call when they get into a conference room or elevator.

   There are many independent studies that have been conducted by the Institute for Industrial and Electronic Engineers (IEEE), ANSII, and other independent consultants with respect to the attenuation of cellular signals penetrating a building. All studies documented indicate average losses between 12 dB and 24 dB at 1900 MHz, meaning that approximately 94% to 99.6% of the signal is blocked from getting into the building.

2. **Mobile Phone Antenna Body Loss – 3 dB**
   Since most people utilize hands free kits for their cell phones, the typical antenna location is at the hip level. The human body blocks and attenuates a small portion of the signal from getting to the mobile phone. This is commonly referred to as "body loss". This effect has been studied expensively.

3. **Statistical Fading – 9 dB**
   –102dBm has been established as the minimum signal level for a GSM phone, the cell phone actually needs to maintain a "reliable" –102dBm in order to make, receive or maintain a phone call. Being part of the electromagnetic spectrum, radio waves exhibit the same characteristics as light waves. There are three basic mechanisms that impact signal propagation in mobile communication systems; reflection, diffraction and scattering. Through a combination of these factors, RF can travel over several different paths between the transmitter and the receiver. The effect can cause fluctuations in the received signal's amplitude, phase and angle of arrival. When the signals coming from multiple paths overlap out of

phase, the net signal is severely attenuated. This phenomenon is termed as Multi path Fading.

With no line-of-sight propagation path and multiple reflective paths, the envelope of the received signal is statistically described as a Rayleigh power distribution function. When there is a dominant non fading signal component present, the envelope is described as Rician pdf. To account for the fading effect of the signal, a Fade Margin is introduced in the Link Budget of the system being designed. The Fade Margin also determines the Area Reliability of the system. Theoretically, with the Rayleigh distribution and no fade margin, the network will be just 50 % reliable. The actual value of the Fade Margin to be used is determined by the Contour Reliability targeted which also extrapolates to the Area Reliability of the network. In practice, a 95 % area reliability is the target objective of most wireless carrier providers.

It is very rare for a mobile phone to have direct line of sight to the nearest cell tower, so the RF path between the cell phone and the tower are not laser-beam line of sight links, but more a combination of indirect signals. Local clutter, such as buildings, vehicles, trees, etc causes scattering of RF signals which is commonly referred to as multi-path. Because of the various multi path components being received, physics dictate that RF signals are therefore dynamic in nature and follow a Gaussian distribution. In many circumstances, received signal levels can fluctuate by more than 6-10 dB without the cell phone even moving. If the average signal level is −102 dBm, approximately 50% of the time it will be better and approximately 50% of the time it will be weaker. A fade margin of 9 dB is introduced into the calculations to insure that the phone receives −102 dBm over 95% of the time. This insures a "quality" phone call.

**References:**


1. *Rayleigh Fading Channels in Mobile Digital Communication Systems Part I : Characterization by Bernard Sklar, IEEE Communications Magazine July 1997*
2. *The Post-Processing Resolution Required for Accurate Coverage Validation and Prediction by Pete Bernadin and Kanagalu Manoj, IEEE Transactions on Vehicular Technology, VOL 49, No. 5, Sept 2000 pp1516-1521*
3. *A Report on Technology Independent Methodology for the Modeling, Simulation and Empirical Verification of Wireless Communications System Performance in Noise and Interference Limited Systems Operating on Frequencies between 30 and 1500 Mhz, pepared by TIA TR8 Group 8.8 Technology Compatibility, May 1997*

Given the above Engineering design guidelines, the "Resulting Design Requirement" for Cingular becomes –75 dBm, this is the minimum design signal level that is needed to insure quality customer service.

| Parameter | Components Description | Value | Units |
|---|---|---|---|
| Receiver Sensitivity | Thermal Noise Floor (1 Hz) | -174 | dBm for 1 Hz |
| | Wb Noise for 200 Khz(271Khz effective) | 54.3 | dBHz for 271 KHz |
| | GSM Phone Noise Figure | 10 | dB |
| | Required Signal to Noise Ratio | 8 | dB |
| | Resulting Mobile Sensitivity | **-102** | dBm |
| Environmental Losses | Body Loss (Phones worn at belt) | **3** | dB |
| | Building Penetration Loss | **15** | dB |
| Statistical Losses | Log-Normal Fade Margin | **6** | dB |
| | Raleigh Fade Margin | **3** | dB |
| | ***Resulting Design Requirement*** | **-75** | dBm |

**Building Attenuation**: Building attenuation was studied for the 850 and 1900 Mhz bands some years ago, and reports were published by ETSI, COST231, FCC, IEEE…

References:

1.H.E Walker, "Penetration of radio signals into buildings in the cellular radio environment" 1983.
2.A.M.D Turkmani, " Radio propagation into buildings at 1.8 GHz" 1991, " Building penetration Losses" Cost231 116 rev1 1991
3."Estimating Coverage of Radio Transmission into and within Building at 900, 1800 and 2300 MHz" 1070-9916/98 IEEE 1998.
4."In building penetration Margin" presented at an IEE conference and published by the FCC.

## FCC Form 601:

Within 5 years of being licensed the FCC requires licensees of PCS spectrum blocks to serve with a signal level sufficient to provide adequate service to at least 25% of the population in the service area or make a showing of substantial service. "Substantial service" is defined by the FCC as service that sound, favorable, and substantially above a level of mediocre service.

In 1996, Cellular operator provided basic outdoor coverage for voice communication. As today GSM customers want to be able to use their cellular phones for voice and data, outside and inside buildings with a 95% reliability.

---------------------------------------------------------X

In the matter of

**Affidavit**

**OMNIPOINT COMMUNICATIONS, INC.**

---------------------------------------------------------X

State of New Jersey )
) ss:
County of Morris )

**MARK COSGROVE,** being duly sworn, does depose and say:

1. I am a national **Director of Radio Frequency Engineering** for Omnipoint Communications, Inc. (the "Applicant" or "Omnipoint"). I submit this affidavit in support of the application by Omnipoint for approval for the installation of a wireless communication public utility facility ("Facility").

2. I am a qualified radio frequency engineer. I have been trained to identify gaps in reliable service in wireless communications systems and to assess the ability of proposed antenna sites to remedy gaps in signal coverage. I have extensive training and experience with respect to Omnipoint's wireless system and technology, as detailed by my curriculum vitae, a copy of which is attached hereto as Exhibit 1.

3. I have 15 years experience designing, implementing and operating wireless networks, specifically Global System for Mobile communications technology ("GSM") based networks. GSM technology is a second generation digital technology originally developed for use in Europe and which is now used by more than seventy-one

percent (71%) of the world market. GSM technology is, therefore, a very common mobile technology.

4. The purpose of this affidavit is to establish the technical and scientific basis for Omnipoint's design criteria as it relates to signal level.

## Omnipoint's Design Criteria

5. By way of background, Omnipoint has established design criteria so that its wireless network will provide reliable wireless service to its customers, whether those customers are on the street, in a vehicle, or in a building. Providing reliable service to Omnipoint's customers within vehicles and buildings is critical for Omnipoint to provide the quality of wireless service that customers demand and successfully compete with other wireless providers, such as Sprint Nextel, Cingular and Verizon Wireless. To meet customer demands, there are three levels of coverage that Omnipoint strives to provide: In-Vehicle coverage, In-Building Residential coverage, and In-Building Commercial coverage. It is important to understand that the levels of coverage do not represent an objective to achieve a higher level of call quality but to maintain a minimum signal strength and hence reliability of service at the mobile handset as the environment changes. As further detailed below, the signal is, by its nature, subject to attenuation depending upon the conditions and characteristics of the area. The following is a brief description of each level of coverage.

6. <u>In-Vehicle Coverage</u>: To successfully provide reliable In-Vehicle coverage, an Omnipoint customer should be able to place or receive a call within a vehicle successfully across 95% of a site's coverage area. In-Vehicle coverage is the minimum level of acceptable coverage within the Omnipoint network in areas with low population and along major highways covering rural areas. One must bear in mind that designing for only the In-Vehicle coverage threshold will typically result in unreliable in-building coverage, and hence customer dissatisfaction. However, since the signal level is stronger closer to the antenna site than further away from the antenna site, there will be some coverage within buildings close to the site. At this time, Omnipoint utilizes the In-

Vehicle coverage design in low population density areas within Omnipoint's licensed coverage area.

7. In-Building Residential Coverage: To successfully provide reliable In-Building Residential coverage, an Omnipoint customer should be able to place or receive a call on the ground floor of a building that is three stories or less in height successfully across 95% of the site's coverage area. In-Building Residential coverage is the mid-level of coverage within Omnipoint's network. In-Building Residential coverage is targeted for residential areas and low-rise commercial districts with building heights of three stories or less. This type of coverage will typically provide reliable coverage over the majority of the cell coverage area; however in some areas, and specifically at the outer geographic boundaries of the cell sites' coverage area, coverage will be restricted only to rooms with windows and will likely lead to customer dissatisfaction if customers try to place or receive a call inside a windowless room, cellar or emergency shelter.

8. In-Building Commercial Coverage: To successfully provide reliable In-Building Commercial coverage, an Omnipoint customer should be able to place or receive a call on the ground floor of a building that is greater than three stories in height successfully across 95% of a site's coverage area. In-Building Commercial coverage is the top level of coverage within the Omnipoint network at this time. In-Building Commercial coverage is targeted for urban residential centers (high-rise buildings), urban business districts and suburban business centers. Coverage issues may still occur in hard to serve locations such as within elevators and parking structures.

9. Signal Strength: To provide these levels of coverage, Omnipoint has scientifically determined the strength of the wireless signal ("signal strength") necessary to provide In-Vehicle coverage, In-Building Residential coverage, or In-Building Commercial coverage. Because wireless signals are attenuated (i.e. degraded or partially blocked) by obstructions such as trees, automobile windows, automobile sheet metal, and building materials such as wood, brick and metal, a wireless signal must be of sufficient strength in the ambient environment (i.e. outside with no obstructions) to reliably penetrate into automobiles and buildings.

10. Assume for example that a homeowner placed a radio on the front lawn of his house and played a song. The sound level would be louder closer to the radio than farther away because audio sound waves weaken as they travel farther away from their source. The song will be clearly audible to a person with average hearing capacity sitting on the front lawn next to the radio. Another person may be able to hear the song within her car parked in the driveway a short distance away from the radio, although she may have difficulty deciphering the words. Still another person within the house may not be able to hear the song at all. For the person within the house to hear the song, the radio must be moved closer to the house. The song cannot simply be made louder within the house by turning up the volume, as there is a practical limit to how much sound (power) the loudspeakers can produce without physically damaging the radio, or introducing distortion into the sound. Similarly, a cell site's transmission power is limited by the physical output power capabilities of the amplifiers and the legal restrictions of the licenses Omnipoint operates under. It is also important to understand that unlike this simple radio analogy, a wireless telecommunication system is a two-way system. The signal is transmitted from the antenna site to the receiver in the wireless phone. The wireless phone transmits a signal back to a receiver at the antenna site. Each signal link must work for reliable two-way communication. Therefore, Omnipoint cannot simply turn up the power on its antenna site to provide a stronger signal level because doing this has no impact on the ability of the mobile phone to transmit a signal back to the receiver at the antenna site. The radio frequency power output of mobile phones is far less than the typical output power at the cell site. Although the cell site has some techniques to redress this power imbalance, the link must remain balanced. Accordingly, the relevant question is as follows: How close must the radio be to the house so that the radio waves are strong enough for the person in the house to clearly hear the song? In like manner, Omnipoint's design criteria reflect the need to provide a wireless signal strong enough to provide reliable service within a vehicle or building.

11. Required Signal Strength Levels: Wireless signal strength is measured on a logarithmic power scale referenced to 1 milli-watt of power. Signal strength levels less than 1milli-watt being negative. The smaller the negative dBm number, the stronger the

signal. For example, -76dBm is a stronger signal level than –84dBm. Omnipoint's system requires an ambient signal level of –84dBm to provide reliable In-Vehicle coverage, and an ambient signal level of –76dBm to provide reliable In-Building Residential coverage. An ambient signal level of –71dBm is required to provide reliable In-Building Commercial coverage. These signal level requirements provide the basis for Omnipoint's design criteria.

**The Technical Basis for Omnipoint's Design Criteria**

12. At present Omnipoint's design criteria for wireless facilities serving an area are based upon providing 95% reliable signal over a site's coverage area to ensure reliable service for customers. This standard reflects a business judgment that 100% reliability is an unrealistic goal at this time due to financial, technical and environmental constraints. A 95% level of reliability is consistent with the level of service provided by Omnipoint's competitors. Providing service at this level allows Omnipoint to satisfy customers' demands and compete on an equal footing with competitors serving this market.

13. To achieve the 95% reliable design goal, maximum path loss values are derived based upon Omnipoint's technology and the area served. Path loss means the amount the Omnipoint signal is degraded from the point at which the signal leaves the Omnipoint antenna site until it reaches the Omnipoint customer's mobile device or telephone. The equation is as follows: In-Building coverage = Receiver Sensitivity + Body Loss + In Building Loss with Standard Deviation + Fade Margin. Each component of this equation is described below.

14. Returning to our earlier example of the radio on the lawn, we must first determine the minimum song volume for a typical person to hear the song. This is the equivalent to the Receiver Sensitivity. We must then determine the degree to which the vehicle, the building and other obstructions in the environment obstruct the song, which is the equivalent to the path loss. Finally we need to introduce the concept of probability. As we do not know the exact location or direction of the listener, we need to make some

adjustments for known variances to provide us with a 95% success target, this is the Fade Margin. These radio frequency engineering concepts are explained in more detail below.

15. Receiver Sensitivity: We start with the minimum signal level necessary for a common Omnipoint telephone or wireless device to reliably operate. This minimum signal level is known as the receiver sensitivity, or RX sensitivity. Using the prior example, the minimum signal level is the minimum volume level the radio must be set to enable a typical person to hear and understand the lyrics of the song.

16. Omnipoint's technology is defined by the PCS 1900 Specification, "Radio Transmission and Reception", J-STD 007 Air Interface: Volume 1, 1998, which is based on the European Telecommunication Standards Institute (ETSI) GSM recommendations (05.05: ETSI EN 300 910 V8.5.0 (2000-07)). Both technical documents specify a Receiver Sensitivity value of –102dBm for mobiles operating in the United States. In these independent technical specifications the Receiver Sensitivity is referenced to certain Bit Error Rates ("BER"). The BER limits the speech quality of the call. Receiver Sensitivity refers to the practical limit at which speech quality of a wireless call starts to be severely impacted. The actual BER attained by a mobile device is dependent on a number of factors, including the build quality of the mobile device, the environment the mobile device is operating in (whether in a City or rural area), the speed the mobile user is traveling (slow moving mobile devices suffer extreme variations in performance), the type of radio carrier carrying the mobile call (GSM uses different types of carriers, each having differing performance characteristics) and finally the amount of interference present from other Omnipoint mobile users and other external sources.

17. Real world Receiver Sensitivities (the true limit of acceptable speech) can vary between -93dBm and -108dBm depending on the above factors. ETSI Technical Report 03.30 (GSM Planning Aspects) recommends Receiver Sensitivity of -102dBm. In addition, this Technical Report also recommends the use of an Interference Margin of 3dB. This is due to the manner in which Receiver Sensitivity is specified in GSM. Receiver Sensitivity is specified as the performance limit in a purely noise limited

environment (a single radio carrier). Mobile handset receivers in real world uses operate in the presence of interference as carrier frequencies are re-used. To account for this additional signal degradation an additional allowance of 3dB is made at the receiver due to the presence of these multiple interfering sources. This reduces the Receiver Sensitivity to –99dBm. GSM interference performance is only guaranteed at signal strengths above Receiver Sensitivity. <u>See</u> GSM Recommendations 05.05.

18. Omnipoint has opted not to expressly highlight this Interference Margin in our design guideline calculation since our practical experience has been that the mobile devices have achieved slightly better performance than that originally specified in the GSM Recommendations. Omnipoint effectively uses a design level of the Receiver Sensitivity of –105dBm plus the 3dB Interference Margin. This design level also matches the output power of 1W maximum available power from the mobile device, i.e. a lower assumption on the Receiver Sensitivity would only make the link limited by the mobile to cell site transmission path.

19. Next, we must factor in the signal path losses relative to the receiver sensitivity. Such signal path losses include the body loss, vehicle or building loss, the standard deviation and fade margin as explained below. To return to the analogy by considering these factors we are addressing, to what extent does the car, building or other variables in the environment obstruct the song?

20. <u>Body Loss</u>: Since the mobile device or phone is carried and used by a person, the position of the mobile device or phone with respect to the user's body has an effect on the received radio signal. When the user's body is situated between the mobile telephone's antenna and the antenna site, the user's body will absorb some of the radio energy. Omnipoint customers do not ordinarily position the telephone so that the antenna on the mobile telephone directly faces the antenna site. Therefore, the customers' bodies often partially block the signal. Additional factors can influence Body Loss. For example, in New York State it is illegal for a customer to use a mobile device while driving, and hence customers use either wired or remote headsets. Customers now generally keep the mobile devices clipped to a belt or in a breast pocket. Studies have

produced detailed measurements of the effect of body shielding with respect to mobile device position for different radio environments. See Sakamoto M. *et al*: "Basic Study on Portable Radio Telephone System Design" IEEE VTC Conference 1982. For mobile devices held vertically, the body loss varies from 1.5dB for the head to 4.9dB for the trunk (a mobile device clipped to a belt or placed in a jacket pocket for example). For a mobile device held horizontally, the loss due to the head increases to 5.8dB, with the loss due to the trunk being 4.2dB. ETSI Technical Report 03.30 GSM Planning Aspects recommends use of a body loss of 3dB. Based on the foregoing, Omnipoint uses an average body loss of 3dB.

21. Building Loss: The concept of building attenuation, commonly referred to as building loss, has long been defined as the difference between the median field strength intensity at street level averaged around the exterior of the building, and the median field strength intensity at a location on the first floor inside the building. This difference is known as the building loss. See Rice LP: "Radio Transmission into buildings on 35 and 150 MHz" Bell Systems Technical Journal 1959. Many measurements have been performed to derive values of the mean building loss for different types of buildings and environments. One researcher found mean losses of approximately 27dB for downtown Tokyo. See Kozono et al: "Influence of Environmental Buildings on UHF Land Mobile Radio Propagation" IEEE Transactions on communications October 1977. Another researcher has described losses of 15dB for downtown Chicago. See Walker E H: "Penetration of radio signals in to buildings in a Cellular Environment" Bell Systems Technical Journal 1983. Extensive measurements were performed at 900MHz in New York and determined that the median value of loss is 20dB. See Durante J: "Building Penetration loss at 900MHz" IEEE VTG Conference 1973. Researchers in Philadelphia, measured building losses averaging 16dB at 1900Mhz and 19dB at 800MHz for a range of buildings in urban, suburban and rural areas. See Tanis W and Pilato G: "Building penetration characteristics of 880MHz and 1922MHz Radio Waves" IEEE Journal 1993. Measurements in Liverpool, UK, showed losses averaging 13.4dB for measurements made at the ground floor of buildings. See Turkmani A and Toledo A: Radio Transmission at 1800MHz in to and within multistory buildings", IEEE Proceedings-1, vol 138, No 6 December 1991. Further measurements

within Liverpool showed losses of between 24dB and 9dB for buildings in the City center and losses on the University campus of between 14 and 18dB. See Toledo A, Turkmani A and Parsons J, IEEE Personal Communications, April 1998. The ETSI Technical Report 03.30 (GSM Planning Aspects) uses building losses of 15dB for urban and 10dB for rural areas. Based on the foregoing, and as further described below, Omnipoint uses an 11dB loss for In-Building Residential and a 16dB loss for In-Building Commercial.

22. In addition to the "static" loss of 11 and 16dB, Omnipoint uses the reported "Standard Deviation" of building loss of 6.5dB and 7.0dB as reported in the references above. Durante and Rice compiled the largest set of measurement results in order to extract the standard deviation of the building loss. Rice quoted a deviation of 12 to 14dB around the mean loss and Durante reported 5 to 7.5dB deviation for ground floor measurements. Turkmani *et. al.* reported a standard deviation of 7.2dB for the buildings in the Liverpool measurement study. Standard Deviation is used to overcome the statistical distributions of building losses in an area. For example, the average loss for Residential buildings may be 11dB. However, some buildings made of brick or with aluminum siding, for example, may have much greater losses as high as 25dB or more. The standard deviation of the building loss is used in a calculation to ensure that 95% of buildings are covered and not just 50% of buildings if only the mean loss was taken into account.

23. Vehicle Loss: With respect to vehicle loss, it is important to note that the majority of customers use hand portable devices without exterior antennas on the vehicle. The signal strength loss due to the need to penetrate the vehicle to reach the handset must be taken into account when designing RF coverage for highways using the In-Vehicle coverage criteria. Extensive measurements have been performed at 900 MHz in three vehicle types; minivan, full sized car and small sports car. See Ivica Kostanic, Chris Hall and John McCarthy, TEC CELLULAR, Inc., VTC IEEE Conference 1997. Measurements were made with the mobile phone adjacent to the driver's head, with the mobile phone on the dashboard and with the mobile phone on the passenger seat. It was determined that for a minivan, losses (including body losses) were between 8 and 9dB with a standard deviation of 2 to 3dB. Losses for a full sized car were between 7.25 and

9dB (including body losses). Due to size of the windows in the small sports car, losses were found to be higher at between 9 and 14dB. ETSI Technical Report 03.30 (GSM Planning Aspects) recommends a vehicle loss of 6dB. Based on the foregoing, Omnipoint utilizes a figure of 6dB for vehicle losses.

24. Fade Margin and Standard Deviation: The standard deviation is a mathematical expression of how a set of data samples varies from the mean value. For example, if an observer was to measure the speeds of cars passing a point and plot the number of cars observed at each speed the graph would probably resembles a "Bell" curve. One speed will be the mean or average speed and represent the top of the Bell. On either side of this mean, fewer and fewer cars will have higher or lower speeds, forming the sloping sides of the Bell. The Standard Deviation is a measure of the width of the Bell. A low Standard Deviation would represent a narrow Bell. A large standard deviation would represent a wide Bell. In a mobile radio environment the observed signal strength varies at any point due to the radio waves taking numerous different paths from the transmit antenna to the receiver antenna and the minute variations in the surroundings (moving objects, vibrations, temperature effects, and local obstructions such as cars and trees). These effects produce "Fast" changing signal strengths at the mobile device. These effects are generally overcome by system features such as "Frequency Hopping", where the radio frequency is changed many times a second. Terrain obstacles, trees, and buildings, produce "Slow" changing effects, where the signal strength at the mobile device can change as the user moves a short distance. All of us will experience these effects if we talk on a wireless handset while walking. The observed signal strength will change as we move along. Slow fading effects result in a margin of error between the propagation tools used to prepare the coverage maps, and the mean signal at the mobile device. These Slow or Shadow fading effects must be compensated for in the design of the system.

25. Digital planning tools try to match a model of the propagation environment to known measurements in an area. If the model is successful then the accuracy of the model will approach the slow fading levels encountered in the field. A good model will estimate the long-term average mean of the signal over the prediction

square or bin (generally a 100 meter or 25 meter square). The slow fading and any additional model errors will be seen as a standard deviation of the tool when compared to known measurements. The planning tool that Omnipoint employs uses industry leading digital terrain and environmental databases and uses advanced calculations to produce an accurate estimation of the signal strength on the ground. The accuracy of the tool is better than 8 to 12dB Standard Deviation depending on environment as quoted by the manufacturer Aircom and verified by field measurements. The tool uses the European Cooperation in the Field of Scientific and Technical Research Subgroup on Propagation (Cost 231) Model. This is an extended version of the industry standard Okumura-Hata model.

26. Slow fading measurements in the field show a typical range of between 4 and 6 dB for non line of sight environments and between 6 and 9dB where a dominant propagation path exists. See Turkmani A and Toledo A: Estimating Coverage of Radio Transmission in to and within Buildings at 900, 1800 and 2300MHz, IEEE Personal Communications, April 1998. Based on the accuracy of the tool in resolving shadowing errors and the residual slow fading error inherent in radio transmissions, Omnipoint utilizes a slow/shadow fading standard deviation of 8dB. It is important to understand that the published measurements of slow fading relate to measurements at a single point whereas Omnipoint is setting a compensation figure for the variance in predicted signal over a wider 100m bin.

27. The building losses also include a measure of variance with the Standard Deviation of the building losses being between 6.5dB and 7.0dB. The slow fading Standard Deviation and the in-building loss Standard Deviation are statistically independent and hence can be combined in to a single distribution using the following formula:

$$\sigma = \sqrt{(\sigma^2_{slowfading} + \sigma^2_{building\ loss})}$$

28. The computer software-planning tool creates a propagation map by predicting the average signal strength for a small area (e.g. a 100m by 100m square), based on a digital terrain database and a computer model that predicts the mean signal for

each small area. A margin of error due to the Standard Deviation of the slow fading and building losses exists between the tool's prediction and the expected mean signal level.

29. The expected signal strength forms a lognormal distribution (a "bell" curve) around the predicted local mean. In other words, due to the variation in the environment across the predicted area, an additional margin is needed such that a certain probability of coverage is attained. This margin is deemed the Fade Margin.

30. Two methods may be used to calculate the Fade Margin. The first method uses the probability of a detected signal strength exceeding a defined threshold across a single prediction square (edge probability). The second method uses the probability across many squares to provide a wide area probability (cell area probability). Both probabilities are interlinked and depend on the variation in signal strength across the small prediction area, i.e. the standard deviation ("σ").

31. Determination of the fade margin and associated area cell reliability figures are calculated using the lognormal fading equations and methodology. See W.C. Jakes, Jr., "Microwave Mobile Communications," John Wiley & Sons, New York, 1974 (p. 126). This is the standard recommended methodology as described by the ETSI Technical Report of GSM Planning Aspects. The appropriate fade margin for 95% reliability employs the following equation:

$$Fu = \frac{1}{2}\left[1 - erf(a) + \exp\left(\frac{1-2ab}{b^2}\right)\left(1 - erf\left(\frac{1-ab}{b}\right)\right)\right]$$

Given that

$$a = \frac{X_0 - X}{\sigma\sqrt{2}} \qquad b = \frac{10n\log(e)}{\sigma\sqrt{2}}$$

Where Fu represents the fraction of useful area for which the signal strength x exceeds a given threshold Xo (the wanted fade margin). σ is the combined standard deviation and n represents the distance/power law relationship. "n" is the rate at which radio waves decrease with the Log of distance. It has been shown to be between 2 and 6, see Turkmani A and Toledo A: Radio transmission at 1800MHz into and within multistory buildings, IEE Proceedings vol 138, No6 Dec 1991. The value of "n" depends on the environment and propagation conditions. Omnipoint uses a value of 3.5 as recommended in ETSI Technical Report 03.30 (GSM Planning Aspects).

For example, in a suburban environment, design levels for In-Vehicle would be calculated by the following:

$\sigma$ = 8dB

Body Loss = 3dB

In vehicle loss = 6dB

Receiver Sensitivity = -102dBm

Path loss n = 3.5.

Reliability = 95%

The required signal on the street outside the vehicle would be:

Xo = Receiver Sensitivity + body loss + In-Vehicle loss

= -102dBm + 3dB + 6dB

= -93dBm

Setting Fu= 0.95, n=3.5 Xo=-93dBm and $\sigma$=8dB and solving for X in the equation above gives X= -84.4dBm, i.e. a total fade margin of 17.6dB.

32. The appropriate signal strength planning levels for all area types are shown in the table below.

| Area | MS (Rx Sensitivity) | Fade Margin and losses | Planning Level |
|---|---|---|---|
| In-Vehicle | -102 dBm | 17.6 | -84.4 dBm |
| In-Building (residential) | -102 dBm | 26.0 | -76.0 dBm |
| In-Building (commercial) | -102 dBm | 31.4 | -70.6 dBm |

33. Based on the foregoing, Omnipoint's design criteria are factually and statistically justified.

## Conclusion

Based on the foregoing, I respectfully request that the application by Omnipoint be favorably considered and the requested approval be granted forthwith.

Respectfully submitted,

Mark Cosgrove

MARK COSGROVE

Sworn to before me this

23rd day of January, 2006

Roberta S. Bornstein

Notary Public

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ROBERTA S. BORNSTEIN
Notary Public of New Jersey
My Commision Expires 7/03/10