Electrical and Mechanical Downtilt and their Effects on Horizontal Pattern Performance

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EXECUTIVE SUMMARY

Inter-sector interference has been a problem for wireless operators ever since RF engineers deployed the first sector array antennas. Radiation patterns that bleed outside the antenna’s defined sector affect not only the quality of service in adjacent sectors within the same cell, but can disrupt service in adjacent cells as well.

In an attempt to confine the signal to its specific sector, operators have employed a variety of techniques, including physically downtilting the antenna. Known as mechanical downtilt, this technique has been effective to some degree, but has also caused additional problems.

Physically downtilting the antenna occurs along a single horizontal plane. As the front of the antenna is tilted down, the back is, by default, tilted up. This limitation creates a variety of radiation pattern irregularities, such as pattern blooming, that are a major source of inter-sector interference. Even still, mechanical downtilt has become an accepted practice. To help compensate for the inherent limitations of mechanical downtilt, the industry has developed certain general guidelines.

The introduction of electrically downtilted antennas gave network operators greater flexibility in tilting the antenna beam and manipulating the radiation pattern. The electrically downtilted antenna enables the operator to tilt the antenna pattern along an infinite number of angles, in effect, creating a three-dimensional “cone of coverage.” As a result, electrical downtilt allows the operator greater freedom in shaping the antenna’s horizontal radiation pattern to minimize inter-sector interference and maximize quality of service within the specified sector.

The use of electrically downtilted antennas has increased significantly since the technology was first introduced. RF engineers, however, continue to apply the same basic guidelines initially developed to help compensate for the limitations of mechanical downtilt antennas.

Additionally, many operators have begun to use mechanical downtilt in tandem with electrical downtilt. While combining the two methods can be effective in very limited applications, data suggests that overall this practice leads to horizontal pattern deformations that can altogether offset the benefits of electrical downtilt.

This paper has been developed in order to demonstrate the horizontal pattern-shaping abilities of sector array antennas using electrical versus mechanical downtilt. Specifically, it illustrates how electrical downtilt can be used to minimize interference in the horizontal plane by systematically lowering gain — at boresite, 180° behind boresite, and at ±90° to boresite. Additionally, this paper seeks to quantify the negative effects of attempting to combine the two technologies.

It also provides a revised and improved guideline for antennas using electric downtilt in order to help operators reduce horizontal pattern irregularities such as pattern blooming, beam squint and front-to-back ratios to acceptable levels.
SECTORIZATION AND INTRA-CELL INTERFERENCE

A key driver in the design of RF networks is the continual need to create greater and greater network capacity. Since the development of the early omnidirectional antennas, engineers have relied upon frequency re-use within the same system in order to generate more capacity.

The introduction of the sector array antenna enabled engineers to employ frequency re-use to an even greater degree and realize higher capacity within a given cell. While the upside has been increased cell capacity, the downside is that sectorized antenna systems can create a greater degree of intra-cell interference.

In a typical three-sector array, three antennas, each with a 65° horizontal beamwidth, cover the area around the tower and some defined distance towards the horizon. Theoretically, each antenna should cover the exact pie-shaped area defined by its sector, and only that area. Practically, that is not the case. Because of the need to provide total sector coverage and ensure consistent high-speed hand-offs, the patterns of adjacent sectors must overlap. The overlap typically occurs at –10 dB from maximum gain. More overlap than this, –6 dB for example, can create significant interference that degrades the quality of service and reduces cell capacity.

Today's high-speed data and video-driven networks are highly sensitive to any signal disruption. Antenna designers are constantly in search of techniques to help them achieve total sector coverage with a minimum of sector overlap. Of these techniques, downtilting the antenna has proven the most cost-effective and, as a result, is among the most frequently used.

Note: Throughout this paper, any discussion of antenna patterns is meant to apply to the antenna's horizontal pattern only.

MECHANICAL DOWNTILT AND ITS AFFECTS ON PATTERN PERFORMANCE

Until recently, the accepted method for downtilting an antenna was to mechanically alter its position on the tower. But as shown by the yellow shading in Figure 1, the antenna represents a fixed unit capable of tilting along one plane only. As the front tilts down to lower the gain on the horizon, the back tilts up, changing the front-to-back ratio and increasing inter-sector interference.

One of the specific results created by the limitations of mechanical downtilt is known as pattern blooming, illustrated in Figure 2. The degrees of mechanical downtilt are indicated by the varying shades in Figure 2. The outermost pattern represents a mechanically downtilled antenna with 0° of downtilt. The change in pattern shading represents what happens as the antenna is mechanically downtilted – 4°, 6°, 8°, and 10°.

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At 0º downtilt, and even at 4º, the pattern is relatively uniform. But notice what happens as the antenna is mechanically downtilted further. The 3 dB beamwidth begins to flatten out. At 8º of mechanical downtilt, the 3 dB beamwidth continues to grow wider, well beyond the 65º pattern for which it was intended. At 10º mechanical downtilt, the pattern is grossly distorted. All these pattern deformities represent varying degrees of a phenomenon known as pattern blooming.

Realizing that mechanical downtilt creates pattern distortion, the industry attempted to define how much pattern blooming was acceptable. A 10% pattern bloom, defined as a 10% increase in the rated azimuth pattern of a particular antenna, became the recommended maximum for this type of horizontal pattern distortion. It was well documented that the typical 65º azimuth antenna, at 0º mechanical downtilt, exhibits about a 10 dB reduction in crossover gain. Therefore, this 10 dB reduction in gain has become the de facto specification for most modulation schemes in high capacity areas.

To help designers determine how much mechanical downtilt could be employed without creating more than 10% pattern blooming, engineers developed a rough rule of thumb through studies using vertically polarized (V-Pol) antennas. The guideline recommended that mechanical downtilt of an antenna should not exceed more than one-half of its vertical beamwidth. While new antenna technologies have continued to develop, this guideline has seen no change since its inception.

Recent studies involving cross-polarized (X-Pol) antennas along with more accurate and sophisticated range measurement equipment have both improved the former rule of thumb and shown that additional performance parameters can also be degraded by aggressive mechanical downtilting.
ELECTRICAL DOWNTILT PROVIDES GREATER PATTERN CONTROL

The development of the electrically downtilted antenna gives operators greater control and precision in shaping the antenna's horizontal radiation patterns. Whereas mechanical downtilt alters the antenna's physical position on the tower, electrical downtilt changes the phase delivered to the antenna's radiating elements — independently and simultaneously. This allows engineers to manipulate gain in a full 360° around the tower and to the outer perimeter of the site. The visual representation of this coverage resembles a cone as seen in Figure 3.

*Figure 3: Cone shaped coverage of electrical downtilt*

When mechanically and electrically downtilted antenna patterns are compared side by side, the ability of the electrically downtilted antenna to reduce anomalies such as pattern blooming becomes apparent. Figure 4 illustrates the results when two antennas with identical specifications — one electrically downtilted and the other mechanically downtilted — are tilted at varying degrees. The pattern on the right (Figure 2 from above) indicates undesirable distortion previously noted. The distortion grows more acute as the tilt position increases. The pattern on the left indicates how the electrically downtilted antenna suppresses the pattern bloom. It is able to achieve this because the individual radiating elements are being manipulated instead of the entire antenna as a fixed unit.

*Figure 4: Electrical vs. mechanical downtilt pattern comparison*
In addition to reducing horizontal pattern blooming, the increased beam forming capabilities of the electrically downtilted antennas have yielded significant improvement in controlling other negative pattern characteristics. These include beam squint, front-to-back ratio and cross-polarization ratio.

**Beam Squint**

Beam squint is defined as the difference between the mechanical boresite and the electrical boresite of an antenna as shown in Figure 5. The mechanical boresite is defined as being perpendicular to the antenna’s back tray while electrical boresite is defined as the mid-point of the 3 dB beamwidth.

![Figure 5: Beam squint](image)

Figures 6 and 7 compare the degree of beam squint created when using mechanical downtilt only versus electrical downtilt only. The data is based on a vertically polarized (V-Pol) 65º azimuth antenna and a DualPol® (X-Pol) 65º azimuth antenna, and is expressed as a percentage of the antennas’ vertical beamwidths for easy comparison.
In Figure 6, the degree of difference between mechanical and electrical boresites remains relatively consistent when using electrical tilt only. Figure 7 demonstrates how the beam squint on the DualPol antenna increases with the degree of mechanical downtilt. At the higher angles of mechanical downtilt on X-Pol antennas, the squint can exceed 10% of the antenna’s azimuth beamwidth, causing coverage holes in some areas and inter-sector interference in others.

![Figure 6: Beam squint with electrical tilt only](image)

![Figure 7: Beam squint using mechanical tilt only](image)
Sector Power Ratio

Sector Power Ratio (SPR) is another measure of an antenna’s ability to minimize interference. SPR is an expression of the RF power radiated outside the sector versus the RF power radiated and retained within the sector. The best performing antenna designs provide SPRs of 3% – 4%, while typical designs using dipole or patch elements yield an SPR of about 8%. Figure 8 illustrates the concept of Sector Power Ratio and the equation used for its calculation.

\[
SPR (\%) = \frac{\sum_{60}^{300} P_{\text{Undesired}}}{\sum_{60}^{300} P_{\text{Desired}}} \times 100
\]

**Figure 8: Sector power ratio**

Much like beam squint, SPR remains relatively constant for both V-Pol and X-Pol antennas using solely electrical tilt (Figure 9). When subjected to mechanical downtilt only, however, SPR performance begins to degrade rapidly as the tilt angle is increased (Figure 10).
Figure 9: SPR using electrical downtilt only

Figure 10: SPR using mechanical downtilt only
ADVERSE EFFECTS OF COMBINED ELECTRICAL AND MECHANICAL DOWNTILT

Since the advent of the electrically downtilted antenna, it has been common for some operators to combine electrical and mechanical downtilt on the same antenna in hopes of achieving better pattern performance. This, in fact, can have the opposite affect.

Reports of worse than normal interference at a site using combined electrical and mechanical downtilt led to Andrew conducting an investigation to analyze the effects of such a combination.

The investigators looked at the degree of pattern variance at different tilt positions using mechanical tilt only, electrical tilt only, and various combinations of mechanical and electrical tilt. Some key findings from this analysis are reflected in Figure 11.

The patterns shown in Figure 11 are examples of various downtilt scenarios (In the legends shown below, M represents the degree of mechanical downtilt and E represents the degree of electrical downtilt).

![Figure 11: Pattern variances](image)
Note that the normalized light green pattern for $M=0$, $E=0$ and the light blue pattern for $M=0$, $E=7$ practically overlay each other. In both cases, the antenna beam has been re-directed using electrical downtilt only. This substantiates the concept that, when using electrical downtilt only, the horizontal pattern remains consistent even as the tilt angle increases. By contrast, the other patterns in Figure 11 illustrate what happens when mechanical downtilt is used by itself or in combination with electrical downtilt. The patterns in which mechanical downtilt is used (Purple and Red) indicate blooming of the horizontal pattern as well as worsening of front-to-back ratios.

Investigators also analyzed the effects of combined mechanical and electrical downtilt on the front-to-back ratio ($F/B$) and Cross-Polarization Ratio ($CPR$).

Front-to-back ratio ($F/B$) compares gain at boresite to gain at point 180° behind boresite as shown in Figure 12. It is often expressed as the $F/B$ ratio over some angle around the 180° point (ie. $180 \pm 30^\circ$).

Cross-Polarization Ratio ($CPR$) as shown in Figure 13 is a measure of the de-correlation of the two polarizations used in a X-Pol antenna — one at $+45^\circ$ and the other at $-45^\circ$.
Figure 14 demonstrates the degradation in F/B ratio and CPR when mechanical downtilt is applied to an antenna already having a large amount of electrical downtilt. The patterns are for a typical 4 foot, 65º antenna employing 15º electrical downtilt and 5º mechanical downtilt.

The F/B ratio has degraded to approximately 18 dB at 180º and the cross-pol is actually worse than the co-pol pattern. Taken over a ±30º angle around 180º this F/B method measures only 8 dB!

Finally, the CPR over the desired sector degrades to only 5 dB at the sector edge — far short of the 10 dB expectation.

With a vertical beamwidth of ~16º @ 850 MHz, the tilt combination is well beyond even the 20% blooming curve of Figure 7. In fact, the horizontal beamwidth is in the neighborhood of 160º or approximately 250% blooming!

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DEVELOPING A MORE ACCURATE RULE OF THUMB

The observations of the investigation team strongly indicated that — in most cases — combining electrical and mechanical downtilt has significant adverse affects on pattern performance. The next step was to revisit the original rule of thumb to ascertain whether it was still applicable.

First, range patterns were measured on different antennas for both the azimuth (through elevation boresite) and horizontal (on the horizon) cuts. This was done at various mechanical and electrical tilt angles. The findings in Figures 15 and 16, show that the old rule of thumb is no longer applicable when electrical downtilt is employed.

But the fact remains that some operators will continue to combine electrical and mechanical downtilt. Therefore, it is useful to have a rough but workable guideline when deploying mechanical and electrical downtilt in order to suppress pattern blooming.

In developing a more accurate rule of thumb, investigators used data points from the latest and most accurately measured range data. Once the data points were plotted, the resulting curves (indicated in Figures 15 and 16), dictated the typical amount of combined mechanical and/or electrical downtilt allowable in order to keep pattern blooming to a maximum of 10% and 20%.

Figure 15 models the performance of an antenna with a 65º azimuth, 48.5 inch height, 19º elevation, and operating at 787 MHz. Figure 16 assumes an antenna with 65º azimuth, 81.5 inch height, 9.9º elevation, and operating at 787 MHz.

![Figure 15: 48.5 Inch height antenna performance](image-url)
Figure 16: 81.5 Inch height antenna performance

As the green (10% blooming) curve demonstrates, the more electrical downtilt is employed, the less mechanical downtilt can be used to stay within the 10% goal. Based on this new data, the investigative team recommended a new rule of thumb to be used in order to keep blooming to within 10%. It states:

$$65^\circ \text{ AzBW } M-\text{Tilt}_{10\% \text{ Bloom}} = \frac{(VBW - E-\text{Tilt})}{2.5}$$

Figure 16 also illustrates another important new finding. Even when no electrical downtilt is used, the old rule of thumb governing the maximum amount of mechanical downtilt is no longer valid. Instead of using a k-factor of 2, the graph in Figure 16 indicates that the correct formula should be:

$$65^\circ \text{ AzBW } M-\text{Tilt}_{10\% \text{ Bloom}} = \frac{VBW}{2.5}$$

It should be noted that the guidelines suggested here apply only to common 65° azimuth beamwidth antennas. Upon further investigation, antennas having azimuth beamwidths other than 65° vary as to the maximum k-factor required to keep blooming within 10%. As indicated in Figure 17, the k-factor ranges from 1.5 for 33° azimuth models to 3.3 for 90° azimuth models. Note that these rules of thumb describe typical band-center performance and can vary somewhat at the band edges. They also only hold true if the combined mechanical and electrical tilts do not tilt the pattern beyond its first upper null.
CONCLUSIONS

The industry has long been aware of the inherent physical limitations of antennas using mechanical downtilt and the challenges they present in trying to adequately balance coverage and interference. In fact, it was this understanding of the shortcomings of mechanically downtilted antennas that led to earlier engineers developing a basic rule of thumb to try and keep pattern blooming in check.

Yet, when this rule of thumb was revisited it was found to be somewhat inaccurate and insufficient in consideration of the use of X-Pol antennas and the demand for more precise RF containment. More accurate range data shows that, in order to keep pattern blooming to less than 10%, the maximum mechanical tilt is not half (50%) the vertical beamwidth as previously believed, but it is more precisely the vertical beamwidth divided by 2.5 (40%). This finding in and of itself is significant as one can readily see how at increased tilt angles, pattern blooming can quickly get out of hand. Couple it with the fact that many of today's engineers are attempting to combine mechanical and electrical downtilt — which adds much greater degree of pattern erosion — and it becomes clear that a new mathematical model is needed.

While we have suggested an alternative model to the old rule of thumb, one that is more accurate and consistent with today's more precise antenna designs, the underlying message throughout
this paper does not change: Engineers employing any degree of mechanical downtilt, whether by itself or in combination with electrical downtilt, must be prepared for unexpected and often undesirable pattern variances.

This effect holds true beyond pattern blooming and can be seen in other horizontal pattern characteristics such as front-to-back ratio, beam squint, sector power ratio, and cross-polarization ratio. Therefore, it would seem that the best and most precise solution would be to eliminate the use of mechanical downtilt altogether. As noted in this paper, antennas using only electrical downtilt produce horizontal patterns that maximize sector coverage while minimizing potential interference, and that their patterns demonstrate a high degree of consistency regardless of the tilt angle.

As the industry continues to evolve, the need to be able to consistently support high-speed, high-capacity video and data traffic will become a subscriber expectation. In this interference-limited environment, keeping inter-sector signal disruption to an absolute minimum will become a key competitive advantage. Those operators who plan now to make exclusive use of electrically downtilted antennas a part of their deployment strategy will be positioned to reap the benefits in the near future.