White Paper

Potential Blanketing Interference from DARS Repeaters to WCS Receivers

The purpose of this paper is to describe in more detail XM Radio's technical analysis of this key issue. The analysis demonstrates the following principles:

- XM Radio has been able to design and deploy repeater receivers and consumer receivers at reasonable cost so that they are essentially immune from blanketing interference in the presence of repeater transmissions. This experience demonstrates that WCS licensees should be able to design and deploy base station and consumer receivers at reasonable cost that are similarly immune from blanketing interference. The principal measure that WCS licensees need to take for their base station receivers is the insertion of filters and, for consumer receivers, the use of wideband Automatic Gain Control.

- The experience of XM Radio with proper repeater facilities deployment also supports the ability of WCS licensees to overcome the risk of blanketing interference.

- XM Radio's modification of its repeaters that operate at $\leq$2 kW to shift from omnidirectional antennas to sectorized antennas reduces the potential for interference to WCS receivers.

- XM Radio's current design, using fewer repeaters with higher power, rather than more repeaters with lower power, reduces the size of any exclusion zone that WCS will experience, even assuming a line-of-sight, free-space-loss analysis for WCS receivers that are highly susceptible to blanketing interference.

I. WCS Receiver Susceptibility Can Be Substantially Improved

A. The experience of the DARS licensees

The experience of XM Radio and Sirius with the design and manufacture of receivers that need to operate in the same RF environment as the WCS licensees' receivers provides ample evidence that potential problems of blanketing interference and intermodulation can be effectively eliminated by careful but not costly receiver design or the use of filters. XM Radio and Sirius each have been able to develop both repeater receivers and consumer receivers that are capable of operating within just a few feet of the terrestrial repeaters of the other's system without experiencing blanketing interference or intermodulation interference.

DARS repeater receivers. Every XM repeater contains a collocated, highly sensitive satellite receiver, which provides error free reception of the XM satellite signal while separated by only 1.8 MHz from the high power terrestrial transmitter. The repeater transmitter does not overload the XM repeater receivers. In addition, the repeater transmit filter severly limits the amount of transmitted signal energy in the adjacent XM Radio satellite receive bands. The XM repeater receivers are protected from blanketing interference by installing notch filters that attenuate the transmitter energy by 35 dB. These are relatively small filters (6"x8.5"x2.5") and the insertion loss is less than 1 dB. The measured performance of the filter is depicted in Figure 1.

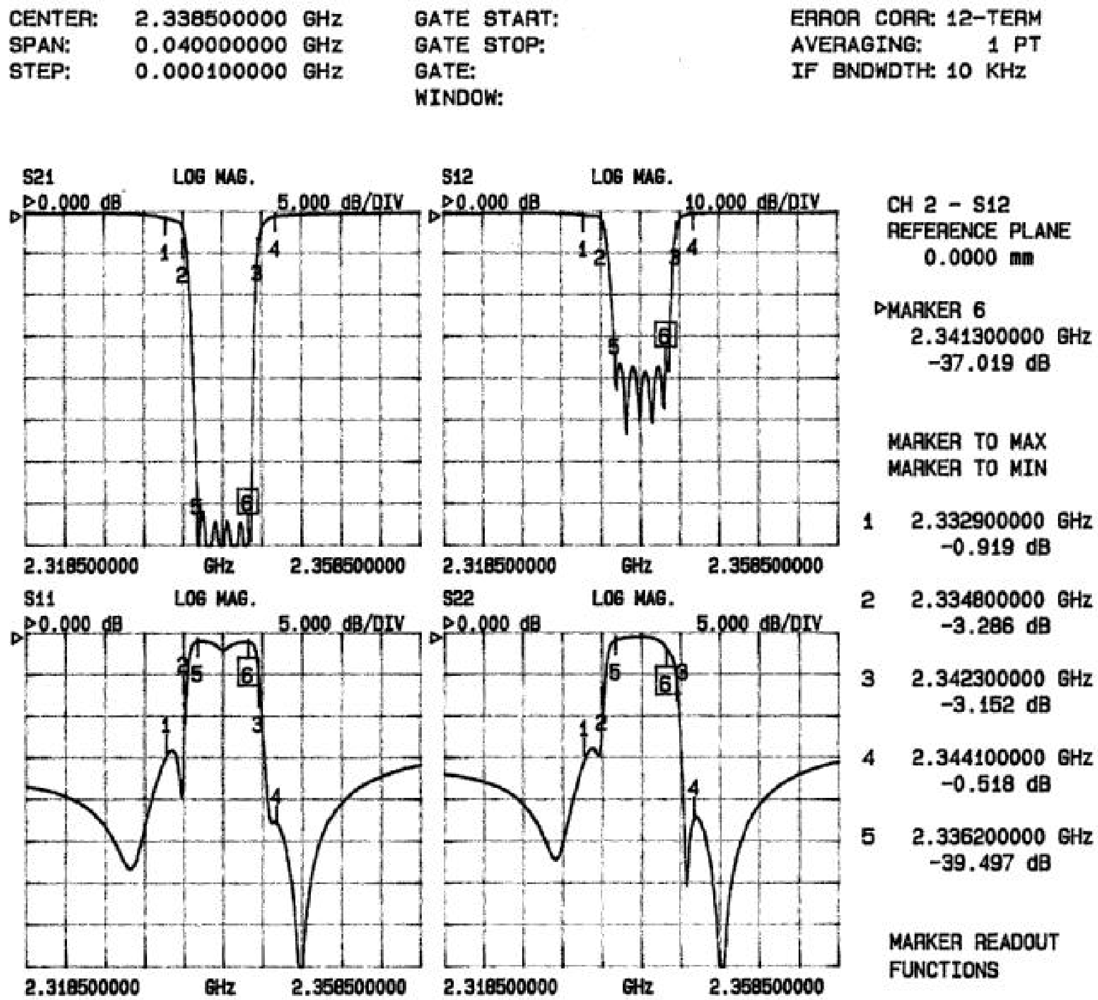


Figure 1. XM Repeater Notch Filter Measured Performance

DARS consumer receivers. In the case of our consumer receivers, we have used wideband automatic gain control (AGC) at the RF front-end to reduce the potential for blanketing interference from Sirius or WCS transmitters. This is very low cost (less than $5 per unit), is widely used in other consumer receivers, and typically raises the overload point by more than 25 dB. The use of RF AGC does not degrade the threshold performance of the receiver. All of XM Radio's consumer receivers have these characteristics. They retail for as low as $199, despite having full capability to receive both the satellite and terrestrial signals.

B. The presentations by WCS licensees

In contrast, the WCS licensees have described base station and consumer receivers that appear to ignore the use of these approaches and exhibit a correspondingly high susceptibility to blanketing interference. That susceptibility is so high as to call into question the systems' ability to provide service to its own receivers, regardless of interference from other system operators in adjacent bands.

According to Table 1, when the signal level at the face of the antenna reaches the overload point, the receiver no longer provides a linear response. With the receiver operating in this nonlinear region, the desired linear modulated signal is distorted, which inhibits error free recovery of the user data. Any signal within the passband of the receiver front end is capable of driving the receiver into the nonlinear region, including the desired signal. According to this data, if a WCS provider installs a 2 kW EIRP base station in a region where the spectrum is otherwise clear and a residence one tenth of a mile away from the base station subscribes to the service, the signal level presented to the face of the CPE receiver antenna installed at the residence will be -21 dBmi, which is 37 dB above the overload points. Thus, service will be unavailable at the residence unless the CPE receiver is modified to operate in the linear region with received signal levels at -21 dBmi. With that design modification effected, by definition, the receiver will no longer suffer from blanketing interference at the levels described in Table 1.

WCS Receiver	Overload Point (dBmi)	2 kW EIRP LOS Exclusion Zone (Square Miles)
ATTWS Base	-45	8
ATTWS RU (24 dBi Ant)	-58	158
BellSouth CPE (24 dBi Ant)	-58	158

Table 1. Blanketing Interference Regions for WCS Receiver Designs

WCS base stations. Base stations must operate over the full receiver dynamic range as signals may be simultaneously received from near CPE transmitters and distant CPE transmitters. Since base stations are not as size constrained or cost sensitive as the RU or CPE, it is reasonable to incorporate a receive notch filter or band pass filter to protect against SDARS blanketing interference. One such filter suitable to protect WCS base stations against blanketing interference is described in Figure 2.

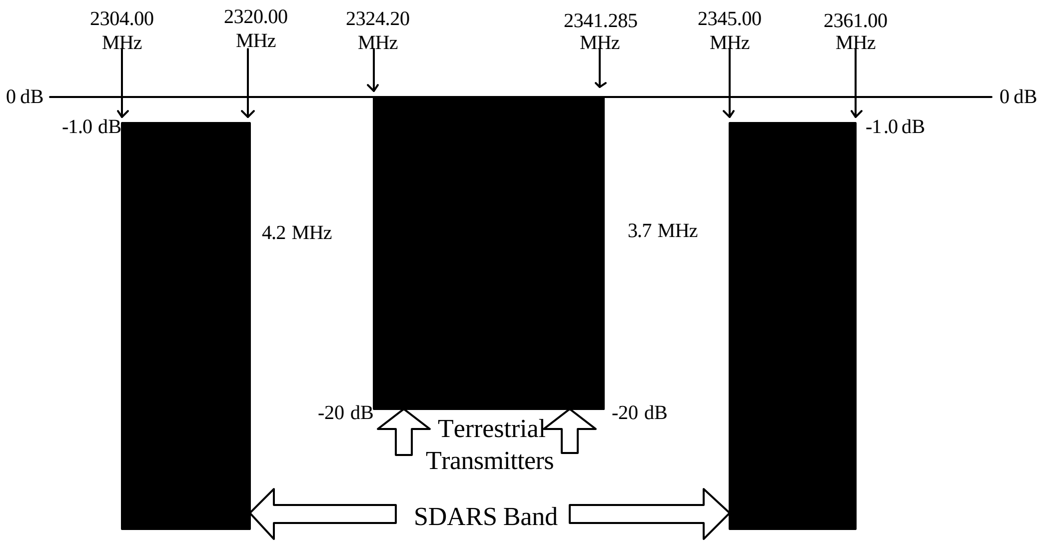


Figure 2. Notch Filter Characteristics for WCS Base Stations

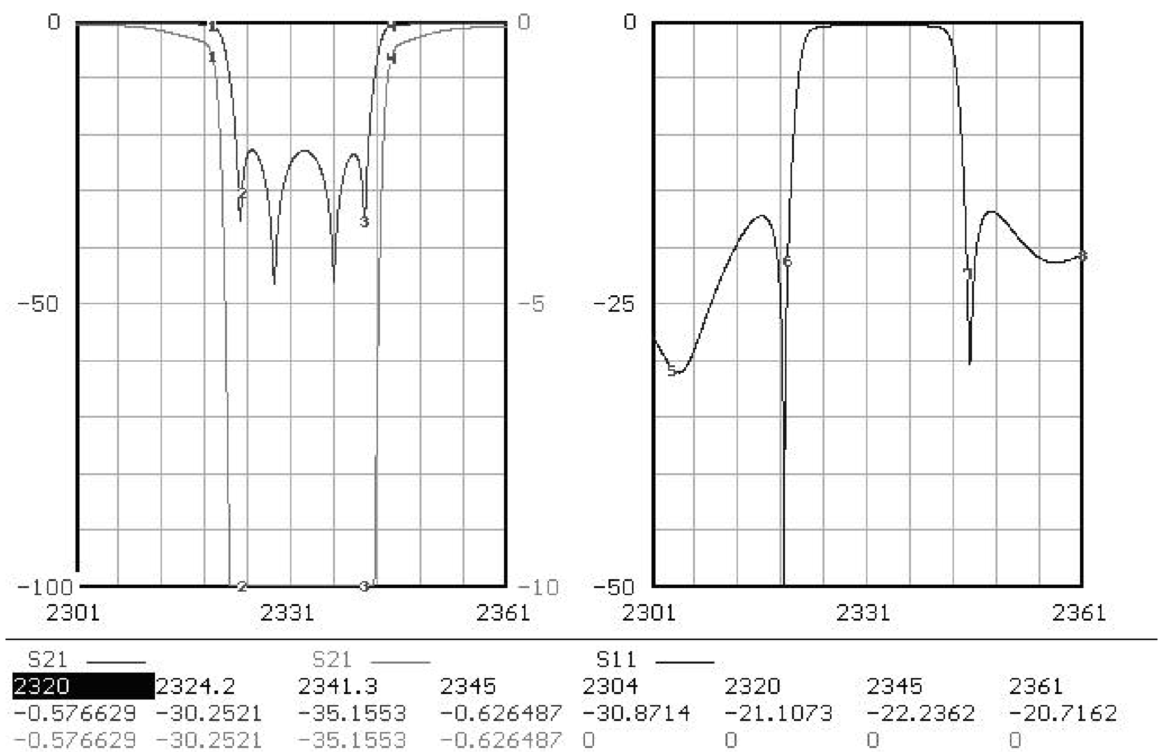


Figure 3. Simulated Performance of FSY Microwave Filter P/N 80452

The filter described in Figure 3 is available from FSY Microwave, Inc. in Columbia, MD. The filter is constructed with 4 ceramic puck resonators and its physical dimensions are 5.9”x5.9”x2.25”, not including connectors. Insertion loss for the WCS bands is typically less than 0.7 dB. The price is no more than $326. Incorporation of a filter exhibiting the performance in Figure 3 will increase the base station overload level by at least 20 dB.

WCS consumer receivers. The low cost design techniques required to improve the "brute force overload" protection of the WCS CPE receivers are based on the fact that these receivers communicate with only one base station, which does not require utilization of the receiver's full dynamic range.

Consider the present BellSouth receiver block diagram and performance in Figures 4 and 5. For interference levels at the receiver input up to -35 dBm, the receiver will operate as long as the desired signal is a minimum of -101.8 dBm, as disclosed in BellSouth's August 21, 2001 filing. Thus, when the interference level rises above -35 dBm, the receiver will experience "blanketing interference" and not operate at all, independent of the desired signal level.

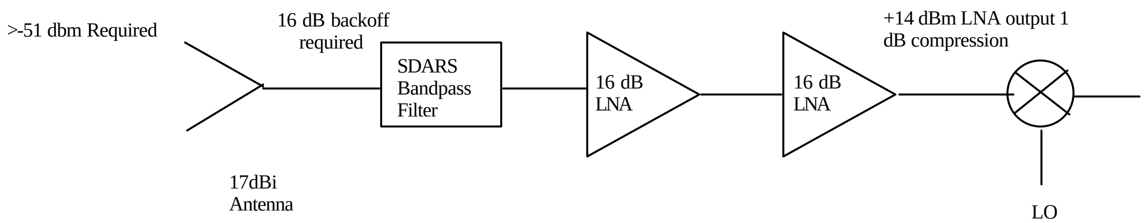


Figure 4. Bellsouth Receiver Line Up

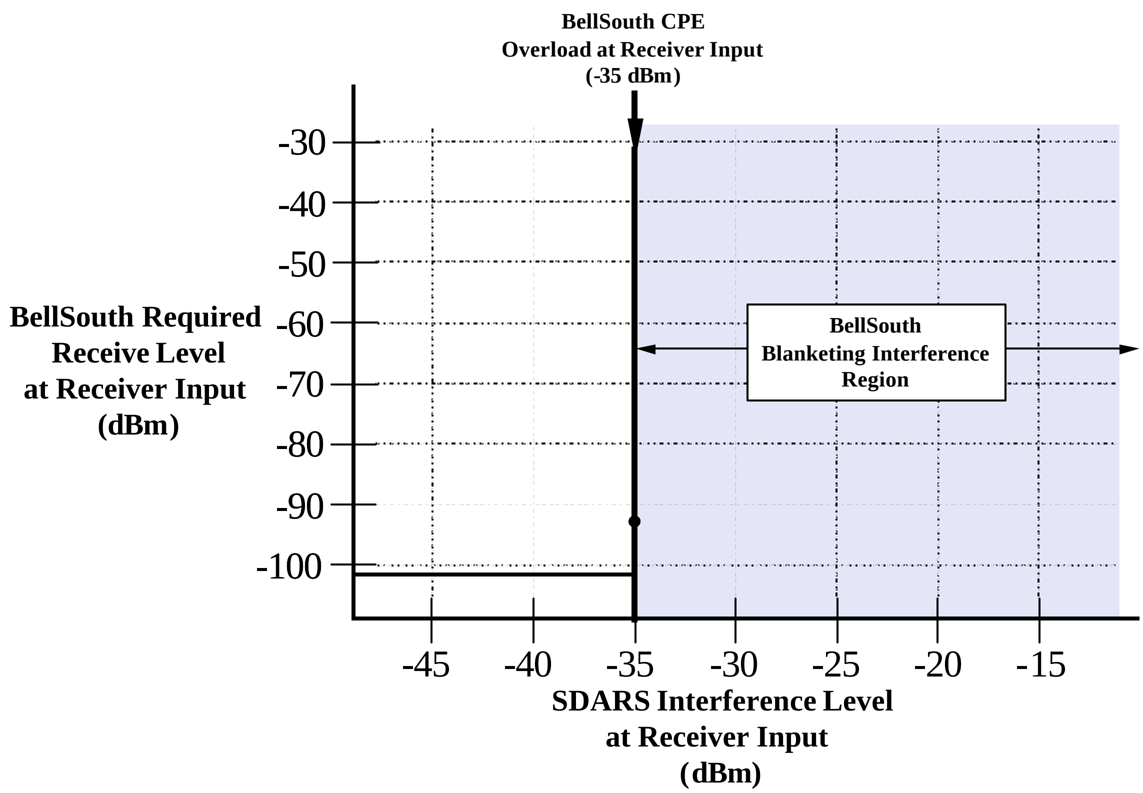
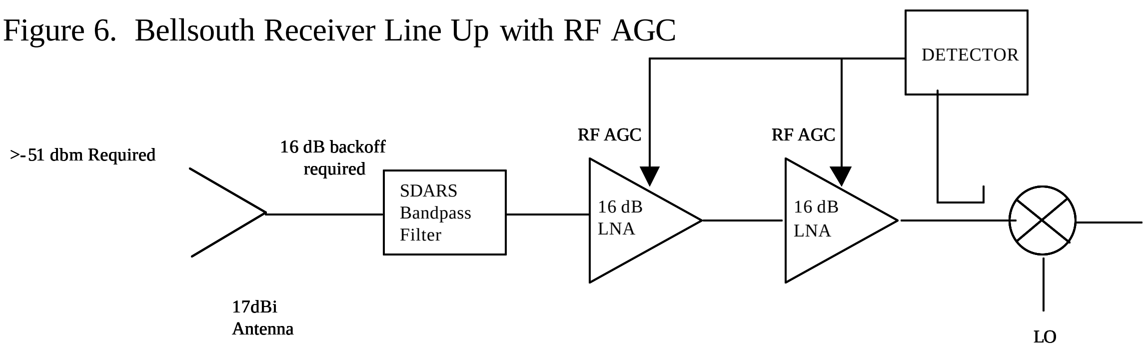


Figure 5. Performance of Bellsouth Receiver Line Up

Next, consider the modified BellSouth receiver block diagram and performance in Figures 6 and 7. Figure 7 depicts the theoretical performance, which can be realized by the addition of RF AGC circuitry to the receiver. As in Figure 5, for interference levels at the receiver input up to -37 dBm, the receiver will operate as long as the desired signal is above the minimum -101.8 dBm threshold. However, when the interference level rises above -37 dBm, which is the RF AGC threshold in this example, the minimum desired signal requirement increases dB for dB with the interference signal. The RF AGC threshold is normally set to engage 2 or more dB below the level at which the receiver is susceptible to signal blocking from either front end compression or intermodulation distortion. Effectively, the receiver immunity to blanketing interference is achieved without filters, provided the desired signal is above threshold. System design methods to insure the desired signal is above threshold when the interference levels are above the AGC threshold are addressed in Section II.

Figure 6. Bellsouth Receiver Line Up with RF AGC



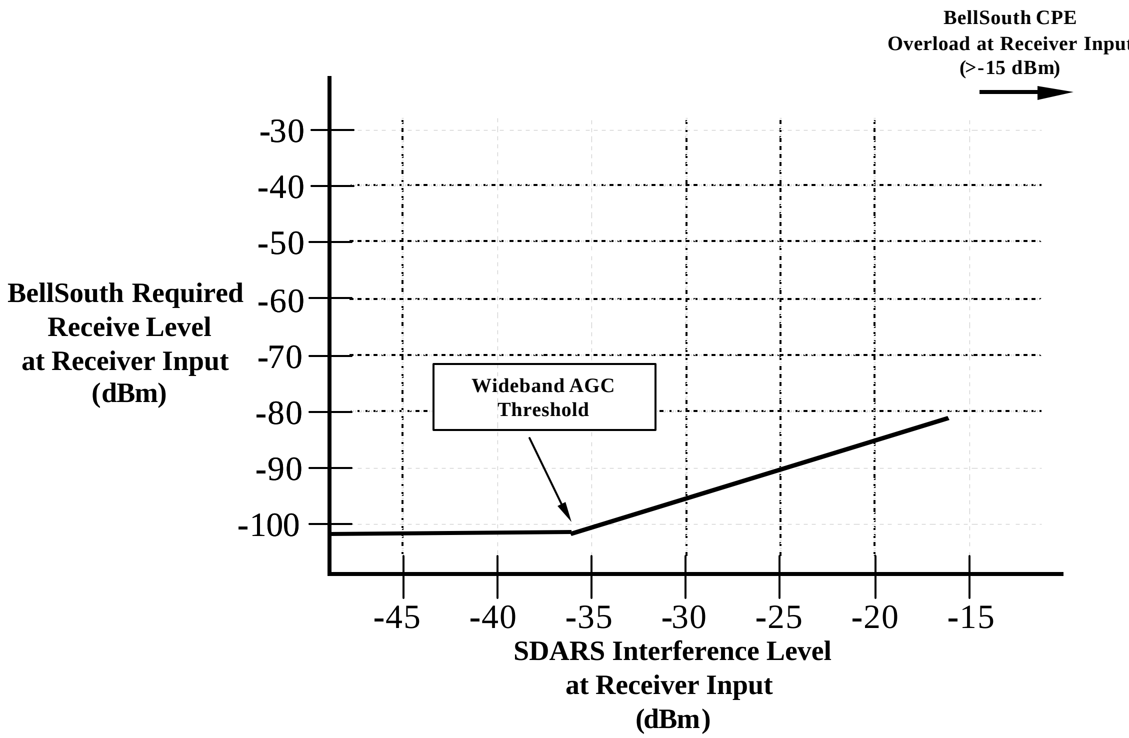
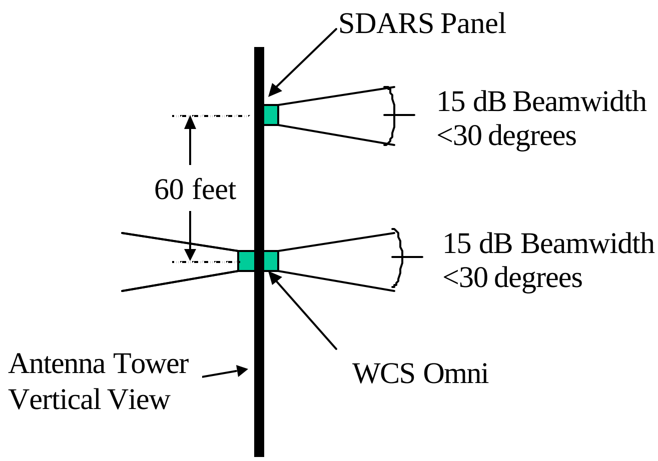


Figure 7. Performance of Bellsouth Receiver Line Up with RF AGC

Low-cost, off-the-shelf components, which are capable of providing the AGC performance described in Figure 7, are readily available for incorporation into WCS CPE receivers. The M/A-COM AT-119 Voltage Variable Attenuator in combination with the Analog Devices AD8314 RF Detector/Controller is one example of an AGC implementation (used in one low-cost SDARS consumer receiver design) that exhibits excellent performance in the presence of 40 kW EIRP SDARS repeaters. Specifications for the AT-119 and AD8314 devices are available from the manufacturer's web sites. Various other AGC designs have been implemented by the many SDARS receiver manufacturers, all of which exhibit similar excellent performance in the presence of 40 kW EIRP SDARS repeaters.

II. Prudent but practical system design is also important to eliminate the potential for blanketing interference

With the deployment of reasonable SDARS filters on WCS base stations, and the deployment of AGC circuitry the WCS CPE receivers, the task of providing quality service in the vicinity of SDARS high power repeaters is straightforward. By deploying base stations anywhere in wide area near otherwise a problematic repeater will insure that adequate signal power is available to the CPE receiver in regions were the AGC threshold is exceeded by the SDARS transmitter. Sirius and XM Radio have demonstrated the successful coordination of their systems using this system design technique and there is no reason why that success cannot be duplicated by WCS system operators.



The importance of this system design element is illustrated by the example deployment of a WCS base station collocated with a 40 kW EIRP high power SDARS transmitter equipped with a 90 degree phased array panel, depicted in Figure 8. (As discussed further below, it is not necessary that the two facilities be collocated, but the principle is easier to illustrate using this example.) For the example tower configuration of Figure 8, the WCS base station receiver will operate without performance degradation based on the specifications in Table 2.

Figure 8. Tower Configuration for Collocated SDARS and WCS Antennas

Parameter	Limit	Unit
SDARS Peak EIRP	76	dBmi
SDARS Main Beam Attenuation	15	dB
Path Loss for 60 Feet	65	dB
SDARS EIRP at WCS Antenna	-4	dBmi
WCS Peak Antenna Gain	16	dBi
WCS Main Beam Attenuation	15	dB
SDARS Signal at WCS Antenna Terminal	-3	dBm
SDARS Filter Attenuation (From Figure 15)	35	dB
SDARS Signal at WCS Base Receiver	-38	dBm

Table 2. Interference Link Budget for WCS and SDARS Collocated Transmitters

The interference link budget in Table 2 supports the ability to collocate WCS base stations with SDARS high power repeaters, as the SDARS signal present at the WCS receiver is below the worst-case -35 dBm overload threshold quoted by BellSouth. As mentioned in Section I, XM successfully collocates a sensitive satellite receiver operating with a 1.8 MHz guard band to the terrestrial transmitter at each terrestrial site. In XM's experience, the main beam attenuation for the SDARS antenna in Table 2 is both realizable and conservative, which will provide additional margin in the interference link budget. For a collocated tower implementation, predicted main beam attenuation may be determined from the -90 degree point on the elevation patterns in Figures 12-15.

With the WCS and SDARS transmitters collocated, the operation of the CPE or RU receivers is illustrated by Figure 9. The coverage zones depicted in Figure 9 have been defined based on a WCS CPE receiver operating with a -37 dBm AGC threshold as defined in Figure 7 coupled to a 24 dBi antenna, which establishes the radiated AGC threshold at -61 dBmi.

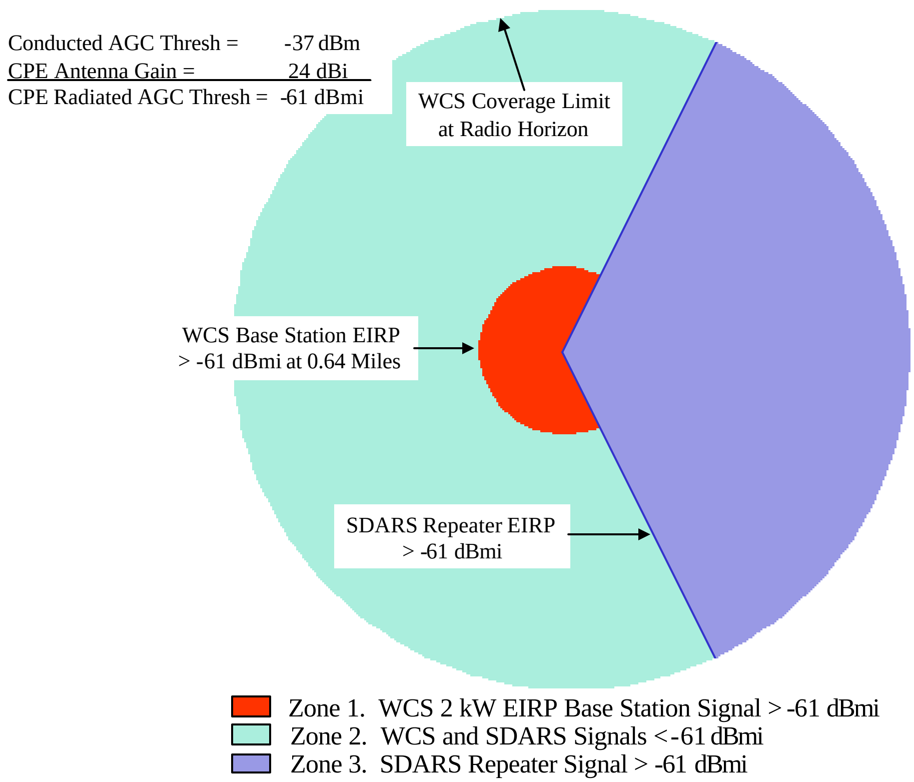


Figure 9. Coverage Zones for Collocated WCS and SDARS Transmitters

Zone 1 depicts the region where the WCS CPE AGC will engage based on the signal received from the WCS base station. Signals from the SDARS repeater are below the signals from the WCS base station in this zone. Zone 2 depicts the region where the WCS CPE AGC is not engaged. The WCS CPE receiver has an adequate interference protection ratio to protect against SDARS interference in this zone. Zone 3 depicts the region where the WCS CPE AGC will engage based on the signal received from the SDARS repeater. For the line-of-sight propagation model used for this example, the SDARS repeater signal will be a maximum of 13 dB above the WCS base station signal throughout this region. A CPE receiver operating with the AGC performance described in Figure 7 will maintain an interference protection ratio which will enable it to receive the desired signal from the WCS base station with substantial margin in this zone.

There is no requirement to collocate the WCS base station with the SDARS terrestrial repeater to insure operation throughout the coverage area. As long as the WCS base station signal strength is within the interference protection ratio of the CPE receiver throughout Zone 3, any exclusion zones will be eliminated.

III. The shift from omnidirectional antennas to panels improves the interference environment for WCS receivers

XM Radio's repeater network design, including the number of repeaters that it expects to deploy, has not changed fundamentally since its original conception. In recent months, however, as a result of tests conducted after the launch of the XM Radio satellites, XM Radio has modified the antenna configuration of over two-thirds of the repeaters that had been designed to operate at $\leq$2 kW EIRP. Without changing the power output from these transmitters, XM Radio has shifted from omnidirectional to directionalized panel antennas. This change, which was made to improve the performance of the repeater network, has the benefit of reducing the potential area in which WCS receivers may suffer blanketing interference.

Rationale for the shift to panel antennas. The SDARS terrestrial RF networks are digital simulcast networks utilizing OFDM transmission schemes. A key RF network design parameter, which must be adhered to in order for the simulcast networks to provide uninterrupted service throughout the coverage area, is the simulcast delay spread. For each location within the coverage area, the composite signal present at the receiver must comply with a waveform specific delay vs. amplitude mask in order for the signal to be reliably processed by the receiver. If, for example, the signals from two repeaters arrive at the receiver with near equal amplitude but at different times, due to different propagation delay distances from their independent locations, when the time difference exceeds the waveform guard interval, destructive intersymbol interference results. In locations such as these, service outages are present even though a strong signal is available to the receiver. The simulcast delay spread is controlled through proper RF network design.

Figure 10 and 11 demonstrate how panels are deployed to reduce service outages due to simulcast delay spread. The diagram on the left in Figure 10 shows the coverage areas for the 3 sites deployed with omnidirectional antennas. The diagram on the right in Figure 10 shows the areas in which there would be mask violations if omnidirectional antennas are used. The diagram on the left in Figure 11 depicts an example coverage area for the same 3 sites as in Figure 10 with panel antennas on two of the sites. The absence of red regions in the diagram at right in Figure 11 shows the effect of using sectorized panel antennas. The network deployed with this configuration would not exhibit simulcast related service outages throughout the coverage area.

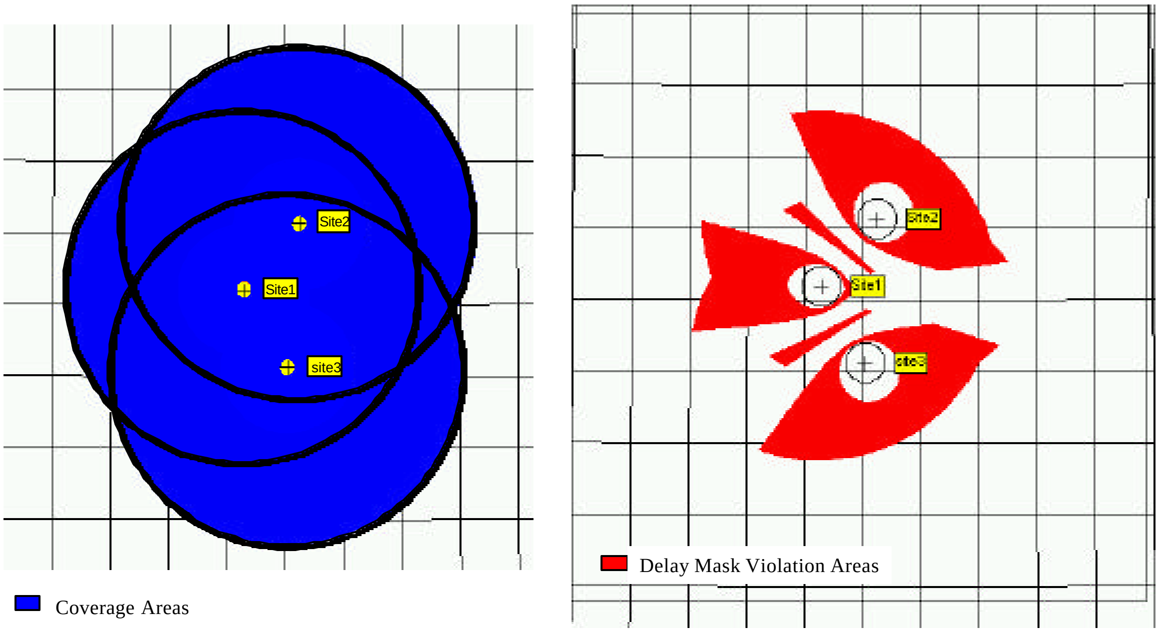


Figure 10. Coverage Contours and Delay Mask Violations for 3 Omni Sites

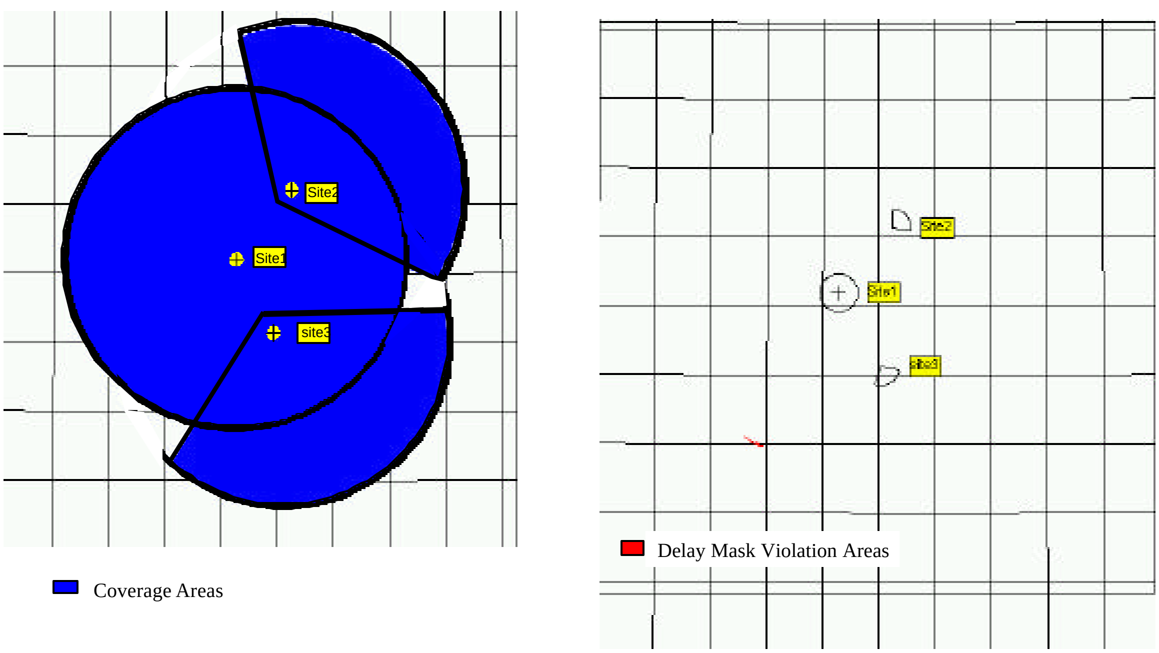


Figure 11. Coverage Contours and Delay Mask Violations for 1 Omni and 2 Panel Sites

Impact on the WCS interference environment. From the standpoint of exclusion zones, the same amount of conducted power applied to a panel antenna will in general result in a **smaller** exclusion zone when compared to an omnidirectional antenna, even though the peak EIRP at the antenna is higher. Consider the azimuth and elevation patterns of a sample of antennas used in the XM Network, depicted in Figures 12-15.

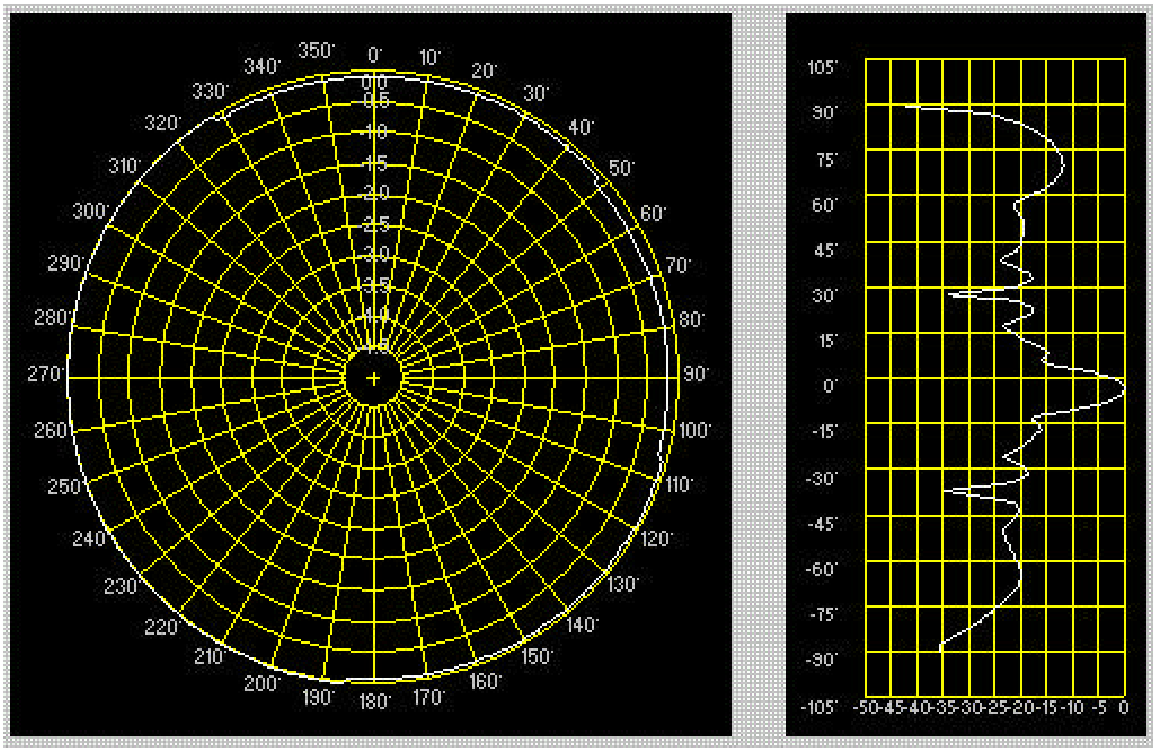


Figure 12. Omni Antenna – Gain 10dBi

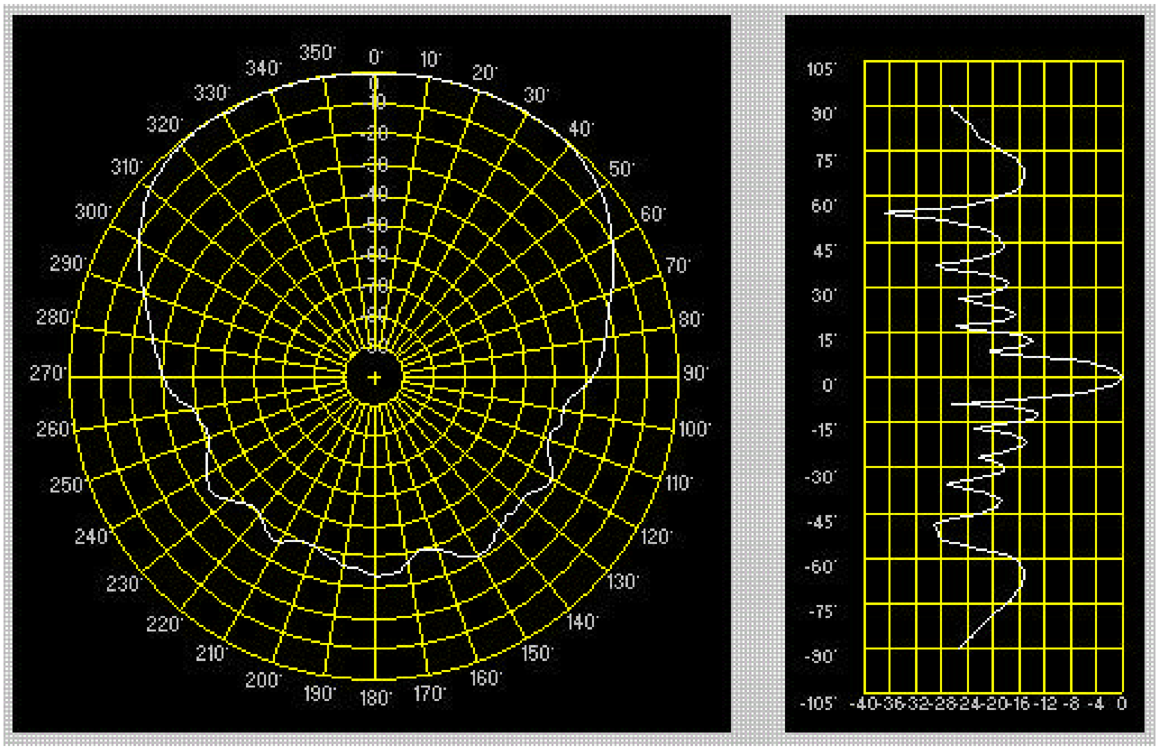


Figure 13. Phased Array Panel Antenna – Gain15dBi, Beamwidth 90 degrees

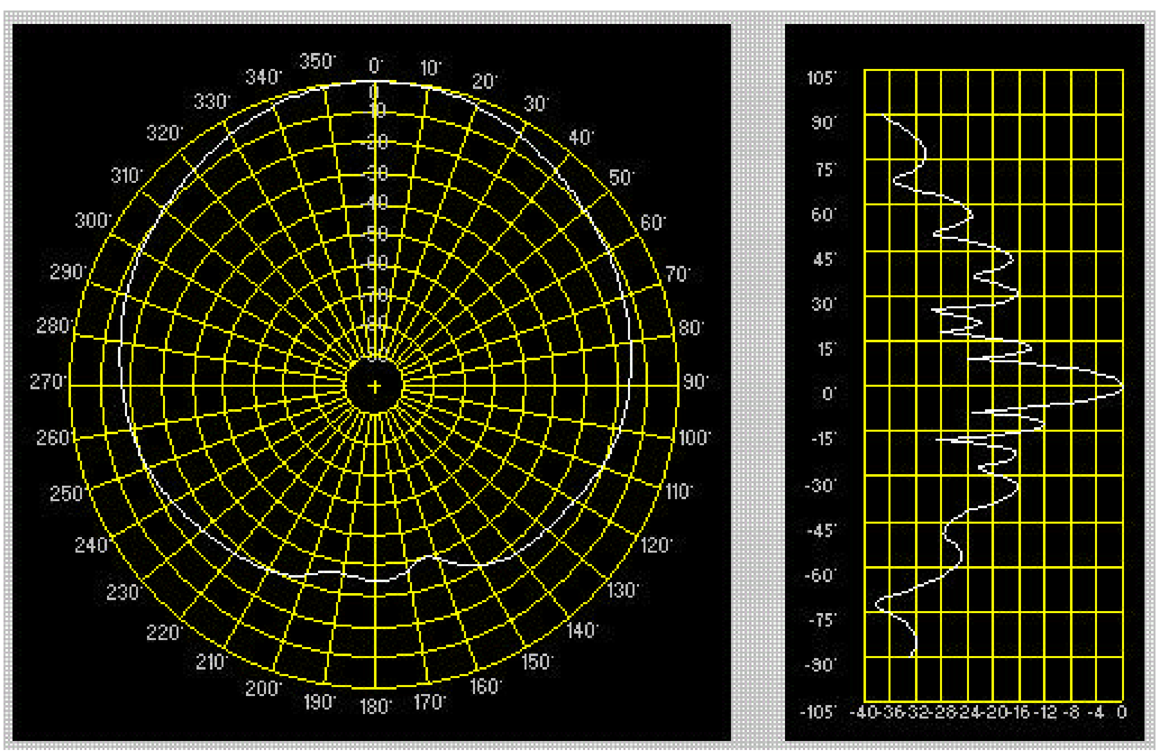


Figure 14. Panel Antenna - Gain 18dBi, Beamwidth 45 degrees

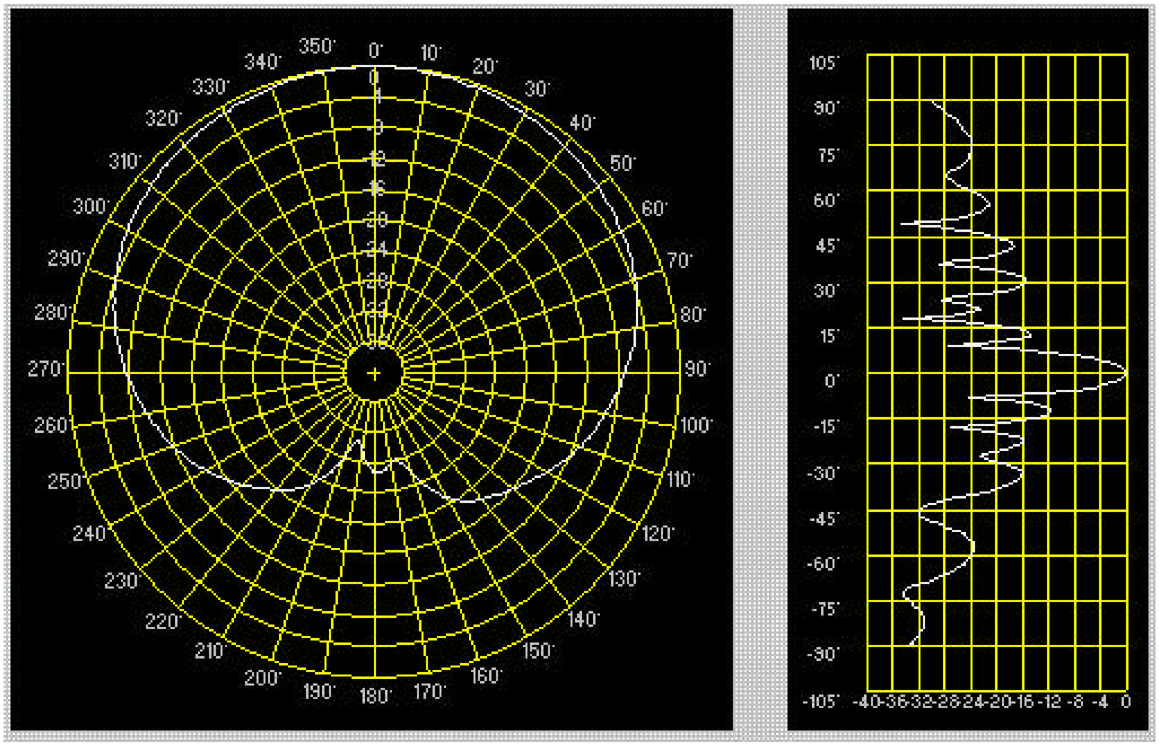


Figure 15. Panel Antenna - Gain 14dBi, Beamwidth 120 degrees

Comparing the azimuth patterns of the panel antennas (left side of Figures 13-15) to that of the omnidirectional antenna (Figure 12), it is evident that while the peak antenna gain of the panels will exceed the gain of the omnidirectional antenna, the antenna gain averaged over 360 degrees in azimuth is lower for the panel than the omnidirectional antenna. Analytically, it can be shown that the area of the line of sight exclusion zone is directly related to the average antenna gain or EIRP, not the peak antenna gain.

Figure 16 depicts the relative exclusion zones for the antennas described in Figures 12-15 when connected to a repeater with the same RF output power.
As is evident from Figure 16, for a given blanketing interference threshold and with equivalent RF power applied to the antenna feed, the area of the exclusion zone will scale in relationship to the average antenna gain.

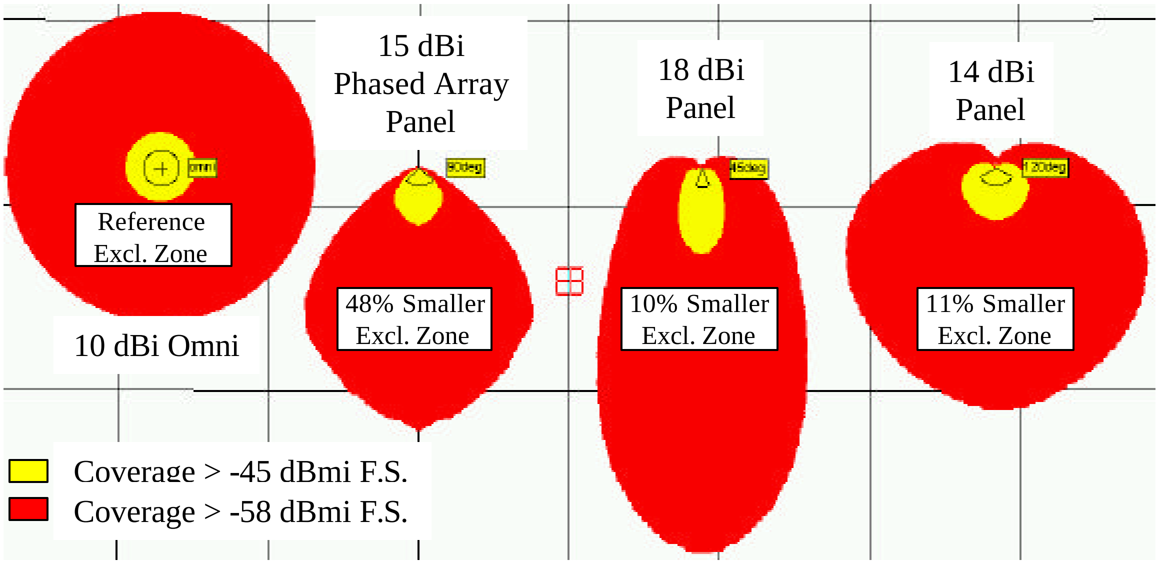


Figure 16. Line of Sight Exclusion Zones for Omni Vs. Panel Antennas

RF Power at Ant. Feed (Watts)	Antenna	Peak EIRP (Watts)	-45 dBmi Excl. Zone (Sq. Miles)	-58 dBmi Excl. Zone (Sq. Miles)	Excl. Zone Reduction (percent)
200	10 dBi Omni	2 000	8.0	158	0
200	15 dBi PA Panel	6 325	4.2	82	48
200	18 dBi Panel	12 619	7.2	142	10
200	14 dBi Panel	5 024	7.1	141	11

Table 3. Peak EIRP and Exclusion Zones for Omni and Panel Antennas

When other factors mitigating signal propagation are included, panels exhibiting a gain average below the 10 dBi omnidirectional antenna, where the gain average is determined by integration of the azimuth pattern, will further reduce the exclusion zones.

IV. The advantages of using fewer higher power repeaters instead of a greater number of low power repeaters

The following set of charts demonstrates the extent to which XM Radio has reduced the likelihood of interference to WCS receivers by designing networks for urban coverage that use fewer repeaters. Figure 17 depicts the exclusion zones (using a worst-case, line-of-sight interference model) where the signal level of a 2 kW EIRP transmitter will exceed the interference limits of -45 dBmi and -58 dBmi, the overload threshold that AT&T Wireless has identified for its WCS base stations and consumer units, respectively.

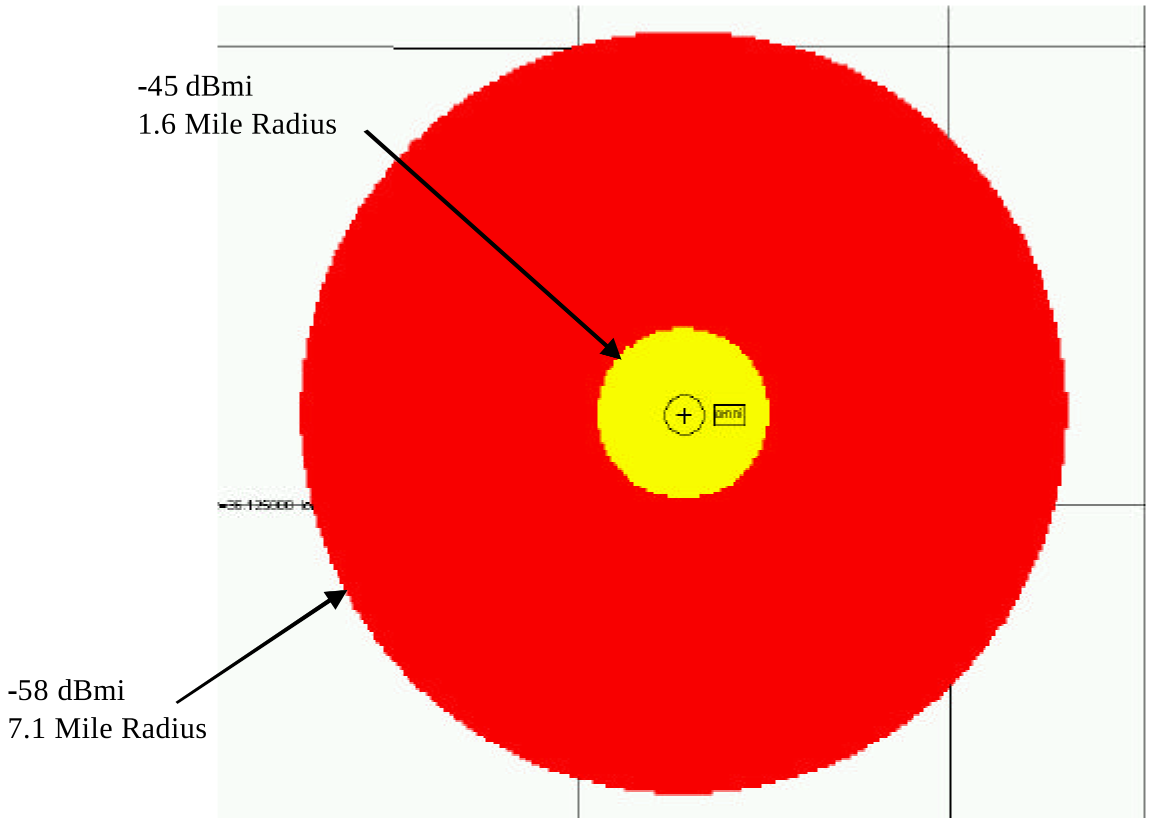


Figure 17. 2 kW EIRP Omni Line of Sight Exclusion Zones For WCS Receivers

The AT&T WCS base stations and consumer receivers will be susceptible to blanketing interference at distances of 1.6 miles and 7.1 miles, respectively, from any 2 kW EIRP transmitters in nearby bands, including those of other WCS licensees. These distances are based on a line of sight propagation model where the path loss in dB is equal to 32.44 + 20 log f(MHz) + 20 log R(Km). This is a worst-case analysis since multiple simultaneous factors must be present for there to be actual interference, such as an absence of shielding or blockage, the receiver operating at threshold, the transmitter being in the boresight of the receive antenna, and the antenna polarizations being aligned.

In an earlier filing, AT&T concedes that the replacement of higher-power repeaters with multiple lower-power repeaters will not reduce the aggregate size of the exclusion zones for consumer receivers. [1] AT&T's analysis of base station interference, however, concludes that the use of multiple lower-power repeaters would reduce their exclusion zones. Our analysis is to the contrary. The apparent error in the AT&T's analysis is its assumption that the lower-power repeaters would be clustered in a way that is actually unrealistic and impractical. The costs associated with site deployment and ongoing site maintenance are high, so RF broadcast networks, by design, avoid inefficient site configurations with large amounts of overlapping coverage. A more

[1] Letter from William M. Wiltshire, Counsel for AT&T Wireless, to Ms. Magalie Roman Salas, FCC, IB Docket No. 95-91 (April 30, 2001), at 8.

realistic comparison of exclusion zones for the line of sight environment is observable in the following examples from Los Angeles and Indianapolis, based on XM Radio's experience in deploying repeater networks in those markets.

In order to establish a correct site configuration to provide highly reliable radio service within a given market boundary, XM Radio follows a terrestrial RF network design process, which includes collection of field strength data from each planned site. This data is then post processed to determine the minimum site configuration necessary to meet the market coverage reliability requirements. Figure 18 depicts the worst-case line-of-sight exclusion zones for a section of the Los Angeles market that is covered by the minimum site configuration, based on the measured field strength data, which includes the 40 kW EIRP high power repeater at site 101. The yellow shaded region represents the area where the signal strength exceeds -45 dBmi and the red shaded region represents the area where the signal strength exceeds -58 dBmi, based on free space path loss plus RMD. Figure 19 depicts the same exclusion zones when XM Radio is limited to deploying repeaters with a maximum EIRP of 2 kW. This is our best effort to model a less-than-ideal case, trying to cover the same area as is covered by the preferred case.

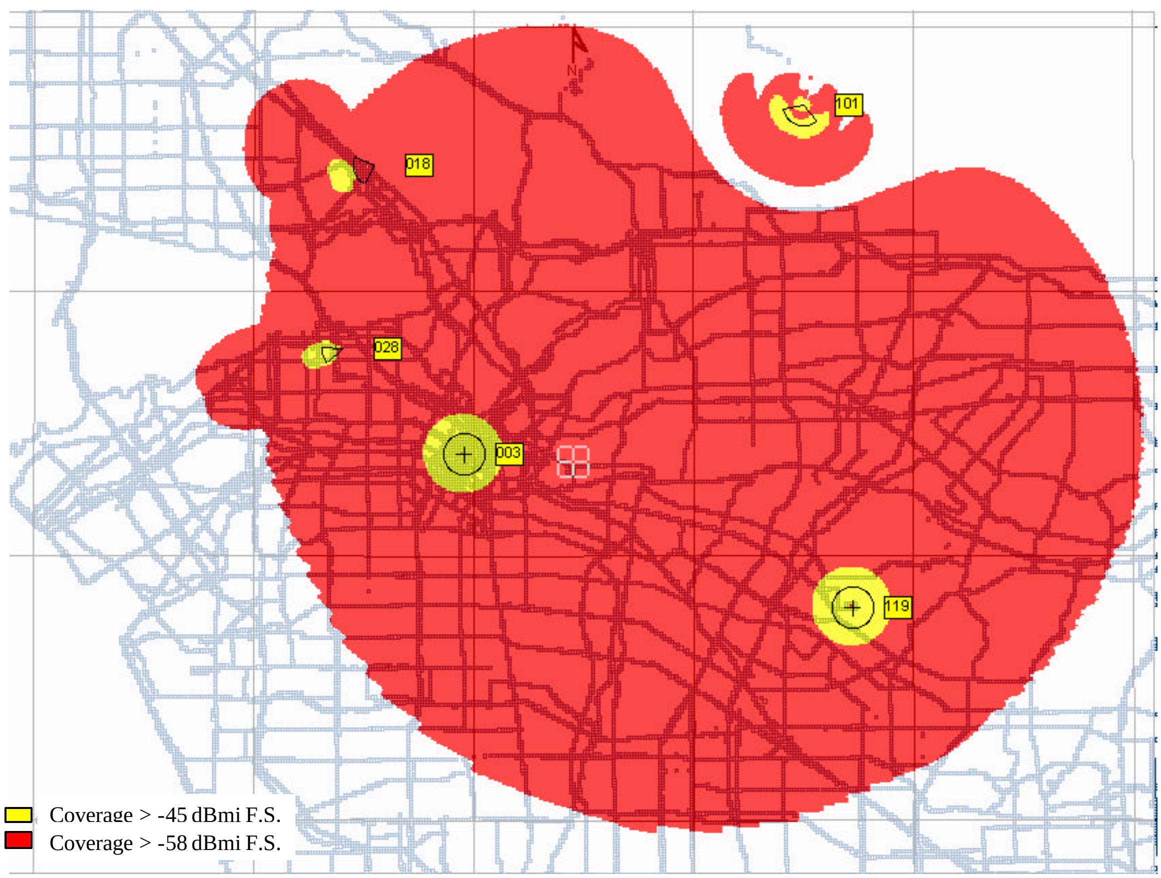


Figure 18. Los Angeles Market Exclusion Zones with High Power Repeater

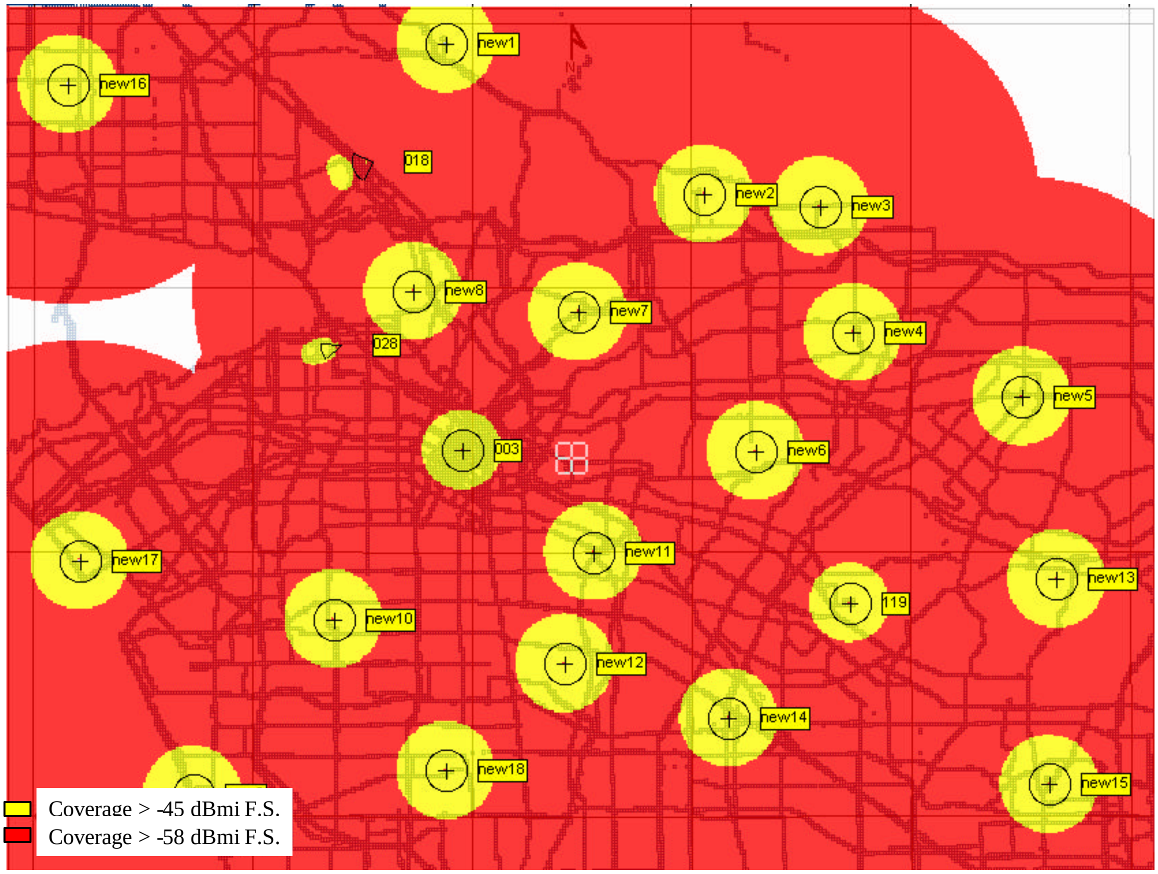
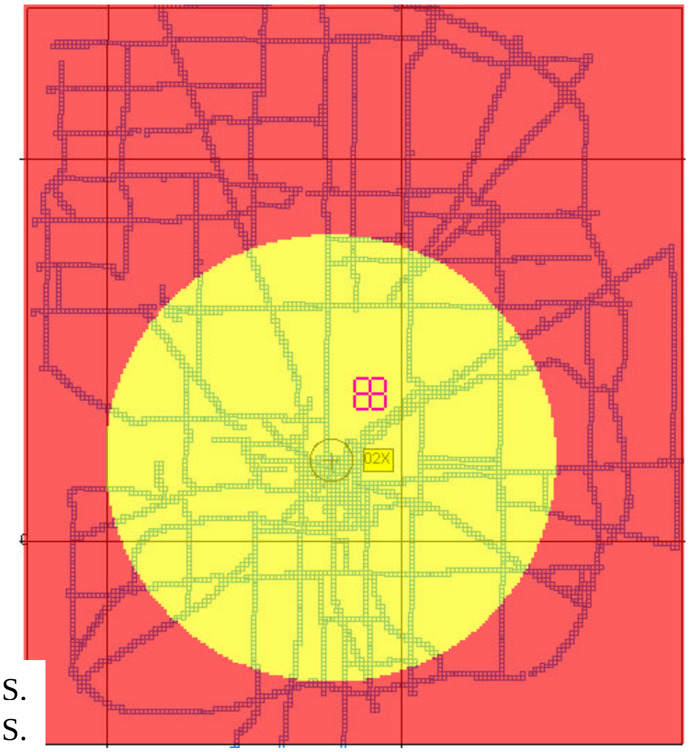


Figure 19. Los Angeles Market Exclusion Zones without High Power Repeater

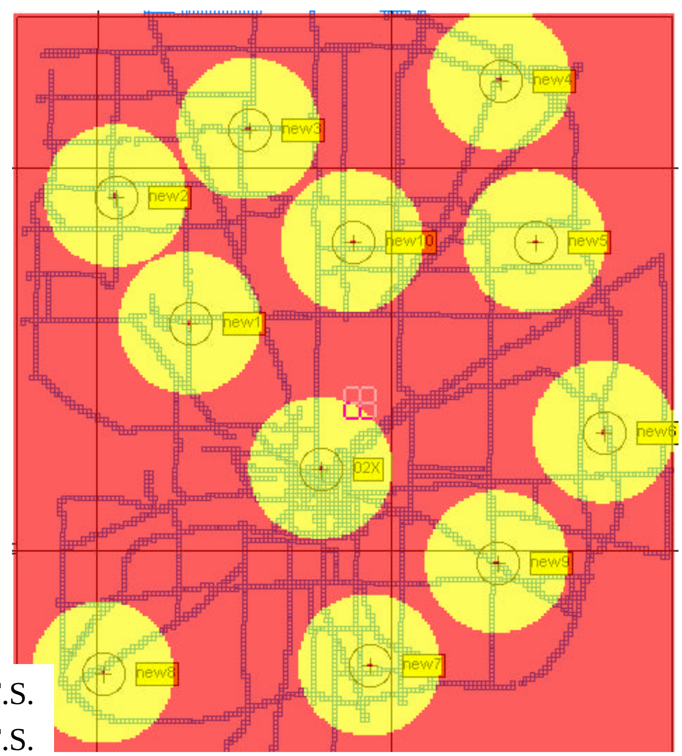
Figures 18 and 19 provide graphical evidence that deploying a greater number of low power repeaters in the XM network design will not reduce line of sight exclusion zones.

Moving to a second example, Figure 20 depicts the worst-case line-of-sight exclusion zones for the Indianapolis market for which a single 20 kW EIRP repeater is deployed at site 02x in the downtown area. The yellow shaded region represents the area where the signal strength exceeds -45 dBmi and the red shaded region represents the area where the signal strength exceeds -58 dBmi, based on free space path loss plus RMD. Figure 21 depicts the same exclusion zones when XM Radio is limited to deploying repeaters with a maximum EIRP of 2 kW and includes the additional sites required to provide equivalent market coverage.



Coverage > -45 dBmi F.S.
Coverage > -58 dBmi F.S.

Figure 20. Indianapolis Market Exclusion Zones with High Power Repeater



Coverage > -45 dBmi F.S.
Coverage > -58 dBmi F.S.

Figure 21. Indianapolis Market Exclusion Zones without High Power Repeater

Table 4 summarizes the exclusion zone area comparison for the Los Angeles and Indianapolis network designs presented in Figures 18-21. The analysis indicates the total –45 dBmi exclusion zone area is increased by replacing high power sites with additional low power sites to provide equivalent market coverage.

Los Angeles RF Network Configuration	-45dBmi Exclusion Zone Area Based on Freespace + RMD
Current Design configuration: 1 25 kW EIRP site with panel antenna 2 1.2 kW EIRP sites with omni antennas 1 4.5 kW EIRP site with panel antenna 1 3.4 kW EIRP site with panel antenna	20 square miles
Low Power Design configuration: 18 2 kW EIRP sites with omni antennas 2 1.2 kW EIRP sites with omni antennas 1 2 kW EIRP site with panel antenna 1 2 kW EIRP site with panel antenna	159 square miles

Indianapolis RF Network Configuration	-45dBmi Exclusion Zone Area Based on Freespace + RMD
Current Design configuration: 1 20 kW EIRP site with omni antenna	81 square miles
Low Power Design Configuration: 11 2 kW EIRP sites with omni antennas	88 square miles

Table 4. Exclusion Zones for Current Network Versus 2 kW EIRP Limit Network

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This paper was prepared with contributions from the following members of XM radio's technical team:

Stel Patsiokas, Senior Vice President, Technology. Previously, Dr. Patsiokas was with Motorola, Inc., where he served in a variety of consumer electronics design and development roles since 1979. Since 1996, Dr. Patsiokas was Director of Product Development for Motorola's Messaging Systems Product Group, where he was involved with developing the PageWriter™ 2000 two-way messaging device. Dr. Patsiokas holds 24 United States patents.

Phil Barsky, Spectrum Management and Regulatory Engineer, has over 30 years experience with advanced wireless communications systems, including systems engineering.

Derek de Bastos, Vice President, Space Segment, has over 14 years of experience with space-based, wireless communications systems.

Paul Marko, Vice President, Subscriber Technology, has 18 years of experience at Motorola, most recently as a Principal Member of the Technical Staff and Director of Strategic Systems for the company's Core Technology and Systems Operations (CTSO). An Engineering graduate of the University of Florida, Mr. Marko has extensive experience directing IC chipset development for advanced digital receiver platforms and developing the architecture, algorithms and IC partitioning for highly integrated receiver and controller platforms. Mr. Marko holds 36 US Patents.

Craig Wadin, Senior Member, Technical Staff, has been at XM Radio for over two years, focusing on consumer product chipset design and the terrestrial RF network design. Mr. Wadin has 25 years experience with Motorola in the area of system level RF digital communication system design. He holds 19 issued U.S. patents.