White Paper

# Patterns of Success

*Antenna Patterns to Play a Key Role in WiMAX Success.*

On October 8, 2008, Sprint Nextel officially ushered in the WiMAX era with the launch of XOHM WiMAX in Baltimore. WiMAX finally appears ready to step out of the shadow of uncertainty that has, for the last few years, labeled it a “future technology”. Since the introduction of the IEEE 802.16 standard by the WiMAX Forum, operators have recognized the potential to substantially improve and transform the efficiency with which last-mile broadband connectivity is delivered.

According to the Telecommunications Industry Association, the number of WiMAX subscribers worldwide is expected to explode, going from 1.2 million at present to at least 37 million by end of 2011. Some estimates put that number at more than 80 million.

WiMAX revenues across the Pacific Rim alone, currently estimated at $58 million (US), are expected to reach $5.46 billion by 2012, according to the latest report by Springboard Research, an IT research company. This translates to a 148% compounded annual growth rate over the next 48 months.

Rider Research, which researches and reports on the digital media industry, sees these projections as conservative at best, stating that these projections will be "comfortably smashed." The company suggests that WiMAX subscription levels "potentially could be massively higher" than projected by TIA.

Buoyed by the optimism, developers and OEM’s are forging ahead with a host of WiMAX applications and host devices. Intel recently announced its intentions to begin incorporating WiMAX chips into its motherboards. Meanwhile the release of the 802.16e standard has pushed the door wide open for a new generation of mobile WiMAX applications and subscribers.

The focus now turns to the RF engineers responsible for optimizing WiMAX networks and allowing operators to make good on promises to end-users and shareholders. Unfortunately, deploying wide-scale, spectrally efficient WiMAX networks is not as easy as simply adapting current voice-driven systems.



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In a traditional cellular network, signal-to-noise ratios as high as 9 dB still make for a clear call. If the coverage is adequate and signal-to-noise ratio (SNR) is above about 9 dB in a traditional cell-phone system, users can make a crystal-clear call and be satisfied.

In a WiMAX environment, however, the data signal link is far more fragile. A 9 dB SNR results can significantly affect transmission and reception of the data signal, owing to the adaptive modulation used by WiMAX. With WiMAX still in its infancy, these differences are often not considered in the planning phases.

As the wireless data market grows, deploying wireless technologies with high spectral efficiency will be of paramount importance. The more effectively systems can manage signal interference, the higher the cell capacity, and the more profitable the system.

In short, the degree to which WiMAX succeeds will depend in large part on the ability to minimize channel interference. This positions the base station antenna system as critical to WiMAX long-term success. Going forward, antenna pattern shaping and interference control will play a significant role in successful WiMAX deployments.

This paper examines some of the key causes of signal interference in the WiMAX environment and discusses techniques being employed and developed to provide RF engineers with greater ability to improve spectral efficiency.

**Signal Interference in the WiMAX Environment**

*Prior to the rollout of WiMAX, antenna pattern anomalies were acknowledged, but, in general, were seen as acceptable within the overall cost benefit analysis.*

In a typical cellular environment, interference can stem from either co-channel or cross-channel sources. In the WiMAX environment this is not the case. The OFDM modulation scheme employed by WiMAX mitigates co-channel interference by breaking the signal into subcarriers. The loss of the data on a small percentage of the subdivided signal does not degrade the reception of the received signal.

For maximum spectral efficiency, WiMAX supports a cell frequency re-use factor of one, meaning that the same sub-carriers are used in adjacent cells. This further impacts the levels of co-





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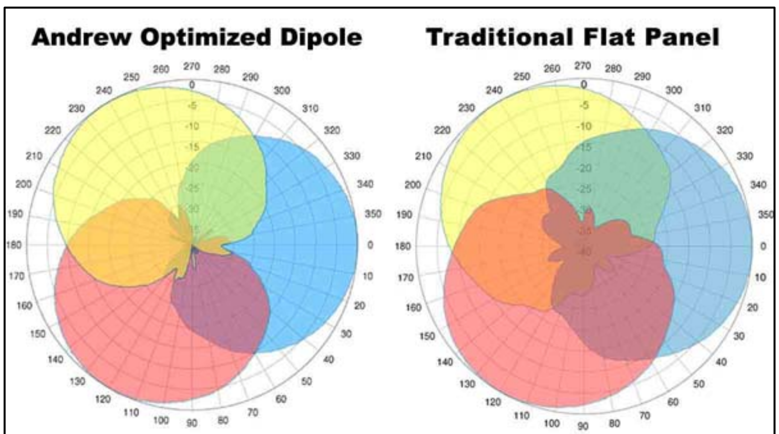
channel interference. As a result, signal containment via antenna pattern is vital. Depending on pattern characteristics, such as high levels of back lobe generation and reflections of upper sidelobes, the unwanted signals on the same channel can end up in non-adjacent sectors and cause interference.

Cross-channel interference can emanate from the operator's own system or from a competing system. If it is strong enough, it also can cause receiver degradation. Whether the cause of the interference is co-channel or cross-channel, the offending signal can usually be traced to one or more anomalies in the antenna's radiation patterns.

Prior to the rollout of WiMAX, antenna pattern anomalies were acknowledged, but, in general, were seen as acceptable within the overall cost benefit analysis. The degradation they caused in slow moving voice signals was minimal when compared to the cost involved in addressing them.

WiMAX, however, presents a much different set of expectations and challenges. High-speed data signals are far more vulnerable to disruption from interference. This is compounded by the fact that pathloss has an inverse-square relationship with carrier frequency. So within the 2.3–2.7 GHz frequency range, engineers must balance the need to reduce signal interference with the realities of higher pathloss.




The higher the antenna pattern precision, the less inter-sector overlap. The result is a much smaller harder hand-off area, better call quality, and capacity.

With so much hinging on WiMAX's capability to effectively conduct high-capacity data, the antenna's ability to precisely control radiation patterns becomes more important.

The majority of problematic pattern anomalies within the WiMAX environment occurs along the azimuth plane and includes pattern characteristics such as: pattern roll-off (front-to-side ratio), back lobe generation (front-to-back ratio), horizontal beam tracking, and beam squint.

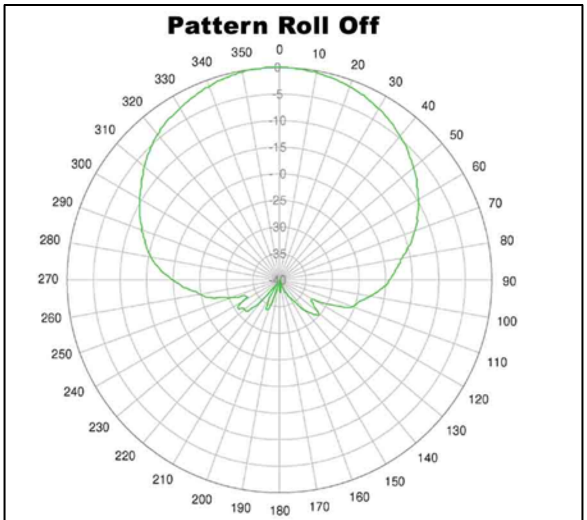
Pattern defects along the elevation plane, while not as many, are just as problematic. Inconsistencies such as upper sidelobe generation and imprecise downtilt control add a significant layer of complexity to the design of antennas suitable for dense urban areas, a key market for WiMAX operators.

These pattern inconsistencies not only produce inter-sector interference, they also effectively reduce overall capacity and, as a result, can dramatically affect the operator's bottom line.

**Pattern Roll-Off**

Also known as front-to-side ratio, pattern roll-off describes the geometry of the main lobe in the horizontal plane.

Conventional antennas begin rolling off in signal strength well before the edge of the sector, but then do not drop rapidly outside the sector, resulting in extraneous energy that can interfere with adjacent sector antennas. Conversely, a sharp pattern roll-off indicates a far more defined azimuth pattern that exhibits good front-to-back ratio.



Smooth, rapid pattern rolloff as exhibited by the Andrew W2X6516DSA-VTM WiMAX directed dipole antenna

Maintaining a sharp pattern roll-off is especially important in data-driven WiMAX networks. Whereas voice connections remain satisfactory with a 9 db signal-to-noise ratio, acceptable high-speed data connections require a signal-to-noise ratio of at least 20 db.

The degree to which a pattern roll-off is deemed slow or rapid is usually not quantified, rather is roughly gauged based on the





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geometry of the antenna pattern. In order to more precisely judge the effects of pattern roll-off, Andrew has developed a unique specification known as the Sector Power Ratio (SPR). This ratio expresses the percent of total energy radiated into the desired sector versus the total energy being radiated outside the sector.

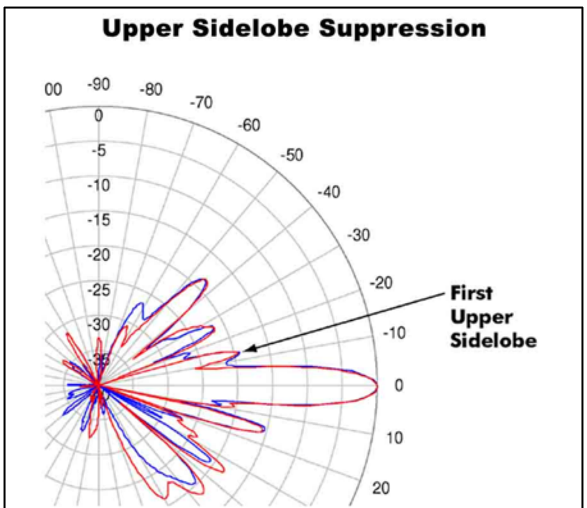
Problems with very slow roll-offs often stem from poor reflector geometry or element selection.

**Upper Sidelobe Generation**

Because of the minimal affects on voice signal, upper sidelobe interference, with the exception of the first upper sidelobe, has been largely ignored. Only now are some antenna designers focusing on techniques for suppressing additional upper side lobe transmissions.
Strong upper sidelobe levels are also receiving new scrutiny because of the significant interference threat posed to satellite transmissions in the C-band frequency. Test conducted by the Satellite Users Interference Reduction Group (SUIRG) in the last quarter of 2007 conclusively found the incompatibility of C-band spectrum sharing between fixed frequency service (FSS) satellite transmissions and WiMAX services.

The frequent deployment of WiMAX antennas with downtilt capabilities makes upper sidelobe suppression more important. Mechanical downtilt of the antenna can result in the upper sidelobe projecting near to or at the horizon and causing adjacent cell interference.

One of the most effective ways for controlling upper sidelobe generation is through amplitude tapering. By altering power output to the outermost elements, engineers can effectively reduce sector interference caused by upper sidelobes.



Amplitude tapering can be effective in acheiving good upper sidelobe suppression.

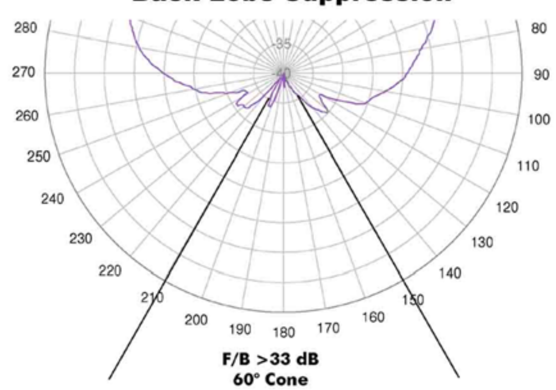
While upper sidelobe generation can be minimized using amplitude tapering, there is a tradeoff with the azimuth pattern gain. Energy re-directed to the main lobe increases the width of the main beam, resulting in gain loss. With upper sidelobe levels at 18–20 dB, gain in the main beam will be reduced by approximately 0.5 dB.

**Back Lobe Interference**

Also known as front-to-back ratio, this is the ratio of the maximum directivity of an antenna to its directivity in the opposite direction. In the past, the presence of some level of back lobe interference has been accepted as a given.

In traditional voice-driven cellular networks, the biggest impact from back lobe interference is in energy loss. Even then, the amount of RF leakage from the back of the antenna is nominal compared to the total energy radiated.

**Back Lobe Suppression**




Azimuth pattern exhibiting good back lobe suppression.

In the data-driven world of WiMAX, however, back lobe interference takes on bigger implications. The problem is not so much the relative energy lost but the adjacent cell interference created, both co-channel and cross-channel. In sites utilizing more than three antennas, the problem is compounded because of the number of back lobes leaking into adjacent cells which may or may not be using the same sub-channel.

Normally, higher gain antennas can provide a higher front-to-back ratio than lower gain antennas. Modifying the reflector geometry and size can help mitigate the effects of back lobe interference to some degree.

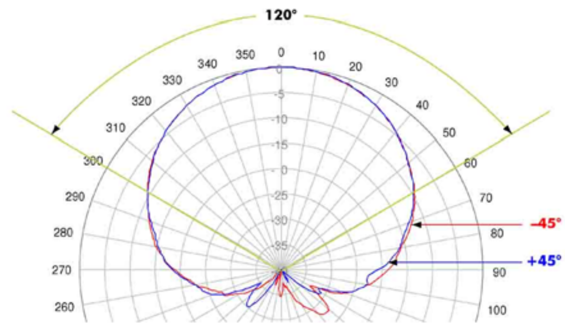
**Horizontal Beam Tracking**

Horizontal beam tracking is a key characteristic, especially in environments where a rake receiver cannot be deployed. Horizontal beam tracking defines the degree to which the plus and minus slant signals are aligned along the horizontal plane.

Misalignment of the beams can often be attributed to the selection of elements or to asymmetries in the feedline network. While generally not reflected in the antenna's specifications, horizontal beam tracking is increasing in importance as tolerances for pattern performance tighten.

Such misalignment can be especially disruptive in GSM environments that depend on successful handoffs from one beam slant to the other. Assume, for example, the control channel is on the plus slant and the voice channel is on the minus slant. Should the control channel squint to the left or right, such that the end user receives the control signal but not the voice signal, the call may be dropped. Additionally, any squinting of either signal will, by default, add interference to the adjoining sector and reduce that sector's capacity.

**Horizontal Beam Tracking**




Horizontal beam tracking presents an increased challenge in having to precisely shape both the plus and minus slants.

### Beam Squint

Beam squint is another source of inter-sector interference. It refers to the amount of pointing error of a given beam referenced to mechanical boresite. The beam squint can affect the sector coverage if it is not at mechanical boresite. It can also affect the performance of receive polarization diversity if the two arrays do not have similar patterns.

Beam squint can be especially problematic in open rural areas where WiMAX cell coverage can extend up to 30km. As the cell coverage increases, the degree of error increases geometrically.

Asymmetrical design in the physical components of the antenna plays a big role in causing the electrical boresite to misalign with the mechanical boresite. In many cases, these physical asymmetries, discussed later, are unavoidable. So antenna engineers must compensate by altering current flow in order to re-shape the pattern and re-align the mechanical and electrical boresights.

**Effects of Downtilt**

Antennas with electrical downtilt capabilities use mechanical phase shifters to electrically tilt the elevation plane of the antenna. This capability allows operators to optimize sector coverage based on end-user traffic and use patterns. Virtually all antennas with remote variable electric downtilt utilize a patented design developed by Andrew.

It should be noted that electrical downtilt, in and of itself, rarely causes interference. Re-directing the antenna beams do, however, alter the effects of other pattern characteristics, most notably interference caused by upper sidelobes.

As the signal is tilted down, upper sidelobes, especially the first upper sidelobe, are directed toward the horizon. Depending on the gain within the upper sidelobe and the terrain, that energy can find its way into adjoining cells where it creates interference and reduces system capacity.

Installation errors in the field often compound such problems. It has been estimated that installation errors can result in the elevation angle being off by as much as 10 degrees.

There are also some isolated situations in which the electrical downtilt system does generate interference on its own. One such instance would be when the motor that controls the phase shifters is improperly insulated, resulting in electromagnetic interference. Another instance is when there is too much play in the mechanics of the phase shifters. In these cases, pattern problems created by electrical downtilt can often be a sign of larger problems in the production and assembly process.

**Physical Design Considerations**

As noted, many of the root causes of signal interference can be traced back to the physical design of the antenna. Considerations such as element selection, placement of mechanical fasteners, and reflector geometry all have a direct and significant effect on signal patterns.

Element selection includes microstrip patch elements or orthogonally-oriented dipole elements. In general, orthogonal dipoles yield a greater degree of pattern control and thus, are preferred.

As for reflector geometry, antenna engineers are limited by weight and wind load restrictions. While it is possible to design a reflector wide enough to minimize pattern anomalies, such as back lobe generation, it would be functionally impractical for the field. However, advanced modeling software has been used to significantly improve reflector shape and size while remaining within the physical confines. Software similar to that employed by the aerospace community uses physical optics (PO) reflector analysis with an optimization subroutine developed by mathematicians.

Finally, there are other design restrictions that ultimately result in asymmetric engineering that will have a negative impact on signal interference. For example, most dipole antennas using a microstrip feedline network use small hooks attached to the legs of the array. In order to achieve symmetry, these hooks would need to be located in the same physical space on the tray. But because two objects cannot occupy the same space, engineers are forced to overlay one hook on top of the other. The result is a geometry that can cause a variety of antenna pattern irregularities, however good design techniques can reduce the effects of the problem.

**Designing Across Frequencies, Polarization, and Tilt**

The difficulty in designing antennas with excellent interference rejection properties can be found in attempting to optimize performance for multiple frequencies, polarizations, and tilt angles. A typical wideband solution antenna, such as the W2X-6516DS-VTM, must be designed and optimized to meet specifications for ten unique frequencies, two polarizations, and three tilt angles. Assuming fifteen pattern characteristics for each unique frequency, polarization and tilt angle, engineers must design and optimize the antenna to meet 900 specifications.

With so many pattern variables linked to a few common design components, such as element configuration, tray geometry, and feedline network, it is easy to see how modifying to optimize along a single pattern characteristic will change many others.

One strategy for overcoming this enormous challenge is designing narrow bandwidth antennas that need only meet the range of specifications across a few frequency designations. The implications of such designs, however, are that operators must select, stock, and maintain a larger inventory of different products and parts.

Designing wide band antennas that optimize pattern characteristics across frequencies, polarizations and tilt angles, involves the use of sophisticated modeling software and rigorous experimental work in the lab.

In developing the W2X WiMAX antenna line, Andrew employs some unique electromagnetic modeling and testing techniques that have enabled the company to shave valuable time off the development process, while still meeting operator's performance and financial requirements. Use of printed circuit board technology in the feedline system, for example, yields superior phase control, resulting in more precise and consistent pattern shaping.

The company has also invested significant dollars on developing phase shifting technology that minimizes RF leakage, a key culprit in the creation of unacceptable back lobe levels.

**Conclusion**

If WiMAX is to realize its full potential as a last-mile broadband mobile solution, RF engineers must continue to push for base station antenna systems that can deliver greater spectral efficiency. One of the best ways to achieve this is by optimizing signal patterns to reduce interference.

"The focus of future technology enhancements should be on improving system performance aspects that improve and maximize the experienced SNRs in the system instead of investigating new air interfaces that attempt to improve the link layer performance. Examples of technologies that improve SNR in the system are those that minimize interference through intelligent antennas or interference coordination between sectors and cells." (Rysavy Research*, Data Capabilities: GPRS to HSDPA and Beyond,* 2005)

Pattern optimization, however, is highly complex given the number and range of possible anomalies and variables. Characteristics such as pattern roll-off, upper sidelobe suppression, horizontal beam tracking, beam squint, and front-to-back ratio are just some of the issues that must be addressed across all possible frequencies, polarizations, and tilt angles.





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On the other hand, the payoff for the industry could be big. In his paper, *Advanced Site Solutions for WiMAX,* Dr. J. R. Sanford, CTO of Cushcraft Corporation, estimates that “we can potentially double the revenue generating potential of the base station if we choose RF hardware that improves the *C/I* by 7dB.”

A well-designed antenna that can generate precise and consistent patterns, such as those being developed by Andrew, can go a long way toward meeting that threshold and helping operators realize the potential that WiMAX offers.

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