APPENDIX 1. MODEL 105 END-FIRE GLIDE SLOPE ANTENNA SYSTEM - OPTIMIZATION SUPPLEMENT

A.1 INTRODUCTION.- This Appendix provides information regarding the manufacturer-recommended techniques, practices, and procedures for antenna adjustments of the Model 105 End-Fire Glide Slope antenna system (EFGS). The material contained herein is provided such that technical or engineering staff will have the necessary knowledge to adjust the antenna support pedestals to achieve optimum performance of the signal-in-space. Knowledge of the influence of each pedestal adjustment is useful when re-establishing ground check readings in the event of damage to the system or when replacing main antenna sections. Application of the techniques contained herein will reduce costly flight inspection time through a direct approach to system optimization. The material is written with the expectation that the system has been installed and adjusted in accordance with the EFGS Instruction Book and that maintenance personnel are familiar with material contained in the booklet.

The EFGS is recognized as a complex antenna system that requires a thorough understanding before optimum, sometimes even acceptable, performance can be achieved. It is not likely that a system installed “by the book” will be performing at optimum levels without some optimization of the antenna system. Here the term “optimization” refers to adjusting the physical location of some of the pedestals that support the antenna system. For the clearance antenna, “optimization” refers to adjusting the angular orientation of the antenna and adjusting the radiated power for optimum performance.

The composite radiation from an EFGS is comprised of contributions from many sources. As with any antenna system the number of sources plays a role in defining the overall complexity. The additional complexity of the EFGS is offset by factors such as narrow radiation patterns, the ability to perform at sites with very limited ground plane and by the inherent capability to control, and therefore optimize, the antenna system to remove site effects.

Course antenna pedestal adjustments must be made carefully. Although in the worst case it may be necessary, personnel should avoid adjusting a single pedestal by more than 2.5 inches. If necessary, the adjustment can be divided between the front and rear array. One should always consider the positive effect of restoring a previous adjustment to the original position before considering any new movements.

A.2 GENERAL THEORY.- An “elemental” EFGS can be constructed of only two dipole antennas spaced at the appropriate distance. With this configuration the azimuth coverage is very narrow, approximately 0.5 degree. If more of these antenna pairs were added in an arc, then the transverse pattern can be increased to provide the desired azimuth coverage. This is functionally what exists with the EFGS. This concept using rays is described in the instruction book in chapter 2, Theory of Operation.

The main course antenna radiation patterns are a summation of contributions from a large number of sources. The sources, referred to as “slots”, are actually cavities operating near resonance at glide slope frequencies. The composite of all currents from the main antennas comprise the signal-in space forming the glide path. The Model 105 EFGS, sometimes referred to as the standard end-fire, uses 96 slots per main antenna for a total of 192 sources comprising the course radiation pattern.

Course signals are fed to the feed ends of the main antennas, and the wave propagates down the antenna toward the load. Probe screws are used to tap energy flowing through the coaxial line to the slot cavities to induce currents on the outer conductor of the antenna. This type of scheme is referred to as a leaky transmission line with a series-fed distribution. The amplitude and phase of the signal at each physical slot is determined by the slot location along the line as it relates to the operating frequency, loading and radiation from the previous slots, the impedance of the slot, and the length of the probe screw used to tap energy from the propagating wave.

A key point to remember about EFGS is, assuming support pedestals of equal height above ground, the relative amplitude from each of the slots has been exclusively determined by the antenna manufacturer. The antenna manufacturer is also responsible for the baseline phase of the slots, but the final phase of the signal from the slots is largely in the hands of the site personnel. In a sense, persons involved in the optimization of the antenna are adjusting the phase parameter of the signal distribution. The intent of adjusting the antenna is to achieve a distribution that most closely represents the ideal case. Phase changes to targeted areas of the antenna are achievable by repositioning of the antenna supports to create the desired advance or delay of the slots affected by that pedestal.

As a result of the wave traveling in the antenna line and coupling to the slots, in conjunction with the curvature of each main antenna, the main antennas have phase patterns that are flat and parallel or constant phase over the intended area of coverage. The alignment and smoothness of these phase patterns determine how flat and wide the transverse structure will be. DDM errors in the transverse structure indicate areas where the two antenna phase fronts deviate from one another.

Figure A1-1 shows the fundamental radiation patterns of the EFGS. The course CSB RF pattern is predominant over the proportional guidance area and the clearance RF pattern “captures” the receiver outside of the course area. The course deviation indicator (CDI) pattern without clearance signal is flat throughout the proportional guidance area and results in a hard fly-down signal at the extremities. The clearance signal is added, with the appropriate power level, to produce a trough shaped lateral CDI pattern

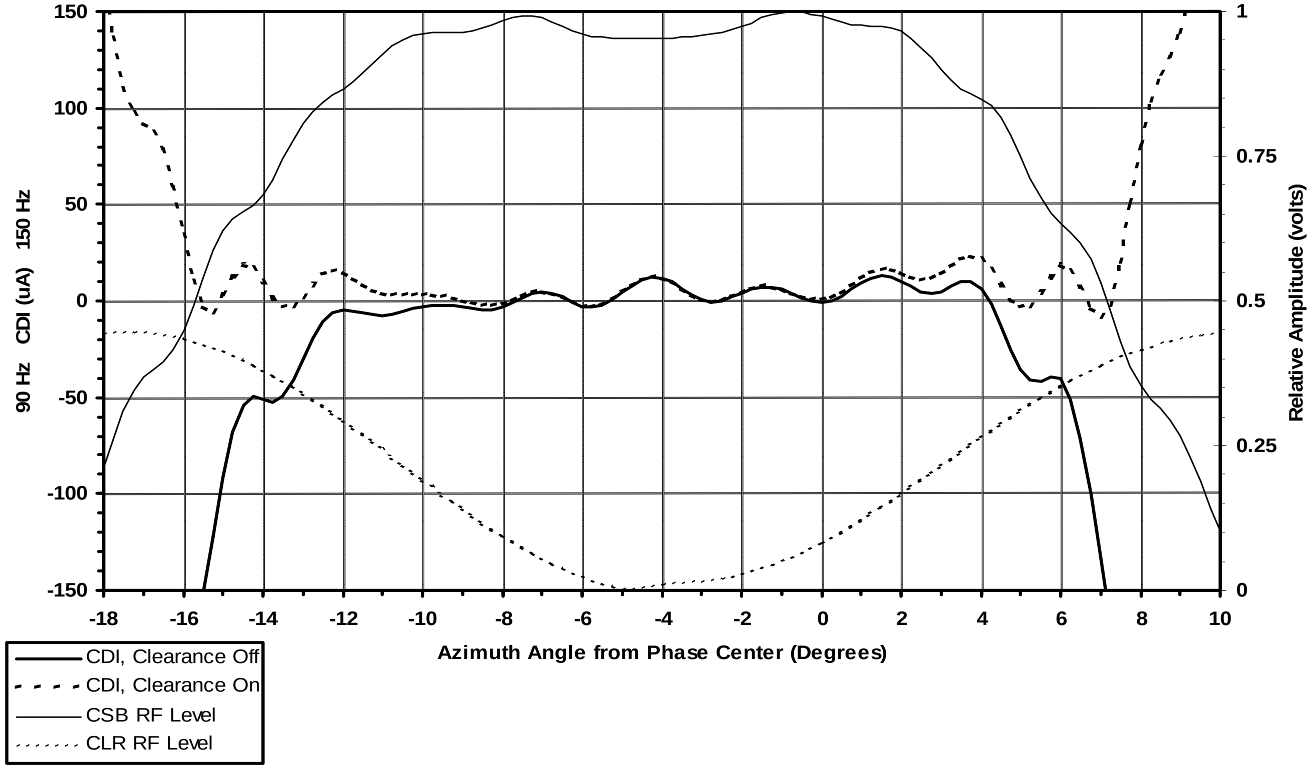


Figure A1-1. Model 105 Fundamental Patterns

A.3 TRANSVERSE STRUCTURE.- The term “transverse structure” is used to identify the glide slope proportional coverage area that is perpendicular, or transverse, to an extended runway centerline. This term is unique to the end-fire systems because of the large lateral apertures of the main antennas and the significant number of radiators that can be adjusted to alter the lateral composite pattern.

The Model 105 EFGS provides nominally 18 degrees of azimuth coverage from the course array. The coverage area is asymmetric with respect to the phase center because of the obvious need to offset the antenna system from the runway centerline and to provide coverage to the threshold for CAT II or CAT III operations. Consequently, less coverage is necessary on the side of the runway that contains the array. The array is positioned such that 5 to 6 degrees of coverage is available on the array side of the runway and the remainder exists on the runway side.

The course structure from the transverse pattern is optimized such that a flat difference-in-depth of modulation (DDM) pattern is obtained by creating a constant tracking phase differential from the main antennas. The result is the existence of essentially the same glide path angle as the aircraft deviates left and right of the localizer on-course while on approach.

The transverse DDM pattern is also directly related to the quality of the approach path. Variations in the transverse pattern, depending on their location, may be superimposed on the approach path in the form of path error. At more complex sites, i.e., those with scatterers under the approach path, a flat transverse structure may not provide the desired approach path quality.

An approaching aircraft, on a centerline localizer, will be at essentially 0.40 degrees azimuth at a 4 NM range (See Figure A1-2). Due to the offset of the antenna system the aircraft will be at nearly 2.2 degrees from the phase center at ILS pt. B or 3500 feet from the threshold. At a range of 900 feet, or ILS pt. C the aircraft is at 6 degrees azimuth from the phase center and at 10 degrees azimuth near the runway threshold. This indicates that the “flatness” of the transverse DDM pattern is directly related to the quality of the approach path.

Any variation in the transverse DDM pattern will be superimposed on the approach path in the form of a path error. Oscillations in the transverse structure present themselves as very slow bends in the approach at long ranges from the threshold and shorter period bends, or roughness, as the aircraft nears the antenna. Transverse optimization is the process of adjusting the antenna support pedestals to affect the phase of the radiating slots such a flat lateral pattern or constant glide angle with respect to lateral deviations is achieved. At less complex sites, i.e., those without reflectors under the approach path, transverse flatness can be directly related to the quality of the approach path.

Transverse optimization is the process of adjusting the antenna support pedestals to affect the phase of the radiating slots such a flat lateral pattern or constant glide angle with respect to lateral deviations is achieved.

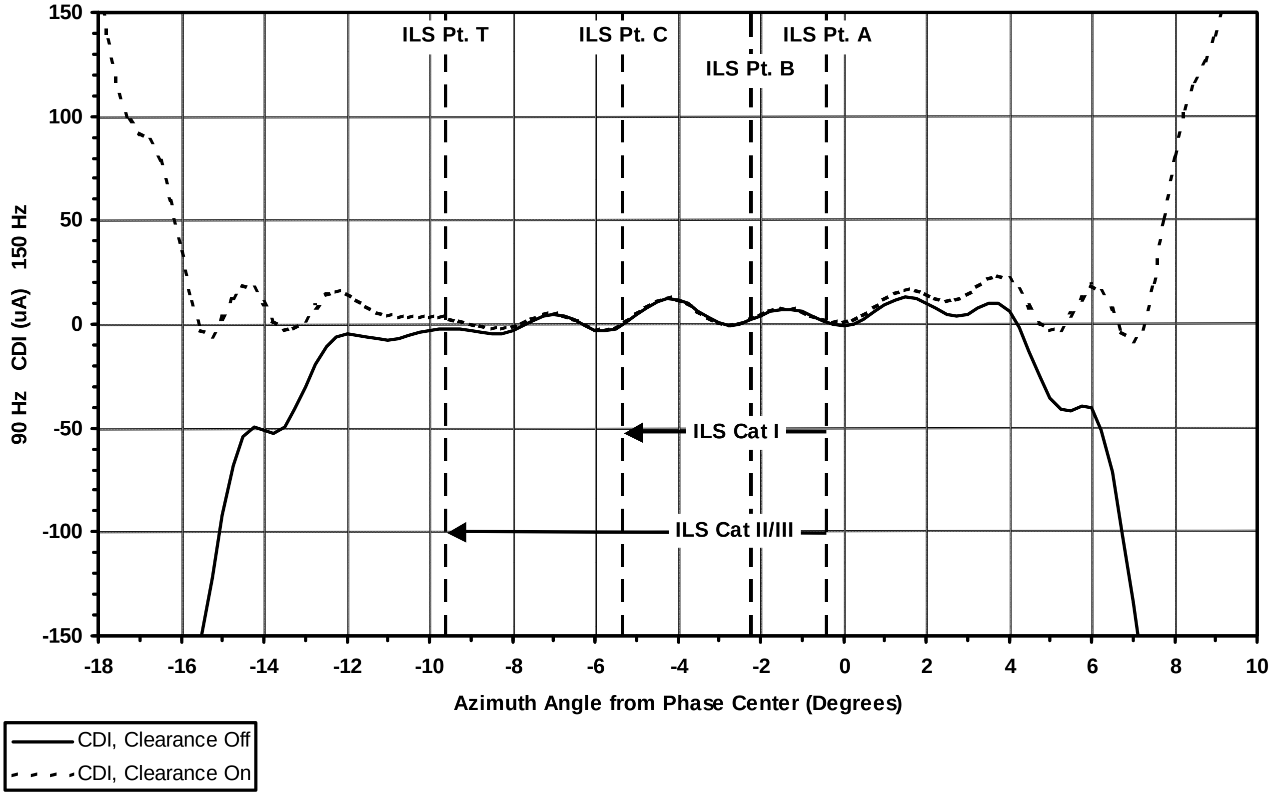


Figure A1-2. Aircraft Range Versus Azimuth Angle From Antenna Phase Center

<u>A.4</u> <u>GROUND MEASUREMENTS AND CHECKPOINTS</u>.- The usefulness of ground measurements of the transverse pattern will vary depending on the site. Because the end-fire systems are designed for sites without good reflecting planes, or with limited real estate, there may not be enough locations available for ground measurements to optimize the system. Also, as with any ground based system, the probability of the existence of reflected or “scattered” signals is much greater on the ground than in the air. These signals, referred to as multi-path, arrive to the observation point by a route other than the direct or intended path. Installation personnel must evaluate if the site has significant potential for multi-path signals in the ground environment. Conditions such as these have resulted in optimizing the transverse structure on the ground only to find that it has a significantly different shape in the air. In short, optimizing the transverse structure on the ground can be a benefit if the terrain and the electromagnetic environment are relatively simple, or a significant waste of effort if the environment is complex. If a flight inspection aircraft is available it is recommended that you proceed directly to airborne measurements.

Ground measurements of the DDM patterns can be taken by placing the front panel EF9 Interface Unit mode switch (S2) in the path-down position. While in path-down, a length of line is electronically switched into the front antenna that moves the path down to zero degrees elevation, with respect to the antenna heights. A 10 dB attenuator is also automatically switched into the front antenna feed-line to essentially balance the front and rear antenna amplitudes at field monitor M2. Path-down, or moving the path to ground level, can be manually affected by physically placing a fixed value of attenuation and a precision delay line in the front antenna feedline.

Ground checkpoint locations every 1-degree in azimuth with respect to the antenna phase center, shown in Figure A1-3, with approximately 8 degrees on the array side and 20 degrees on the runway side are required to optimize the antenna system. Although current Federal Aviation Administration (FAA) standards require fewer ground check points to maintain an end-fire facility, locations at one degree are also needed to determine exclusively which pedestal/s may be responsible for a change in baseline ground check readings. Ground checkpoints on each side of the course coverage area are used so the clearance signals can be evaluated at a later time. If temporary, ground checkpoints should be identified by stakes driven in the ground with markings to indicate the azimuth angle or by paint marks at the threshold or runway overrun. The range for the ground measurements should be determined to acquire the needed data with minimal interruption in airport operations. Zero degrees azimuth can be found by measuring, at a range of approximately 900 feet forward of the phase center, the distance from the runway centerline that is equal to the phase center offset. Projecting a line from the phase center through the measured point and out into the approach region identifies zero degrees azimuth.

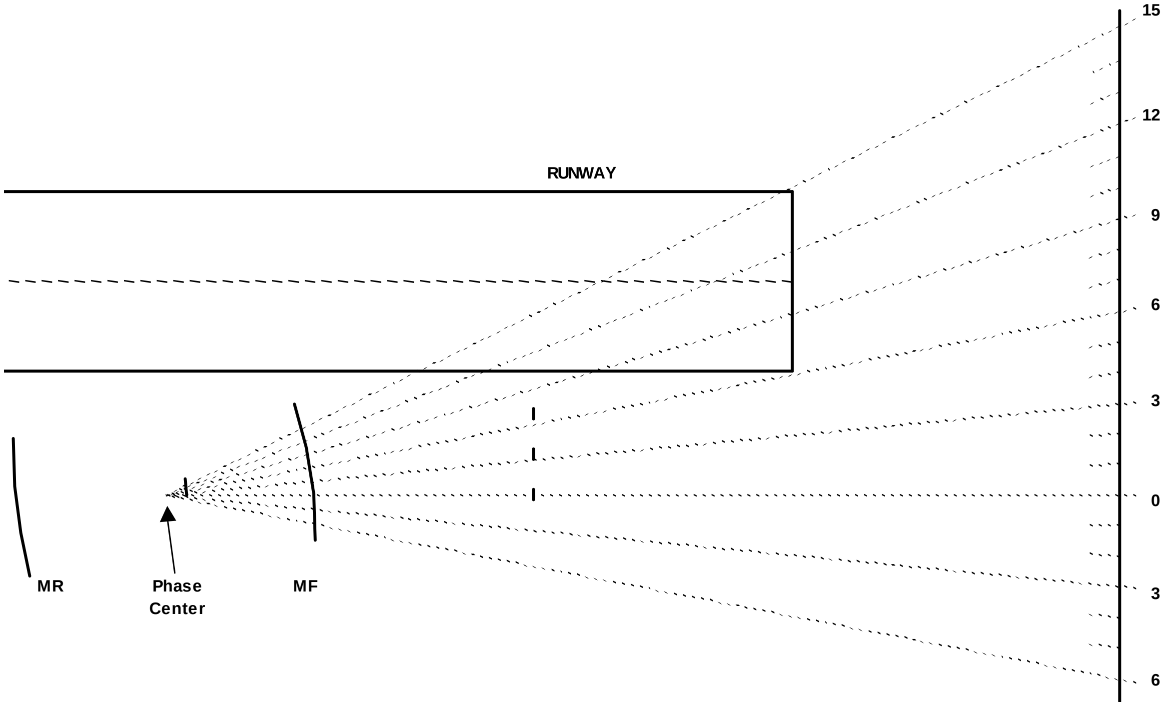


Figure A1-3. Model 105 Optimization/High Resolution Ground Check Points

Figures A1-4 and A1-5 depict the required FAA ground check points (GCP) used to maintain the antenna system. Check points 1, 2 and 3 are located in a line projected from the antenna system phase center and intersecting the center of field monitor antennas M1, M2, and M3. In path-down, the points are used to measure the transverse contour of the course signal. In facility normal, the path is up and the ground check points, now including GCP4 and GCP5 as shown in Figure A1-5, are used to measure below the path to ensure that adequate fly-up signal exists. Points 4 and 5 are located with the path up and the clearance transmitter turned off or terminated into a dummy load. Starting at GCP3 and moving in a direction away from GCP2 a strong 150 Hz fly-up signal from the course antenna will be measured on the PIR. The value of the fly-up DDM will decrease as measurements are made further from the course region. Ultimately a point will be found where the 0 DDM contour from the course antenna will intersect the ground and the DDM will pass through zero and go into the 90 Hz, indicating fly-down signal. The location where the zero DDM point is found identifies GCP4. GCP 5 is found in a similar manner except by starting at GCP1 and moving in a direction away from GCP2 until the zero DDM intersection is found on the opposite side of the course area. When clearance signals are added, GCP4 and GCP5 will indicate a strong 150 Hz fly-up signal. These points are used subsequently to detect changes in the fly-up signal at low elevations due to a change in either the course or clearance signal levels. The two points are located in what will be described later as the lateral “capture region”.

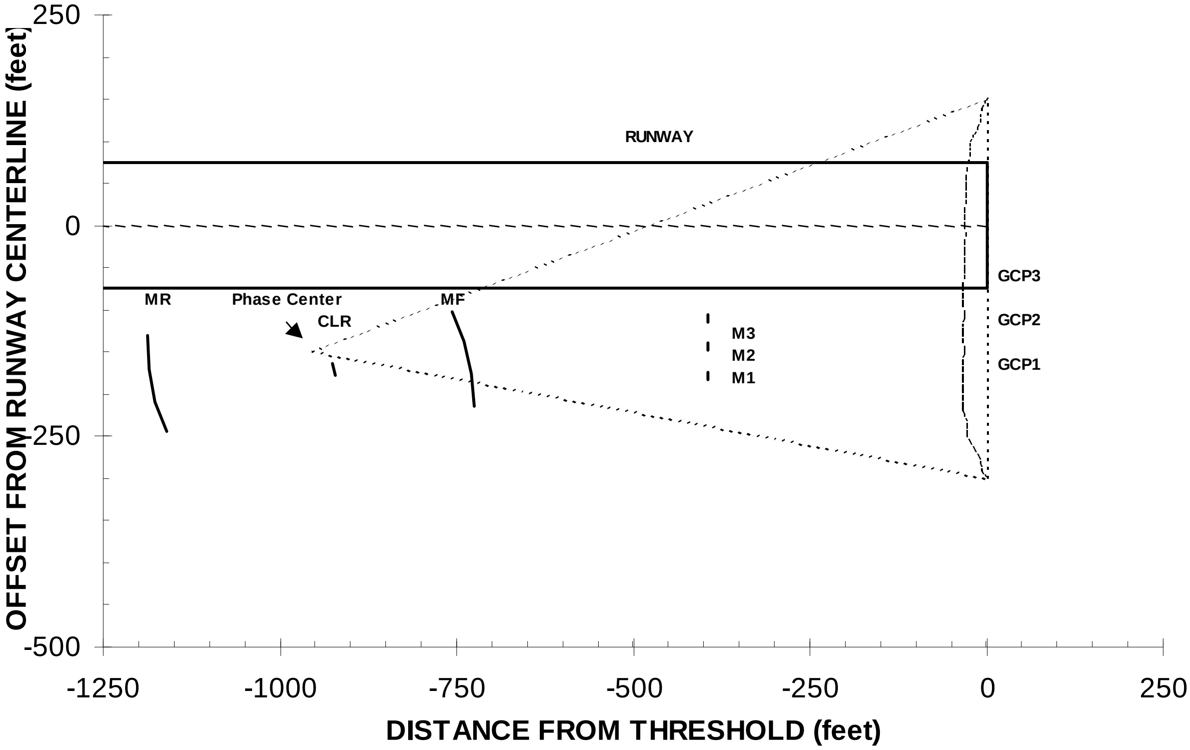


Figure A1-4. Required FAA Facility “Snap-Down” Ground Check Points

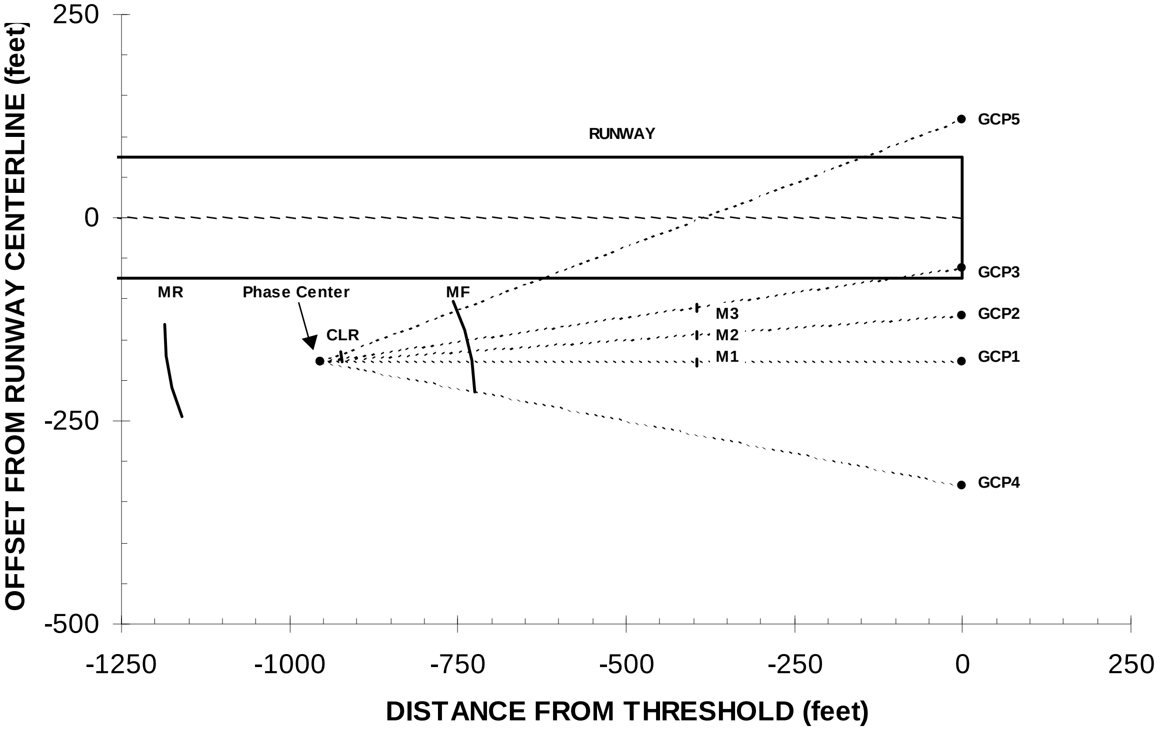


Figure A1-5. Required FAA Facility “Normal” Ground Check Points

For precise antenna optimization on the ground, the nominal 10 dB attenuator in the snap-down circuit may need to be temporarily changed to a value that provides essentially equal front and rear signal levels at the minus two degrees azimuth point and at the GCP range. A RF level measurement of each antenna radiated independently will determine the optimum value of attenuation. The course transmitter should be adjusted for approximately 4 watts of CSB power and 350 mW of SBO signal. If 4 watts of CSB signal is not available from the course transmitter, the SBO should be scaled to maintain this proportion. Although the typical SBO power required for a three-degree approach to a flat runway is approximately 220 mW, it is advantageous to optimize the pedestals with a higher SBO power to increase deflection sensitivity. The clearance transmitter should be turned off. With the system in a path-down configuration, adjust rear antenna phaser A6Z4 for Zero DDM at the minus two degree ground check point and begin the transverse GCP measurements.

The efficacy of ground optimization of the transverse structure will vary depending on the site. Because the end-fire systems are designed for sites without good reflecting planes, or with limited real estate, there may not be enough locations available near the edges for a complete set of ground measurements to optimize the system. Installation personnel should also consider if the site has significant potential for multipath signals in the ground environment. Most importantly, the approach region terrain must be evaluated to determine if conditions are such that the local and distant transverse pattern could be different as a result of lateral scattering or upsloping terrain features. Conditions such as these have resulted in optimizing the transverse structure on the ground only to find that it has a somewhat different shape in the air. In short, optimizing the transverse structure on the ground can be a benefit if the terrain and the electromagnetic environment are relatively simple, or can be a significant waste of effort if the environment is complex. If a flight inspection aircraft is available, it is recommended that you proceed directly to pedestal adjustments using airborne data.

A.5 AIRBORNE MEASUREMENTS.- Airborne measurements of the transverse structure are obtained by flying a constant radius arc from the glide slope point abeam at the intercept altitude and typically a range of 4 to 5 NM. An altitude is selected that will intercept the glide path at the desired range. Errors in the vertical flight track of the aircraft and changes in range will induce errors onto the transverse structure. These errors will be random in nature and will not likely repeat from run to run. The transverse structure should be adjusted only when two repeatable recordings have been obtained in a course signal only configuration with flights in the same direction. The other arc direction should also be measured to determine that no anomalies exist.

Large variations in the data from flights in opposite directions may indicate the existence of lateral multi-path and the influence of the aircraft receive antenna pattern. This infrequent condition could exist in the event of significant rising terrain on either or both sides of the approach path. Level runs made at various azimuth angles are needed to determine which transverse recording correlates best with the inbound level runs before pedestal adjustments can be made.

When adjusting pedestals using airborne data, consideration should be given to the fact that the zero degree reference for the airborne data is extended runway centerline from an origin on the runway centerline abeam the glide slope. However, the zero degree reference for the plots contained in this supplement is a line parallel to the runway centerline and intersecting the antenna phase center. The error is less than 1 degree at long ranges but may be a factor if a high precision targeted adjustment is required. The plots provided here are referenced to the phase center so that ground optimization can be performed prior to the actual flight inspection.

An end-fire system that has been optimized by ground measurements, or in the air by a contractor, may require additional adjustments to obtain optimum performance during commissioning. Flight Inspection should either land or downlink the transverse structure data to maintenance personnel so that a thorough analysis can be conducted and corrective action taken. Although not a commissioning requirement, a transverse structure with and without clearance signal is needed to determine if the undesirable characteristic is a result of the course or the clearance signal. Without this interaction and data, ground personnel can only assume that the system will pass the flight inspection. In many cases this assumption will be in error and may only become apparent after several hours of flight inspection.

The “recommended engineering tolerance” shown in Figures A1-6 and A1-7 is the first figure of merit to determine that the overall flight inspection will be successful. Figure A1-7 shows the glide slope CDI polarity inverted on the “Y” axis to illustrate the potential variation between airborne flight measurement equipment. Systems that fail to meet transverse tolerances will likely fail the overall flight inspection on one of the runs. The tolerance is “recommended” because it may be necessary to make pedestal adjustments to improve the centerline approach structure roughness that would result in degradation of the transverse structure quality. A transverse structure exceeding the tolerance can be accepted only if evaluated and approved by engineering personal, thus “recommended engineering tolerance”.

Tolerances are applied to the transverse structure such that the path angle tolerance for high and low angle is applied across the glide slope system lateral coverage area. Specifically, there can be no greater than 48 uA of fly-down signal within the glide slope coverage area of +/- 8 degrees and no greater than 64 uA of fly-up signal within the localizer edges. With a 3.0 degree commissioned path angle the transverse DMM tolerances relate to 0.225 degrees low and 0.30 degrees high, respectively, or a path angle between 2.775 and 3.30 degrees.

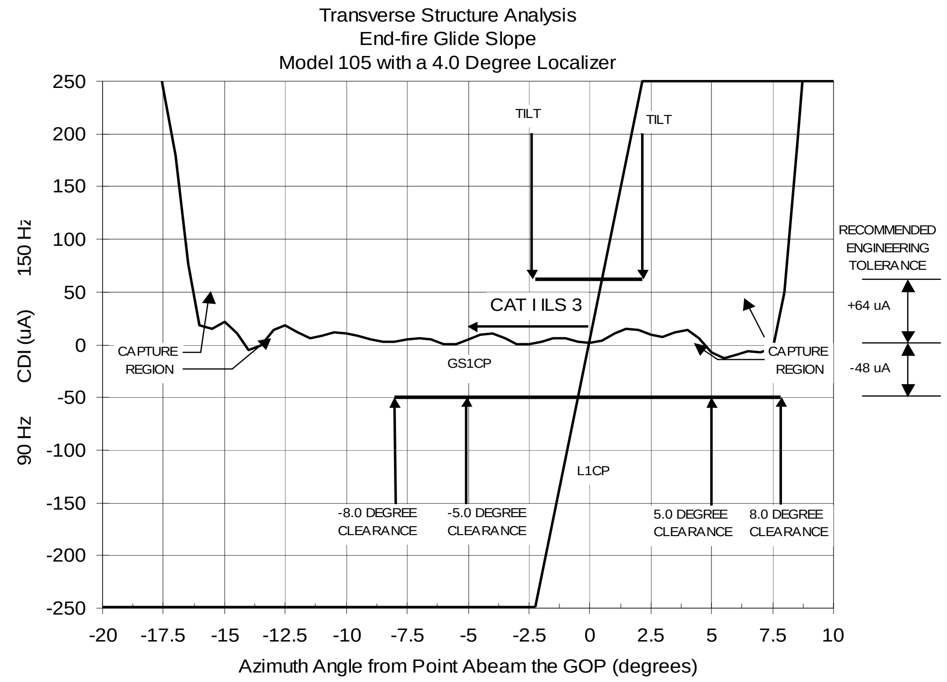


Figure A1-6. Recommended Engineering Tolerance - 4 Degree Localizer

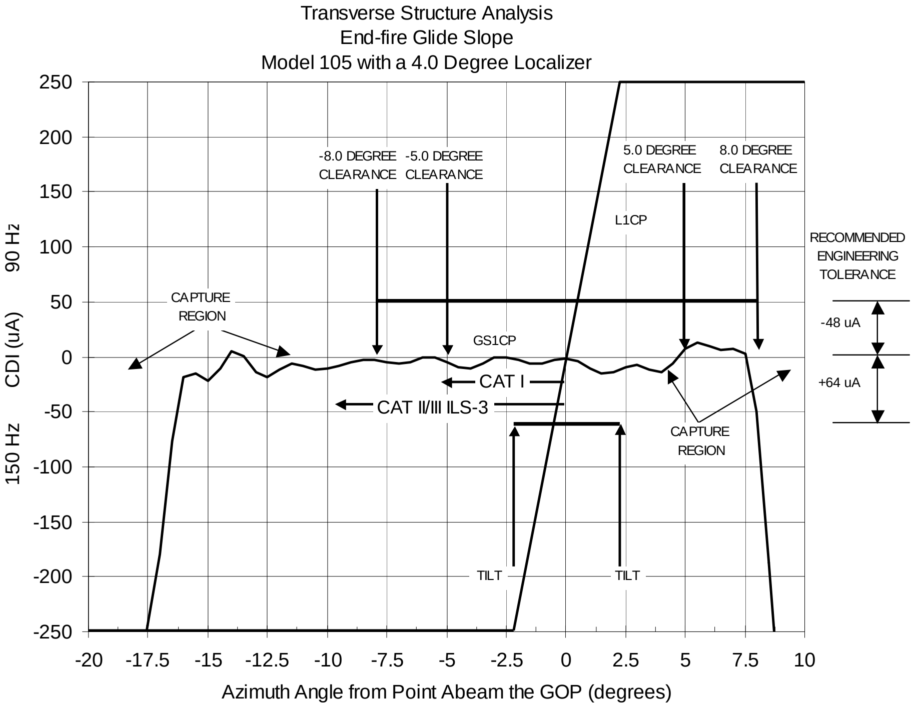


Figure A1-7. Recommended Engineering Tolerance - 4 Degree Localizer

Early identification of any issue regarding transverse performance can save considerable time during the commissioning. A single transverse structure recording can be analyzed to predict the results of measurements taken during several flight inspection profiles.

Figures A1-8 through A1-12, indicate what areas are of particular interest for flight profiles flown during the commissioning. The flight profile related to any area near the tolerance limit should be flown first to verify the profile will pass the tolerance.

Figure A1-8 shows that cuts are made at +/- 2 degrees of the transverse structure to determine the “tilt” of the glide slope at the course edges of a 4.0 degree wide localizer. Obviously, if a 6 degree localizer were used the areas of interest would be +/- 3.0 degrees. The glide path angle measured on the localizer centerline is the reference for glide slope tilt tolerances at the localizer edges. The centerline value is used to determine the glide path angle change on each localizer edge with respect to the centerline value. By using the differential DDM to relate to path angle, an assessment can be made to determine if the system would pass a “tilt” evaluation.

Figure A1-9 shows the azimuth angles of interest for an inbound approach on the localizer centerline. With the typical antenna phase center offset of 178 feet from centerline, the area of 0 to 2.2 degrees is transversed during the approach from 4.0 NM to ILS Point B, or 3500 feet from the threshold. The area from 2.2 degrees to 6.0 is transversed during the centerline approach from ILS PT B (3500 feet) from threshold to the end of the Category I qualifying zone at ILS PT C, typically 900 feet from the threshold. From ILS PT C to the runway threshold would involve the area from 6 degrees to approximately 10 degrees for Category II/III approaches as shown previously in Figure A1-2. Any variations in the transverse CDI values in this region will be added to the site effect error and superimposed on the centerline approach structure. A flat transverse in this area will result in a straight approach with minimal roughness providing that no significant site effects exist.

The azimuth angles of interest for above and below clearance runs conducted outside of the localizer edges are shown in Figure A1-10. Generally, a low path angle at these azimuths could indicate a deficiency in the required fly-up signals below the path and clearing obstructions. A high path angle may indicate a deficiency in above path clearances and could result in narrowing the coverage area and narrowing of the typical lateral restrictions.

Flight profiles of the localizer edges are shown in Figure A1-11. One localizer edge uses substantially less transverse area because the inbound flight is nearly aligned with the antenna phase center and only a small azimuth region is transversed. Although there is no tolerance for structure roughness on glide path and on the localizer edges, the flatness of the transverse will determine the glide path angle measured for glide slope tilt using the inbound approach method. In addition, there is a tolerance for fly-up signal below the path and while clearing obstructions. A low path angle in these regions, i.e. an area of significant 90 Hz fly-down CDI, indicates an area along the approach with a reduction in fly-up signal at low angles. Figure A1-12 is a composite showing all of the areas of interest for flight profiles of the end-fire system and supports the concept of the single “recommended engineering tolerance” on the transverse structure.

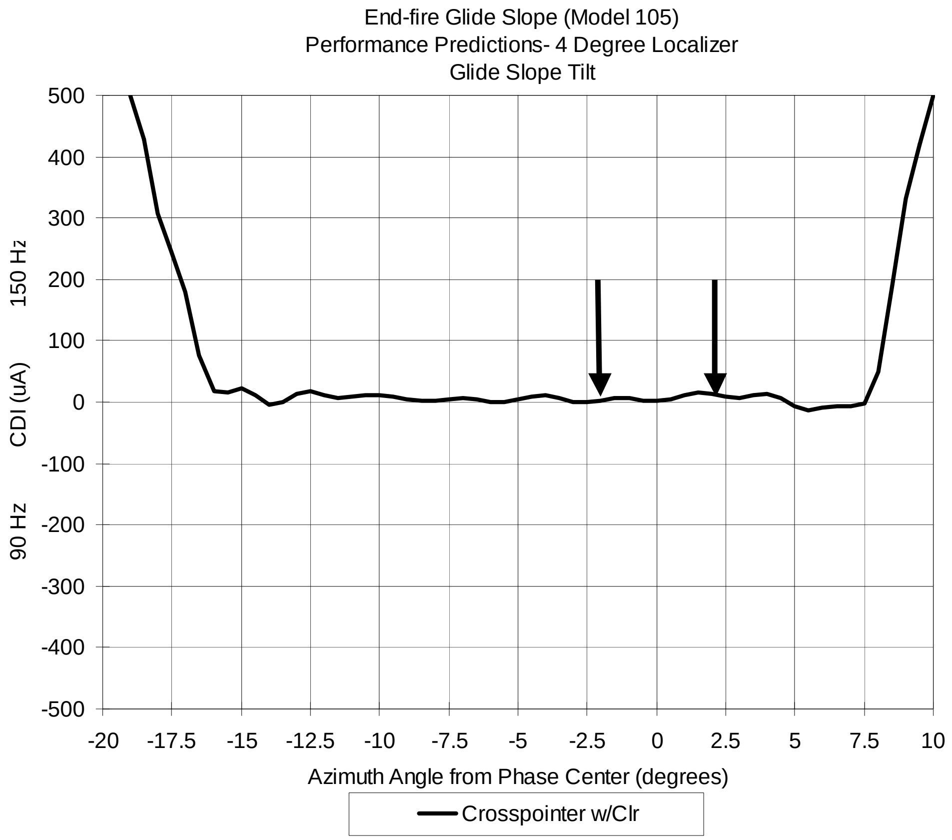


Figure A1-8. Performance Predictions – Glide Slope Tilt

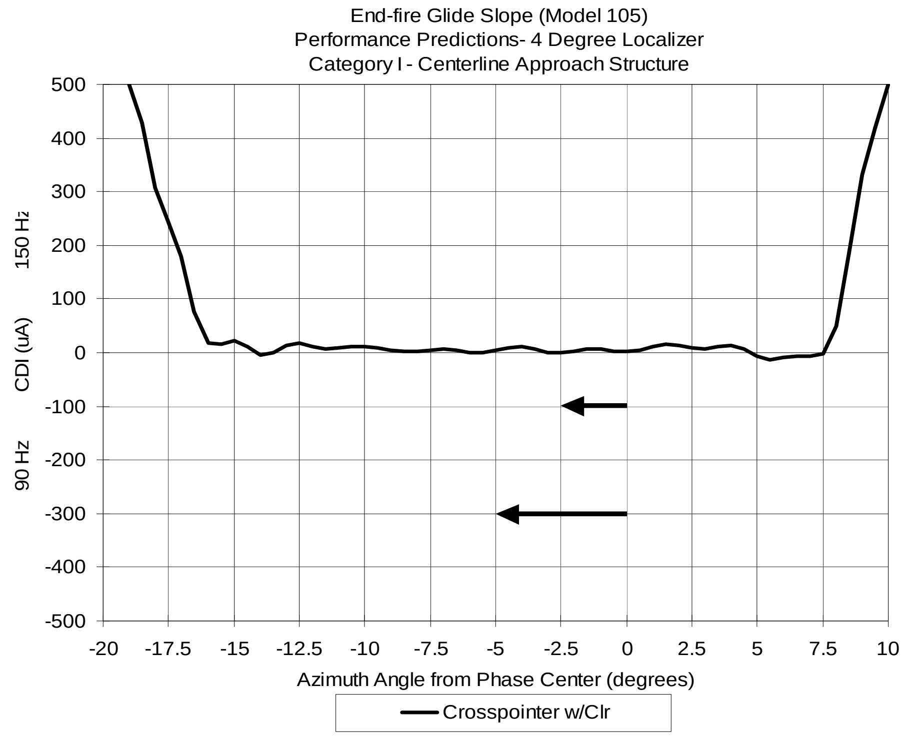


Figure A1-9. Performance Predictions – Centerline Approach Structure

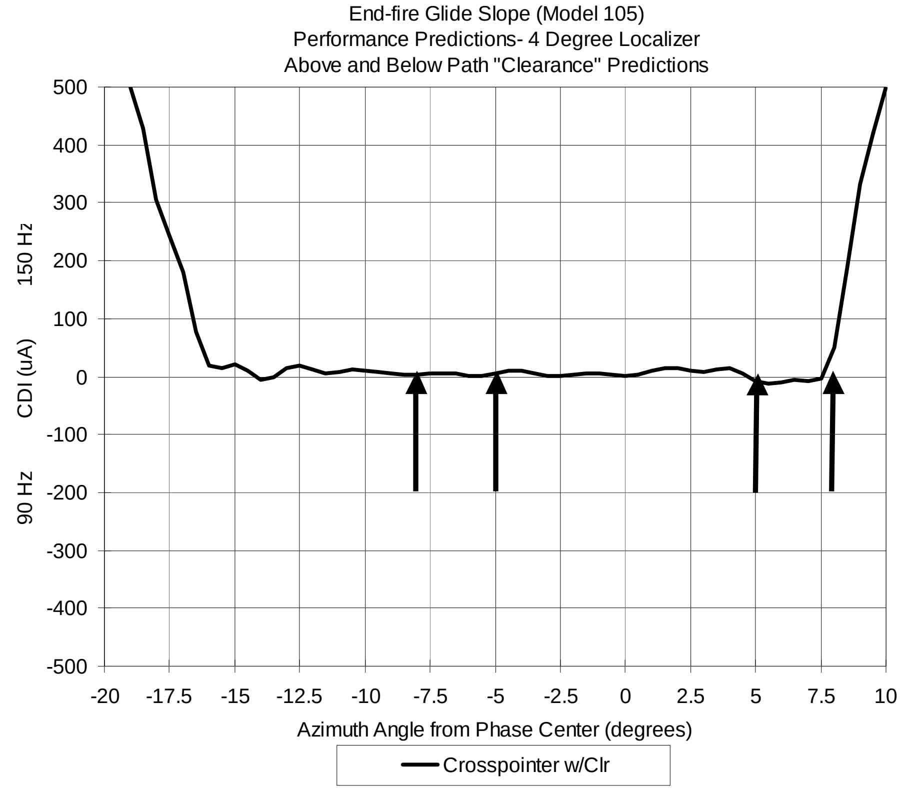


Figure A1-10. Performance Predictions – Above and Below Path “Clearance”

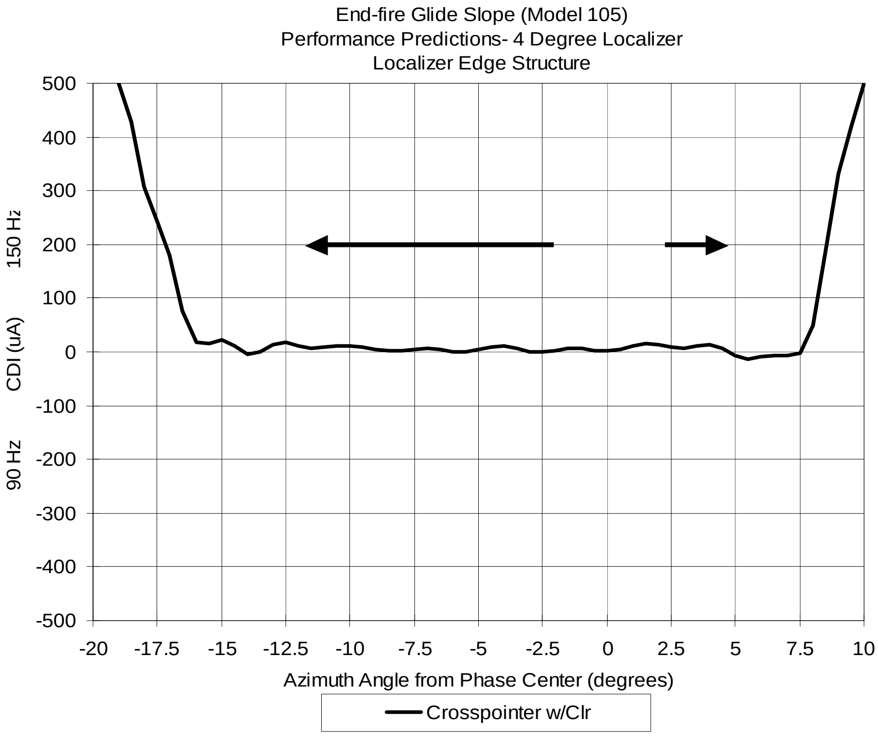


Figure A1-11. Performance Predictions – Localizer Edge Structure

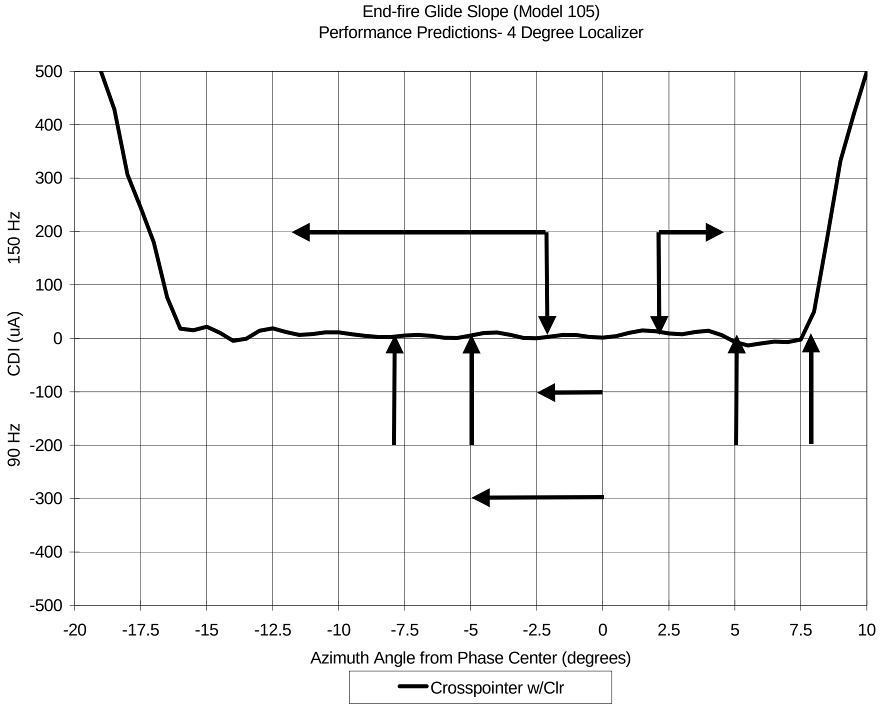


Figure A1-12. Performance Predictions – Composite Areas of Interest

A.6 COURSE ANTENNA PEDESTAL ADJUSTMENTS.- The manufacturer is responsible for the baseline of phase of the slots. The final phase parameter, however, is effectively altered by the curvature of the antenna, position accuracy of each pedestal, and the slope of the runway shoulder containing the antenna. Final optimization of the antenna involves adjusting the phase parameter of the signal distribution to create parallel phase fronts from the main antennas that result in a smooth transverse structure. Phase changes to targeted areas of the antenna are achievable by repositioning of the antenna supports to create the desired advance or delay of the slots affected by that pedestal.

The intent of adjusting the antenna is to achieve a phase distribution that most closely represents the ideal case. At first the choices of pedestal adjustments may appear overwhelming, but careful review of the data of each pedestal movement will reveal the proper adjustment to be made. Although numerous adjustments can be made that will appear to have optimized the system, selection of the wrong pedestal(s) will produce side-lobes or will result in an undesirable sensitivity to a given parameter. The remainder of this document will focus on identifying which pedestal(s) should be relocated to provide optimum system performance.

Before any pedestal is adjustment is made, a voltage distribution should be taken of the main antennas to determine that no anomalies exist. In addition, the location of each pedestal relative to the antenna taping point should be measured and compared to the taping table in the main body of the Instruction Book. Errors in the measured pedestal positions should be corrected to achieve a baseline to begin the optimization process. A visual inspection of the antenna curvature should be made to determine if any pedestal appears out of position and perturbing the smooth arc that should be formed by properly positioned pedestals.

Movement of a single pedestal adjusts the effective phase of all slots in the vicinity of the pedestal. The resulting phase change to adjacent slots decreases in nearly a linear fashion with distance away from the affected pedestal. Since radiation from a single slot is broad, the effect of the adjustment is felt in varying degrees across the entire transverse pattern.

The first step in optimizing the transverse structure is to identify slopes in the DDM pattern. Slopes exist over the entire transverse pattern. The second step is to identify slopes existing only over a partial section of the transverse structure. The latter is defined as a transverse flair. Flairs are large sectors, 5 degrees or more in azimuth, where if a linear increase or decrease in DDM were removed, the residual DDM would be essentially constant or exhibit roughness of a very small magnitude (i.e. < 20 micro-amperes). The third and final step is to identify discrete pedestal adjustments to correct irregularities in the transverse pattern shape that appear much more random and irregular than a slope or flair. It is very important to review the pedestal adjustment book in this supplement prior to attempting to remove a transverse flair. Some individual pedestals movements will produce a result that may appear as a transverse flair. Movement of the single pedestal may result in a considerable time savings and should be implemented if the correction is warranted at all azimuth angles influenced by moving the pedestal and will also result in removal of the flair.

A.6.1 Selecting the Primary Antenna. - The primary antenna is defined as the antenna, either front or rear, that appears most desirable for making either slope, flair or single pedestal adjustments. The antenna may have been selected because the voltage distribution closely represents the ideal slot distribution, or because the antenna is mounted on a significant lateral slope, or simply because the feed and monitor return lines on the other antenna are routed tightly and would not permit reasonable pedestal movements. For example, if an abrupt change is evident in one antenna voltage distribution, the other antenna would provide pedestal adjustment results that would more closely represent the ideal case. The antenna with the smooth distribution would be the primary choice for adjustments. Using this method, the pedestal adjustments will more closely track intuition and modeling outputs if available. The other antenna is by no means ruled out as a source of desirable pedestal effects but the behavior of the adjustments made to the primary antenna will be more predictable.

Another example would be if the antenna system were installed in an area where the runway shoulder characteristics are much different for the rear antenna than the front. Perhaps the front antenna has a substantial slope due to a sloping shoulder and the rear antenna is installed on an essentially flat shoulder. If the character of the transverse structure is a slope, errors in approximating the slope of the shoulder containing the front antenna is most likely responsible. Consequently, the front antenna should be adjusted to remove the condition. However, if the antennas are on a flat shoulder or a shoulder where the slope is essentially constant for both antennas, then both the front and rear antennas should be adjusted, 50 percent each, to remove the condition.

A variation in the linearity of the runway shoulder slope containing one antenna is the type of condition that could produce a transverse flair. Obviously then, the antenna contained in this region should be considered primary in correcting the transverse structure. Other examples are the existence of signage or drainage ditches that could influence the pattern of a particular antenna.

Unfortunately, it is not uncommon to find the system cables routed so tightly that a particular antenna cannot be adjusted for slopes or flairs. Another possibility is that the pedestal supports are mounted close to a limit on the adjustable uni-strut. Before considering pedestal adjustments, the physical installation should be review to determine what factors are limiting options for pedestal adjustments so that alternate options can be studied.

<u>A.6.2</u>   <u>Course Antenna Transverse Slopes.</u> - The course antenna distribution represents a very complex circuit where errors tend to accumulate near the ends of the antenna. For example if the frequency of operation is changed, the physical position of the slot must also change to compensate for the different wavelength signal flowing in the antenna. The electrical length of the antenna, being air-filled and assuming a velocity of propagation near 0.95, represents approximately 43 wavelengths at mid-band. If a smaller error exists in calculating the loading of the complex antenna slots, the error is multiplied by 43 as the wave arrives at the load end. This condition of cumulative error will exist in both the front and rear main antennas, however, a delay in the rear antenna raises the glide angle and a delay in the front antenna lowers the path. Since the end-fire can be simplified as rays across the phase center, the overall effect of the errors is to produce a smooth and increasing slope across the entire transverse structure.

A lateral slope of the runway shoulder containing the array will create errors in the CDI pattern due to a difference in the slant range distance from each of the slots observed in the far-field. The effect of a change in frequency, and the lateral slope of the runway shoulder, is compensated for during the system layout stage by application of the “FRFU” or frequency function formula identified in the instruction book. It is not uncommon that the front and rear antennas of the end-fire are located in regions with different lateral slopes. Separate FRFU calculations are used to remove the lateral slope errors and the remaining error is removed during the optimization process.

CDI or DDM slopes that exist over the entire transverse structure are removed by a rotation of either the front or rear antenna, or both. Because the antenna is numerous wavelengths long, an increasing amount of movement of the support pedestals is necessary along the entire antenna.
The amount of the rotation needed is dependant on the magnitude of the DDM slope in the transverse recording.

Numerous options exist to remove a slope:

1) Pivot on the FRONT ANTENNA starting at pedestal F1
2) Pivot on the FRONT ANTENNA starting pedestal F12
3) Pivot on the FRONT ANTENNA about the center
4) Pivot on the REAR ANTENNA starting at pedestal F1
5) Pivot on the REAR ANTENNA starting at pedestal F12
6) Pivot on the REAR ANTENNA about the center

7) Pivot 50 percent on the FRONT ANTENNA and 50 percent on the REAR ANTENNA using the combinations above.

Pivoting about the center of one or both antennas will hold the path angle essentially constant and will center the adjustments on the uni-struts. To introduce an increase in 150 Hz fly-up signal the longitudinal aperture, the distance between the antennas parallel to the runway, should be increased. To produce a 90 Hz fly-down affect the array should be compressed. For instance, if the runway is to the right of the array as you face the approach region, and a slope exists of 50 uA into the 90 Hz on the array side to 50 uA into 150 Hz on the runway side, either the front or rear antenna should be rotated so that a greater distance exists between the FEED end of the front antenna and the LOAD end of rear antenna. In addition, a shorter distance should result between the LOAD end of the front antenna and the FEED end of the rear antenna.

Example adjustments are shown in Table A1-1 for either antenna with the pivot point centered between pedestals 6 and 7. Note that if the rear antenna is used the adjustments are opposite when compared to the front but the effective changes in the longitudinal aperture are the same. The units given are in inches and Positive (+) values indicate movement toward the runway threshold. Figures A1-13 through A1-20 shown computer modeling outputs where a transverse slope was intentionally introduced. Also shown on the plot are the pedestals moved and the amount of movement, identified on the "Y" axis on the right. Each consecutive figure shows the transverse repeated with the same pedestals being moved but with clearance signals added.

The slope can also be removed by progressive increases or decreases in the pedestal adjustment from the feed or load end of the array. With this method the center portion of the antenna will be moved and a significant adjustment of the rear antenna phaser will be necessary to re-establish the path angle.

Table A1-1. Example of Pedestal Adjustments to Remove a Transverse Slope

FRONT ANTENNA	ADJUSTMENT	REAR ANTENNA	ADJUSTMENT
F1	+2.25	R1	-2.25
F2	+2.00	R2	-2.00
F3	+1.75	R3	-1.75
F4	+1.50	R4	-1.50
F5	+1.25	R5	-1.25
F6	+1.00	R6	-1.00
F7	+0.75	R7	-0.75
F8	+0.50	R8	-0.50
F9	+0.25	R9	-0.25
F10	-0.25	R10	+0.25
F11	-0.50	R11	+0.50
F12	-0.75	R12	+0.75
F13	-1.00	R13	+1.00
F14	-1.25	R14	+1.25
F15	-1.50	R15	+1.50
F16	-1.75	R16	+1.75
F17	-2.00	R17	+2.00
F18	-2.25	R18	+2.25

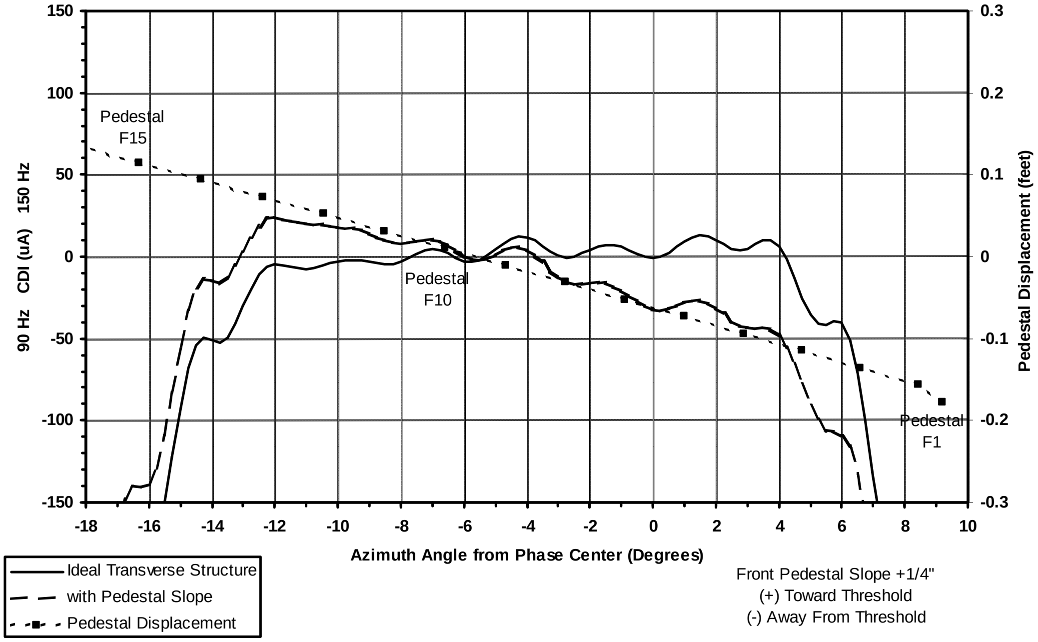


Figure A1-13. Model 105 End-Fire Glide Slope Pedestal Slope Modeling – Front Pedestal Slope +1/4”, Clearance Off.

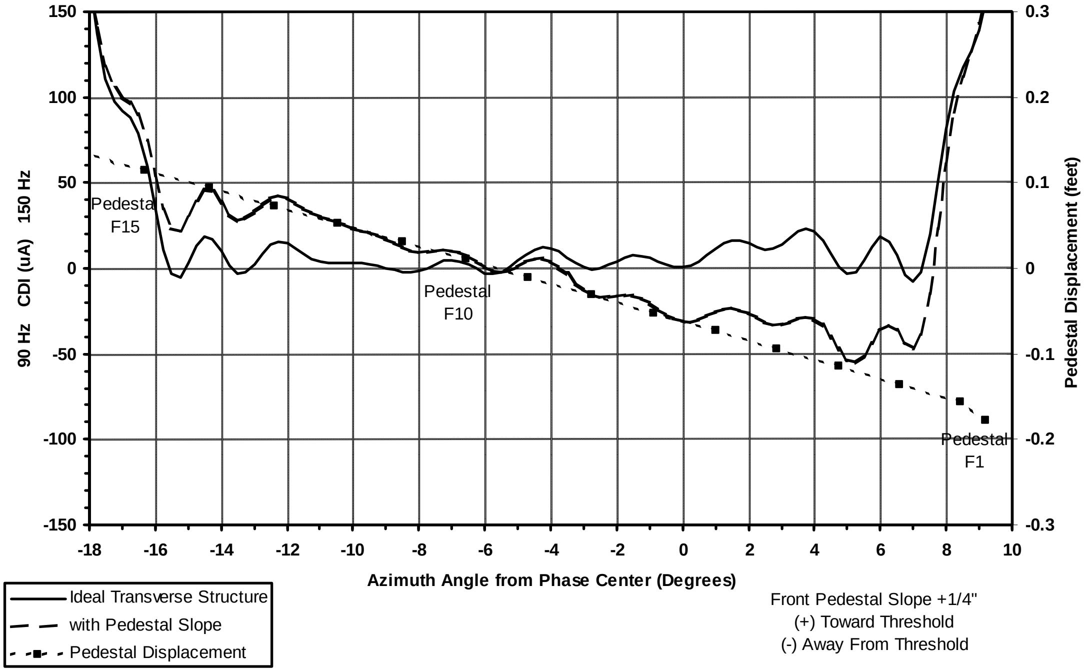
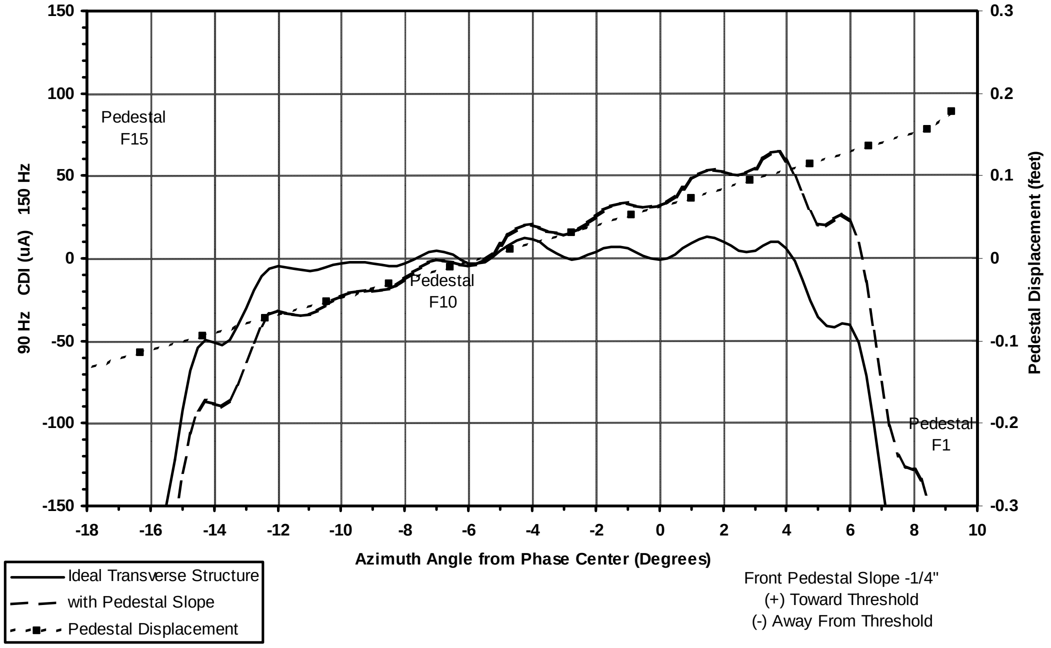
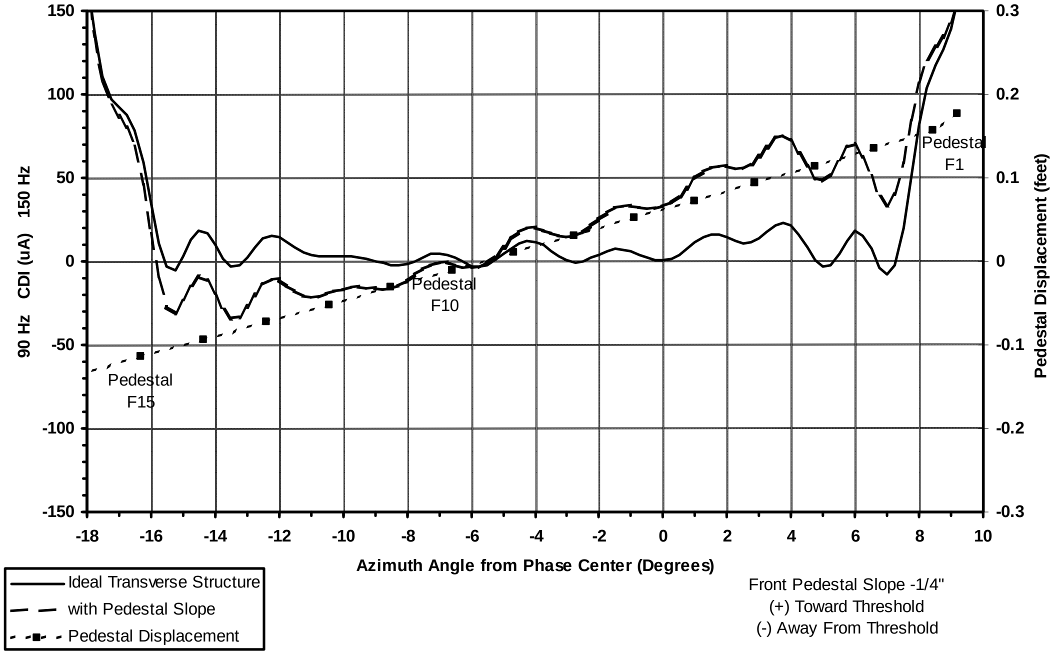


Figure A1-14. Model 105 End-Fire Glide Slope Pedestal Slope Modeling – Front Pedestal Slope +1/4”, Clearance On.



Front Pedestal Slope -1/4"
(+) Toward Threshold
(-) Away From Threshold

Figure A1-15. Model 105 End-Fire Glide Slope Pedestal Slope Modeling – Front Pedestal Slope -1/4”, Clearance Off.



Front Pedestal Slope -1/4"
(+) Toward Threshold
(-) Away From Threshold

Figure A1-16. Model 105 End-Fire Glide Slope Pedestal Slope Modeling – Front Pedestal Slope -1/4”, Clearance On.

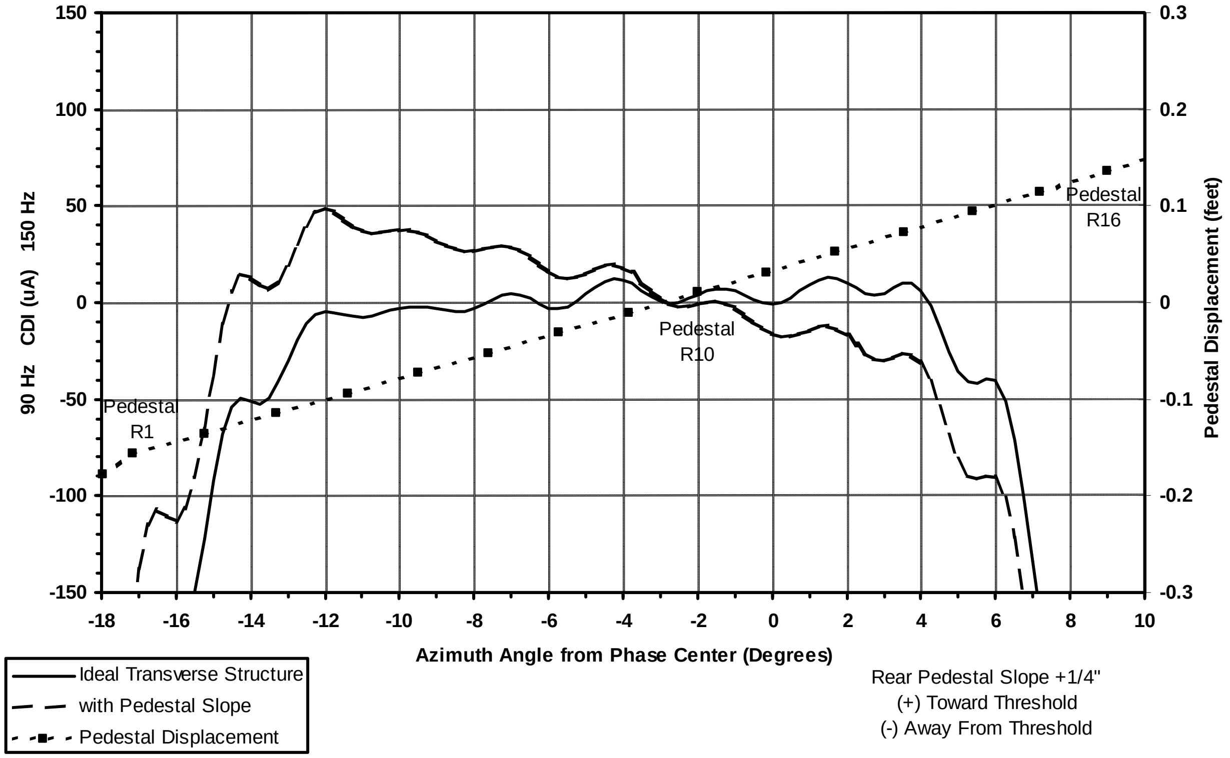


Figure A1-17. Model 105 End-Fire Glide Slope Pedestal Slope Modeling – Rear Pedestal Slope +1/4", Clearance Off.

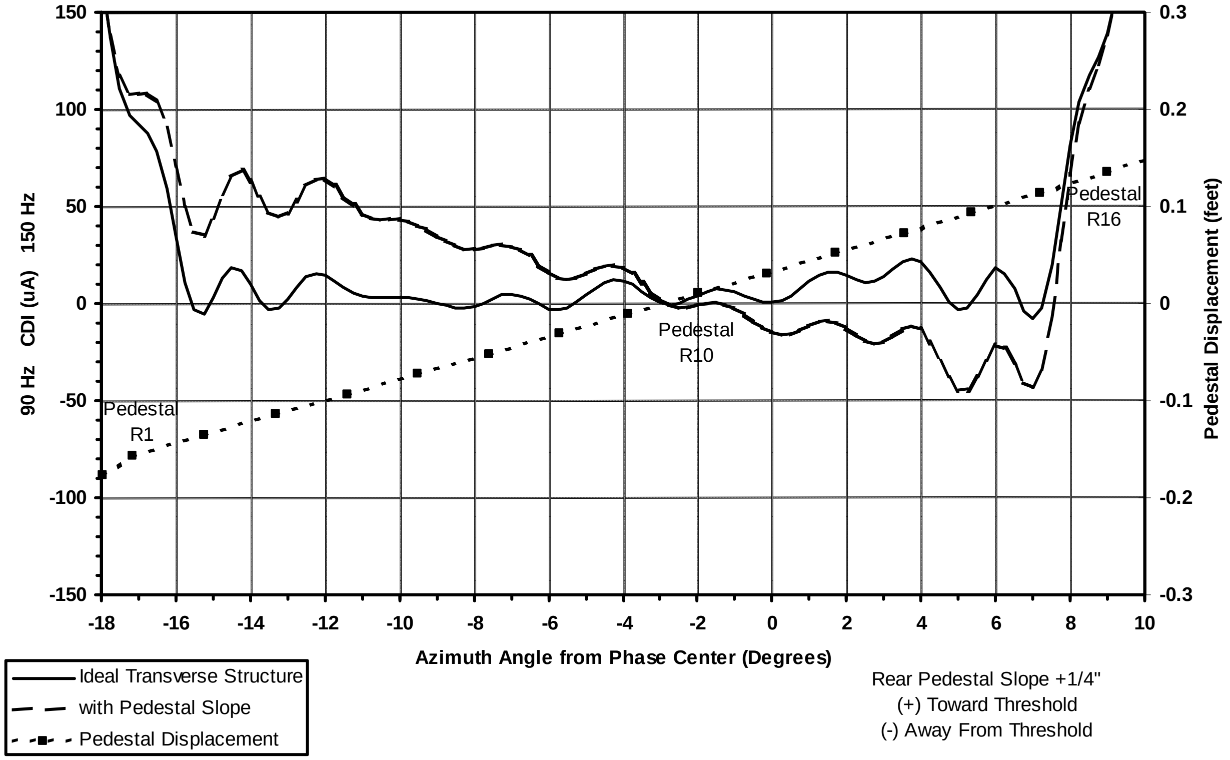


Figure A1- 18. Model 105 End-Fire Glide Slope Pedestal Slope Modeling – Rear Pedestal Slope +1/4", Clearance On.

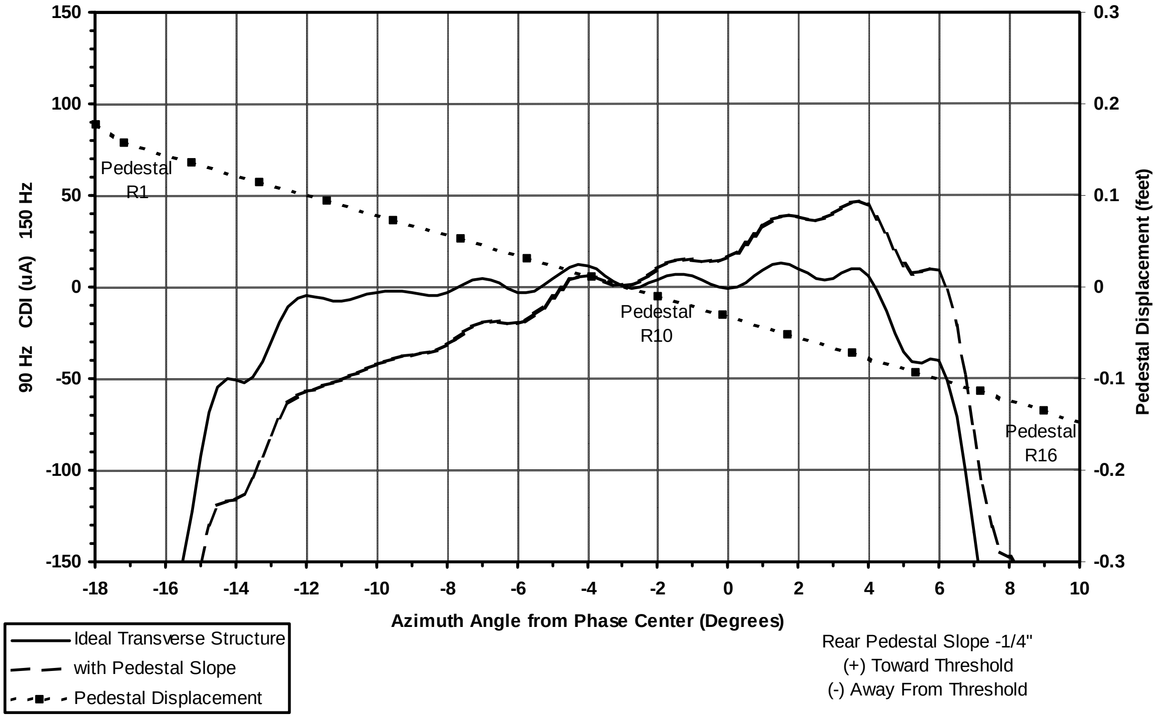


Figure A1-19. Model 105 End-Fire Glide Slope Pedestal Slope Modeling – Rear Pedestal Slope -1/4”, Clearance Off.

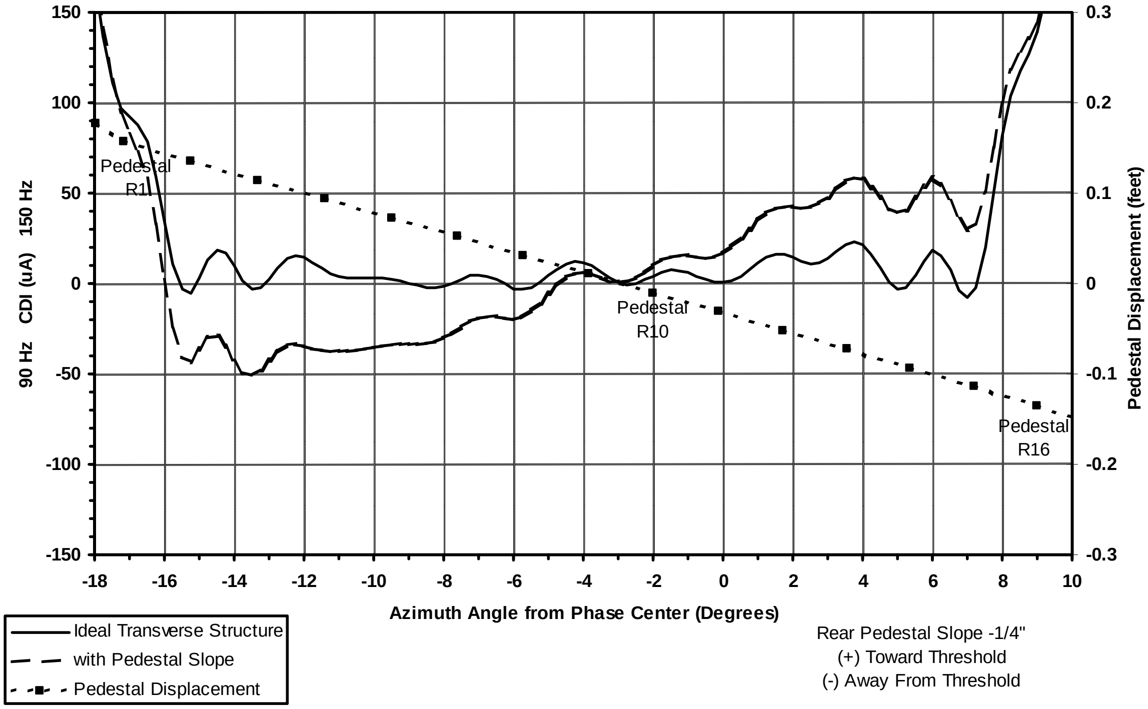
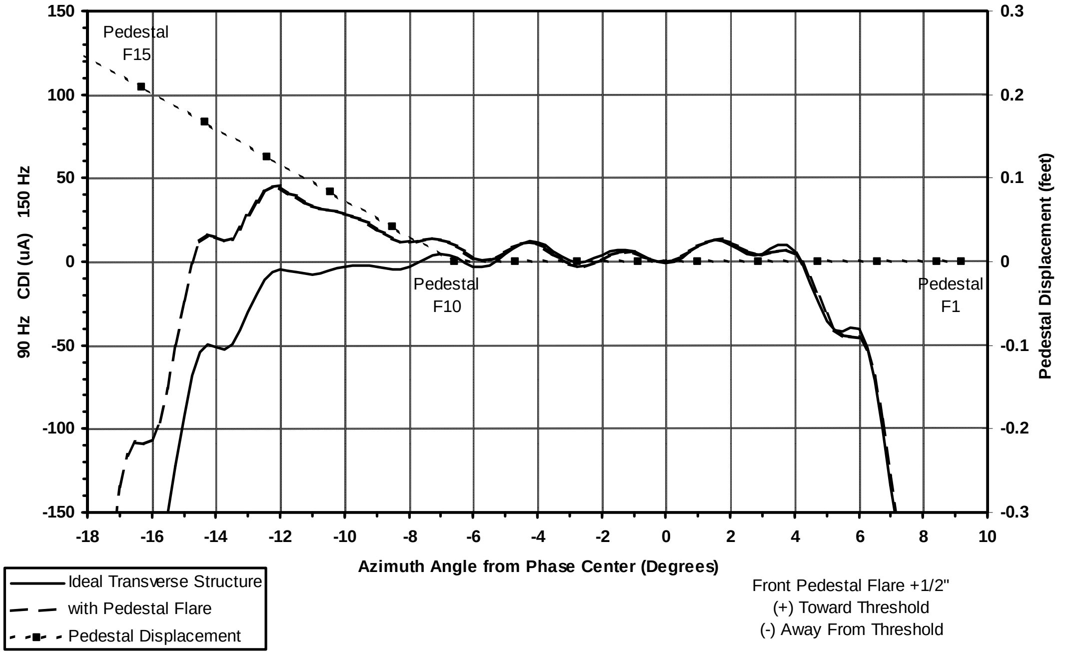


Figure A1-20. Model 105 End-Fire Glide Slope Pedestal Slope Modeling – Rear Pedestal Slope -1/4”, Clearance On.

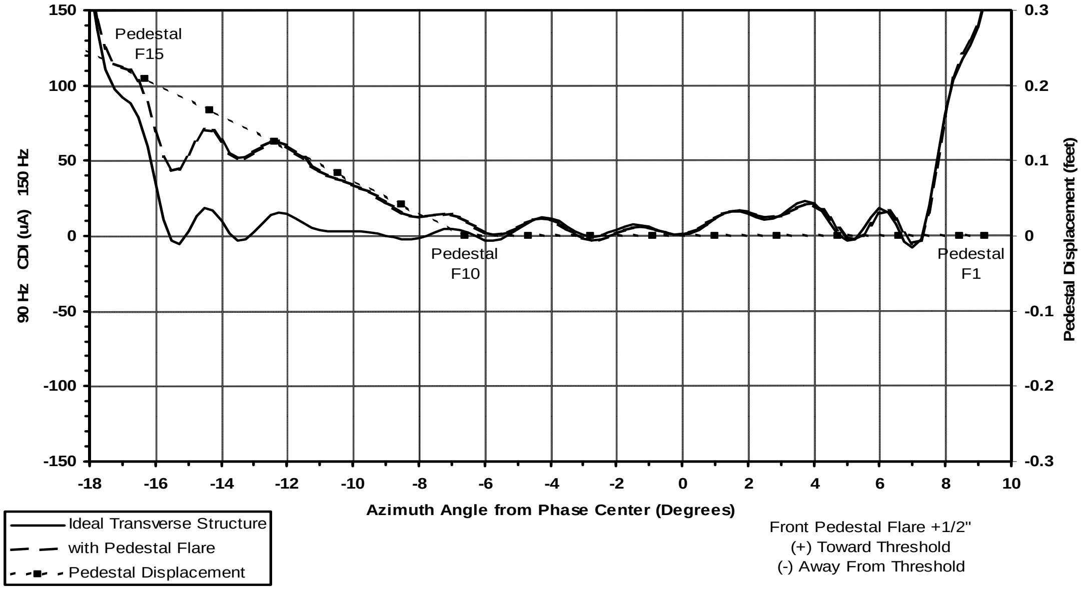
A.6.3 Course Antenna Transverse Flares. - Flares in transverse structure are removed by using the same basic procedure outlined to remove slopes except only some of the pedestals are adjusted. Flares, when they exist, are typically located on the extremities of the transverse pattern. The pedestals on the ends of the arrays are incrementally adjusted to remove them.

Figures A1-21 through A1-28 shown computer modeling outputs where a transverse flare was intentionally introduced. Also shown on the plot are the pedestals moved and the amount of movement, identified on the “Y” axis on the right. Each consecutive figure shows the transverse repeated with the same pedestals being moved but with clearance signals added.



Front Pedestal Flare +1/2"
(+) Toward Threshold
(-) Away From Threshold

Figure A1-21. Model 105 End-Fire Glide Slope Pedestal Flare Modeling – Front Pedestal Flared +1/2”, Clearance Off.



Front Pedestal Flare +1/2"
(+) Toward Threshold
(-) Away From Threshold

Figure A1-22. Model 105 End-Fire Glide Slope Pedestal Flare Modeling – Front Pedestal Flared +1/2”, Clearance On.

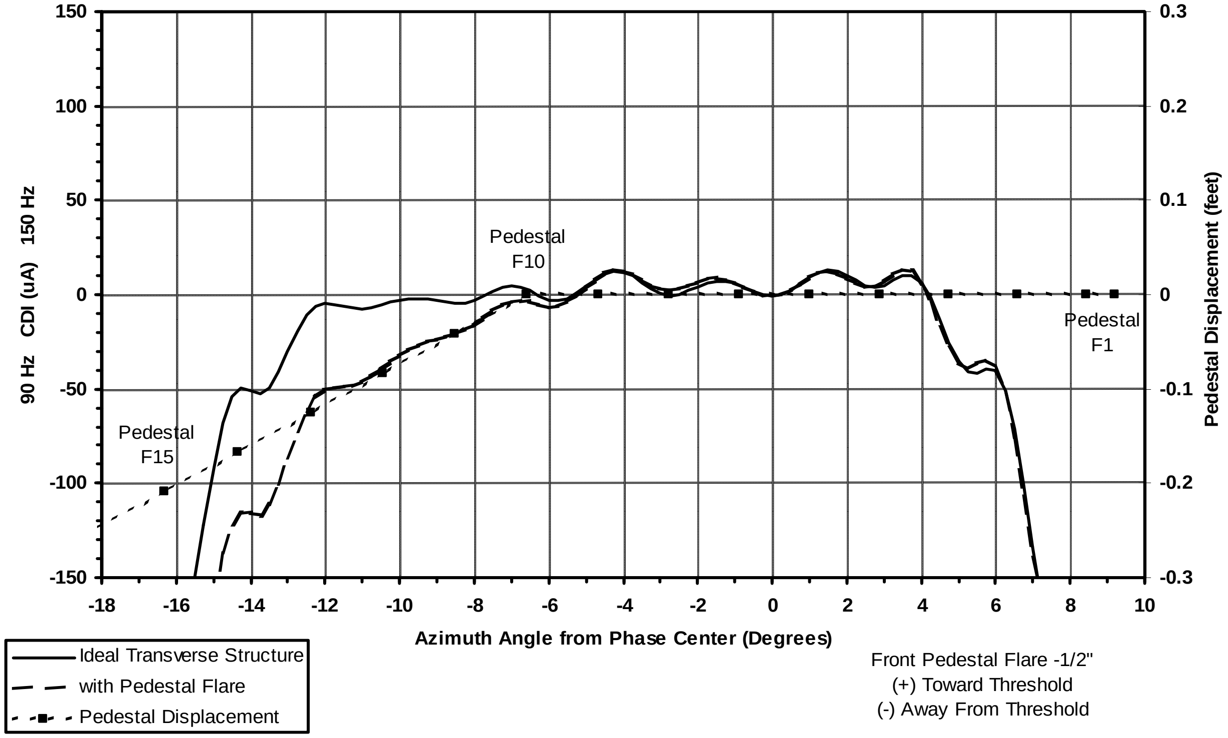


Figure A1-23. Model 105 End-Fire Glide Slope Pedestal Flare Modeling – Front Pedestal Flared -1/2", Clearance Off.

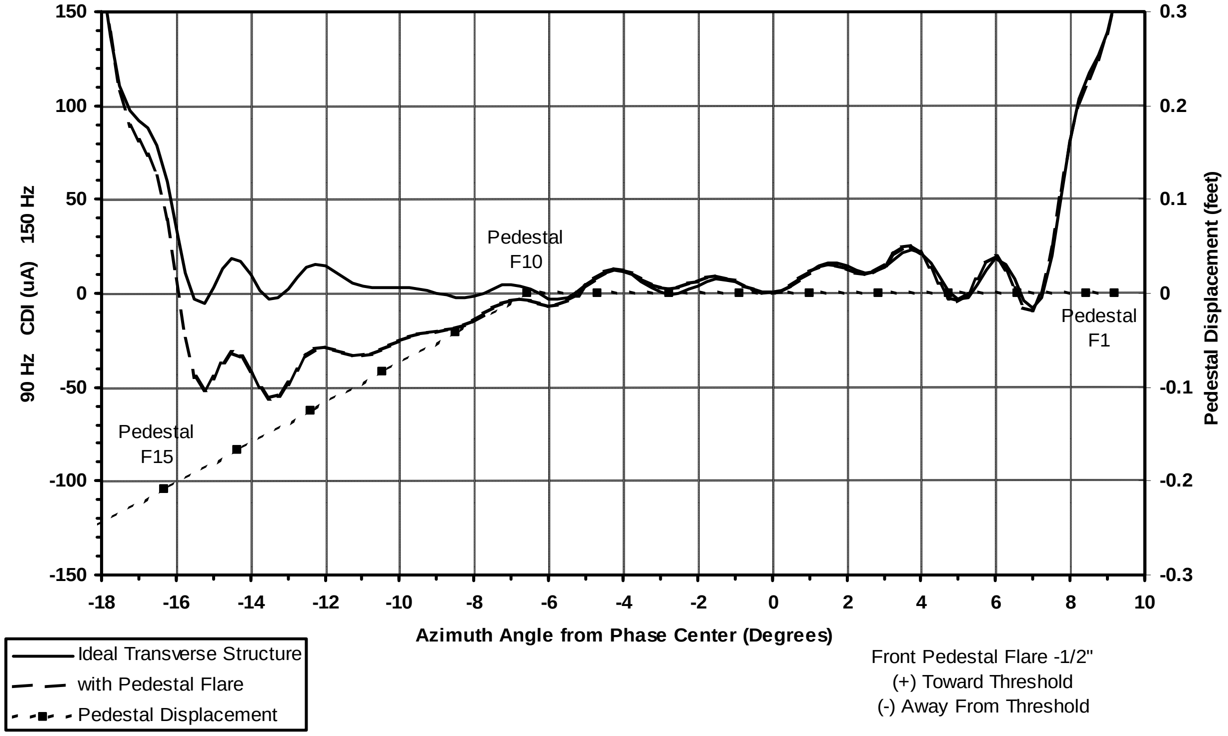


Figure A1-24. Model 105 End-Fire Glide Slope Pedestal Flare Modeling – Front Pedestal Flared -1/2", Clearance On.

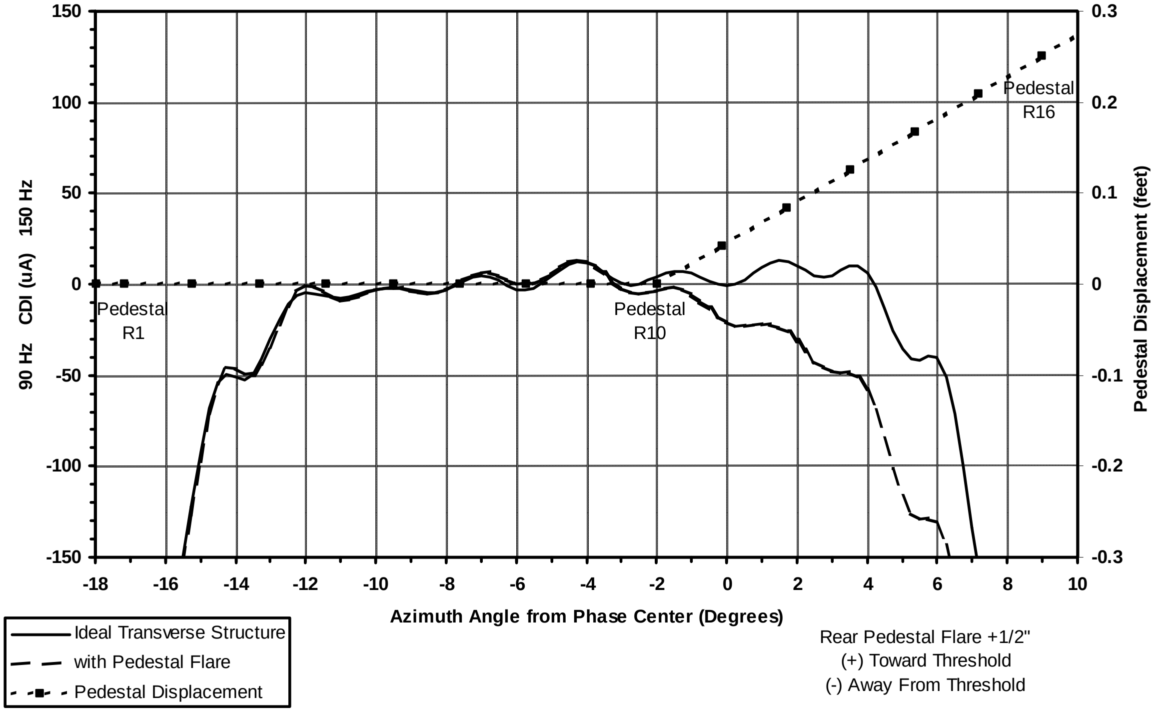


Figure A1-25. Model 105 End-Fire Glide Slope Pedestal Flare Modeling – Rear Pedestal Flared +1/2", Clearance Off.

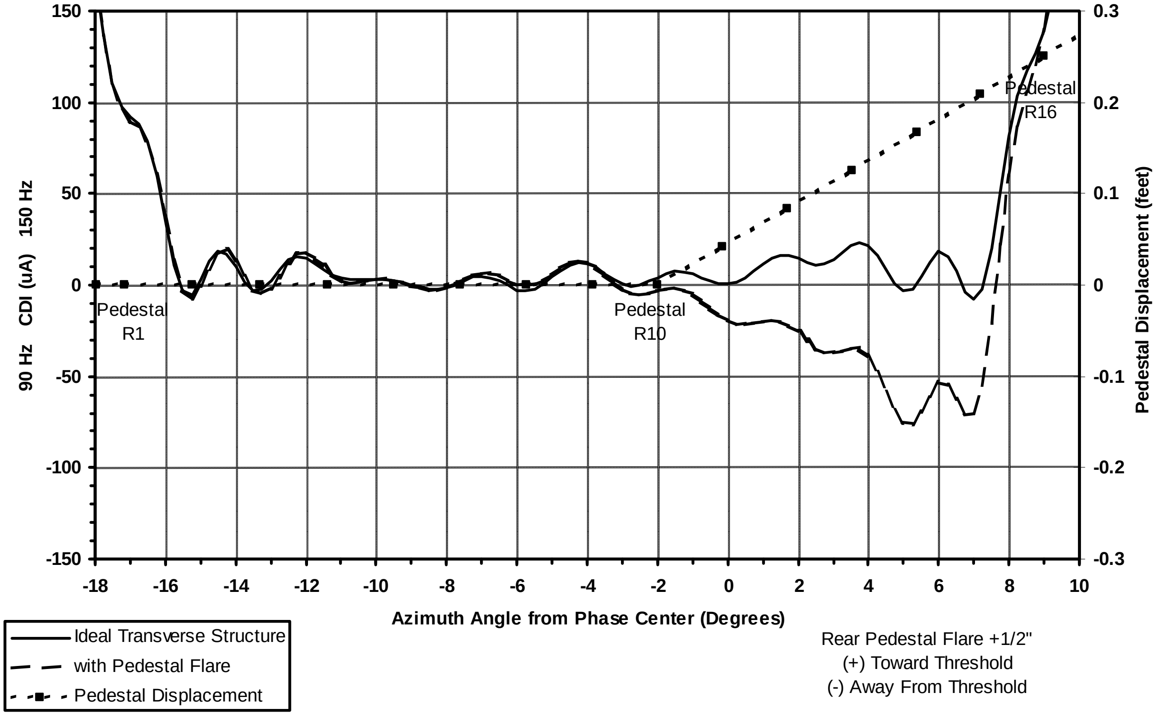


Figure A1-26. Model 105 End-Fire Glide Slope Pedestal Flare Modeling – Rear Pedestal Flared +1/2", Clearance On.

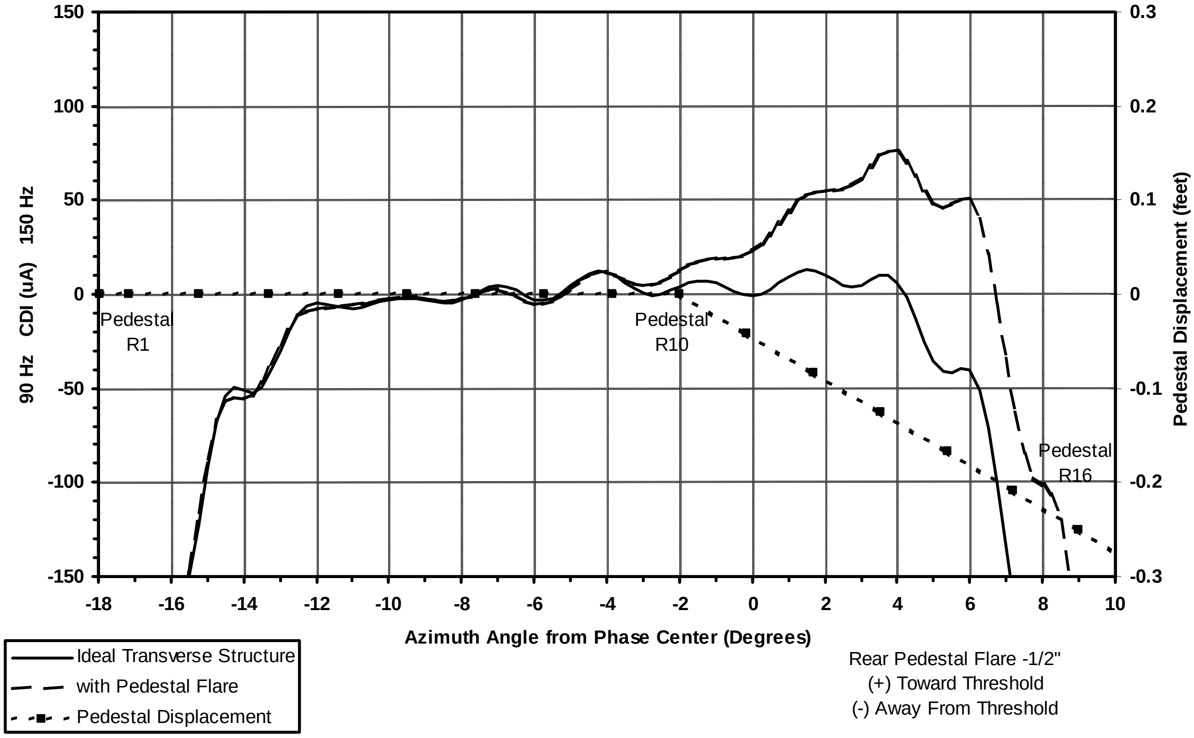


Figure A1-27. Model 105 End-Fire Glide Slope Pedestal Flare Modeling – Rear Pedestal Flared -1/2”, Clearance Off.

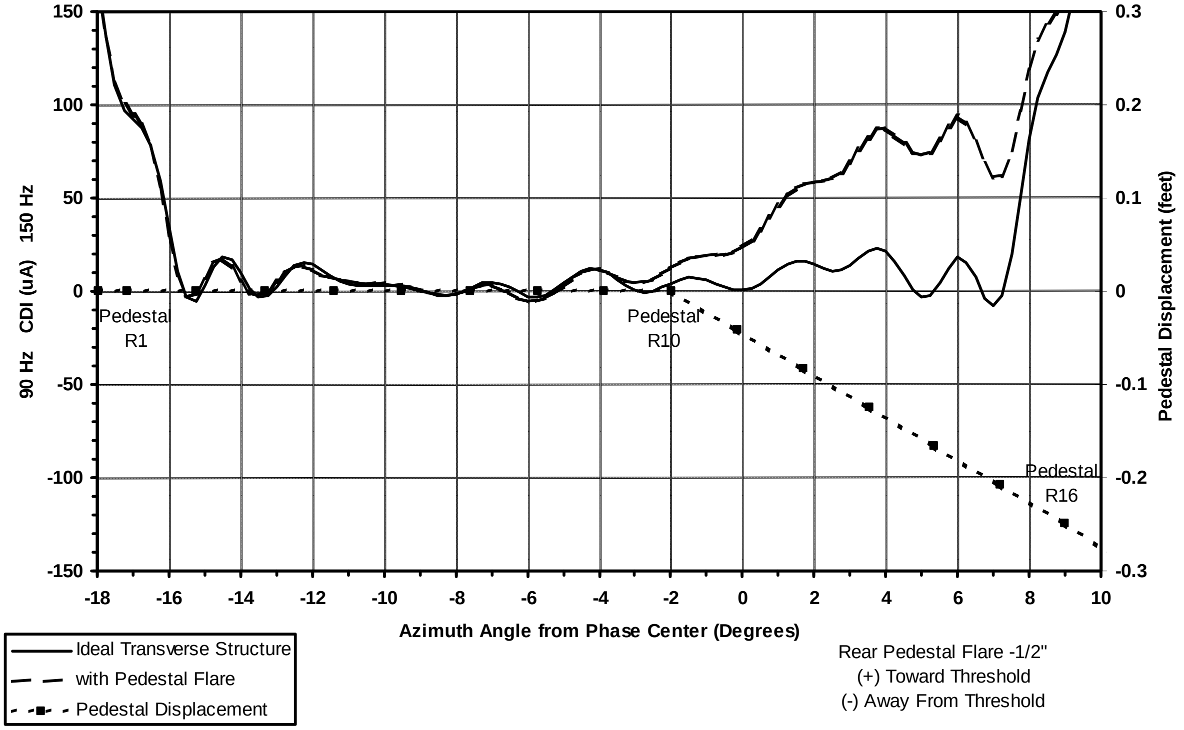


Figure A1-28. Model 105 End-Fire Glide Slope Pedestal Flare Modeling – Rear Pedestal Flared -1/2”, Clearance On.

A.6.4 Course Antenna Single Pedestal Movements.- The movement of a single pedestal adjusts the phase of numerous slots in the vicinity of the pedestal. The resulting phase change to adjacent slots decreases in nearly a linear fashion with distance away from the affected pedestal. Since radiation from a single slot is broad, the effect of the adjustment is felt in varying degrees across the entire transverse pattern. When analyzing a transverse structure recording, three characteristics of the transverse perturbations are used to determine to appropriate single pedestal adjustment. They are:

1) Amplitude of the Deviation
2) Frequency of the Oscillation
3) Principal Azimuth Angle of Occurrence

When attempting to minimize approach structure roughness, a centerline approach and a transverse structure recording are required. In addition to the three characteristics listed above relating to the transverse recording, a fourth area of interest must be analyzed on the approach recording:

4) Principal Range of Occurrence

A.6.4.1 Amplitude of Deviation.- At any point in the transverse structure, the course DDM is a result of radiation from 192 slots. It is helpful to imagine all of the slot radiations as vectors. Using superposition, these vectors can be placed together to form two composite vectors of given amplitudes and relative phases, one representing the 96 sources of the front main antenna and the other representing the 96 sources of the rear main antenna. The largest change in phase can be produced in either composite vector by affecting the individual vectors representing slots with the greatest amplitudes. Keep in mind that a pedestal adjustment shifts the phase of many slots and that large movements produce significant phase changes.

Figure A1-29 shows the antenna slot distribution and the location of each pedestal with respect to level of energy being radiated by the portion of the antenna where the pedestal is located. In order to introduce a large change in the DDM pattern, only those pedestals supporting slots with strong voltage excitations are capable of producing such a change. Pedestals supporting the antenna in the area of slots with small excitations produce only small changes in the composite pattern. Pedestal adjustments in the feed area of each antenna are more effective than a similar adjustment at the antenna load end. The energy at the antenna load end is reduced as a result of radiation for the proceeding slots. This characteristic should be kept in mind when choosing pedestal movements.

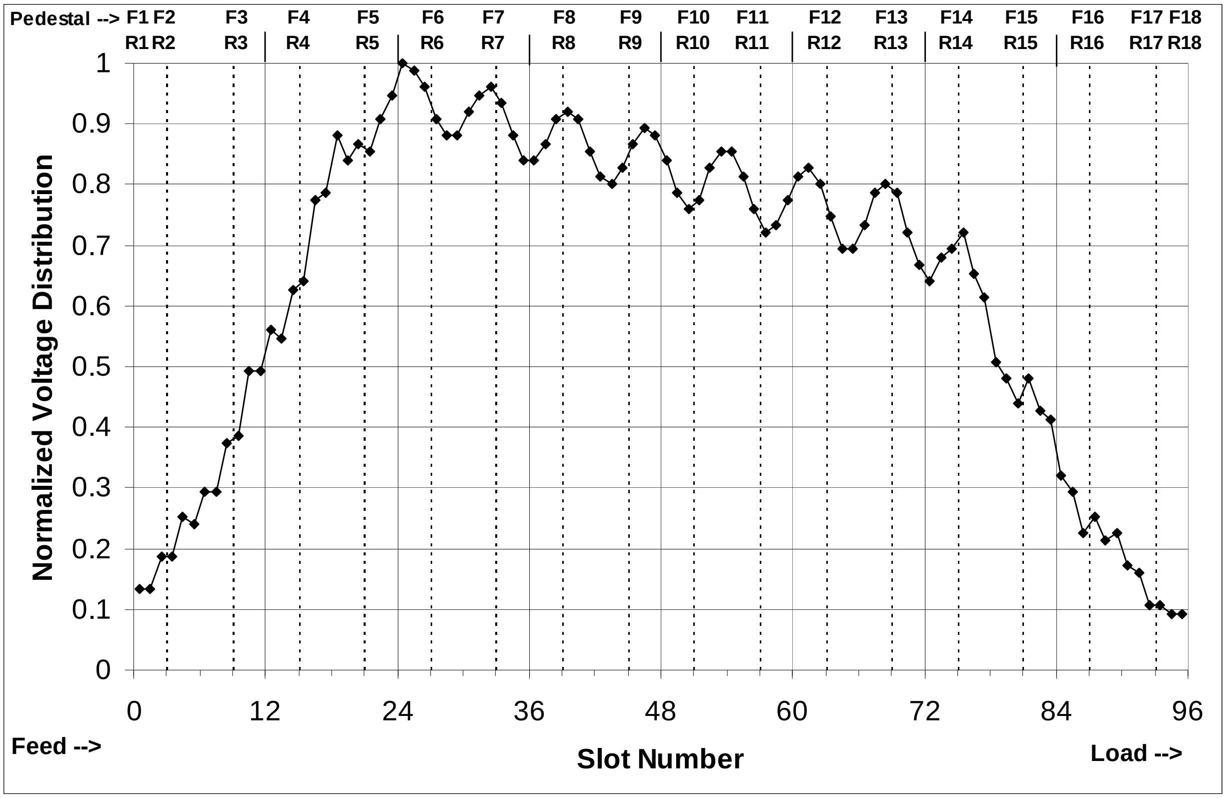


Figure A1-29. Support Pedestal Location Related to Antenna Voltage Distribution.

<u>A.6.4.2</u> <u>Frequency of Oscillation</u>.- The frequency of the oscillation in the transverse pattern indicates what slots or pedestal should be adjusted. Each pedestal movement produces a different period of oscillation in the transverse DDM pattern. This is due to the different lateral displacements of each pedestal from the phase center of the array. If the frequency is low, then a pedestal near the phase center needs adjusted. If the frequency is high, then one of the outboard pedestals requires adjustment. If the amplitude of a high frequency oscillation is substantial in terms of DDM, an outboard pedestal may require significant movement. If the amplitude of a low rate oscillation is small, then a minor adjustment is necessary near the center of the front or rear array.

In many cases the transverse oscillations will not look like a single period but rather a complex combination of numerous frequencies. The challenge is to identify each frequency component that represents a support pedestal movement and the amplitudes that make up the composite pattern. Once this is accomplished, a reasonable approach to optimizing the system can be determined. The data should be studied to determine which pedestal most closely represents the most significant DDM errors in the transverse pattern. The pedestal should be moved and the ground or air transverse structure should be measured again. By repeating this process the transverse will become increasingly flatter by smaller and smaller pedestal adjustments.

<u>A.6.4.3</u> <u>Principal Azimuth Angle of Occurrence</u>.-The transverse structure recording must be evaluated to determine what azimuth angle exhibits the greatest amount of error. The pedestal producing the greatest error is likely near a line through the antenna system intersecting the phase center and projecting out into the approach region.

A.6.4.4 Principal Range of Occurrence.- Approach roughness may be improved by determining the aircraft range where the roughness begins and again where the roughness ends. Given the antenna offset, the azimuth angle relative to the glide slope phase center can be calculated for the beginning and end of the roughness area and an inverse correction in the glide slope transverse structure can be made at the pertinent angles to minimize the approach roughness. Roughness at long ranges is difficult to remove as very little transverse structure is used to form the approach from 4 NM to 1 NM. Conversely, the final segment of the approach uses much more transverse structure and more options exist to improve the structure. In order to provide a quality glide path at difficult sites it may be necessary to exceed the “Recommended Engineering Tolerances” of the transverse structure.

A.7 COURSE ANTENNA PEDESTAL ADJUSTMENTS.- The plots contained in Section A9 entitled “Course Antenna Pedestal Adjustment Book” are outputs of an end-fire glide slope model using an ideal pedestal geometry and slot excitations. The Model 105 end-fire glide slope has 18 pedestals that support the front main antenna and an equal number that support the rear main antenna. Movement of each of the pedestals supporting the slotted cable antenna produces individual effects to the overall transverse structure. This series of plots was generated by individually modeling the effects of a +/- 0.3 feet movement of each pedestal forward and then back from the ideal locations. A total of 72 plots are provided. Large movements, such as 0.30 feet are sometimes necessary, but in most cases it is desirable if the movements are small or tapered over several pedestals to reduce stress on the antenna system and support structures. To determine the result of each pedestal movement, the transverse structure resulting from the adjustment is compared to that of an ideal system and the angular position of the pedestal is indicated to show that the greatest effect is in a line with the pedestal and intersecting the antenna system phase center.

Radiation patterns and CDI deviations are calculated by summing the direct signal amplitudes and phases from each of the slots at the observation point along a transverse arc flight profile. The model does not take into account any of the topography in the vicinity of the antennas or in the approach region. Effects of pedestal movements of an actual system will vary slightly from the modeled ideal system. Discrepancies occur in slot excitation voltages, sideband power level, variations in the pedestal locations, and terrain considerations from the model to that of an actual system. The most significant differences between modeled and measured transverse structure are due to the variations in the antenna slot excitations. However, the general trends that are established by the movement of the pedestals should correlate well with model predictions.

Pedestals are numbered starting from the feed end of the antenna, located farthest from the runway. Pedestals in the front antenna are designated as F1 through F18. Rear antenna pedestals are designated as R1 through R18. Pedestal movements toward the threshold are considered as positive and the movements back from the threshold are negative. Azimuth angles are given in degrees. Zero azimuth is a line parallel to the runway and through the phase center of the antenna system. Negative angles are on the runway or “wide side” and positive angle on the array or “narrow side”. Course deviation indicator (CDI) units are plotted in microamperes (uA).

A.8 CLEARANCE ANTENNA ADJUSTMENTS.- The plots contained in this section are outputs of an End-Fire glide slope model. End-fire radiation patterns produce a DDM shape forming a horizontal conic that dissects the earth surface, see Figure A1-30. In simple terms the conic is laid down so the earth divides it symmetrically into two half sections. The cone is oriented so the glide slope coverage area is limited to the region that is essentially flat in azimuth, however, zero DDM exists along the entire surface of the cone. With significant displacement from the coverage area the zero DDM surface will eventually intersect the earth. This means that the path angle lowers outside the coverage area and an aircraft at 3.0 degrees will receive strong 90 Hz fly-down signals in this area. End-fire systems employ a second transmitter and antenna to limit the azimuth coverage of the course array to the region that is no greater than 48 uA of fly-down or 2.775 degrees if the commissioned angle is 3.0 degrees. This is achieved by “capture effect” signals in the horizontal plane and clearance power settings are predicated on meeting this requirement.

The clearance antenna is comprised of single structure oriented outward toward the approach region. The radiation pattern provides a minimum in the course region and maximums to each side in the clearance region. When displaced from the phase center of the system the course signals become weaker while the clearance radiation becomes stronger. Figure A1-31 identifies the “capture regions” where the airborne receiver is transitioning from the course to the clearance signals. Figure A1-32 shows a similar plot but provides the CDI resulting from the composite course and clearance signals. Moving further laterally, the airborne receiver will ultimately “capture” only the clearance signal, modulated with 150 Hz predominant fly-up signal, and a strong fly-up indication will be observed on the cockpit instrumentation. A “capture region” exists on each side of the course antenna proportional guidance area.

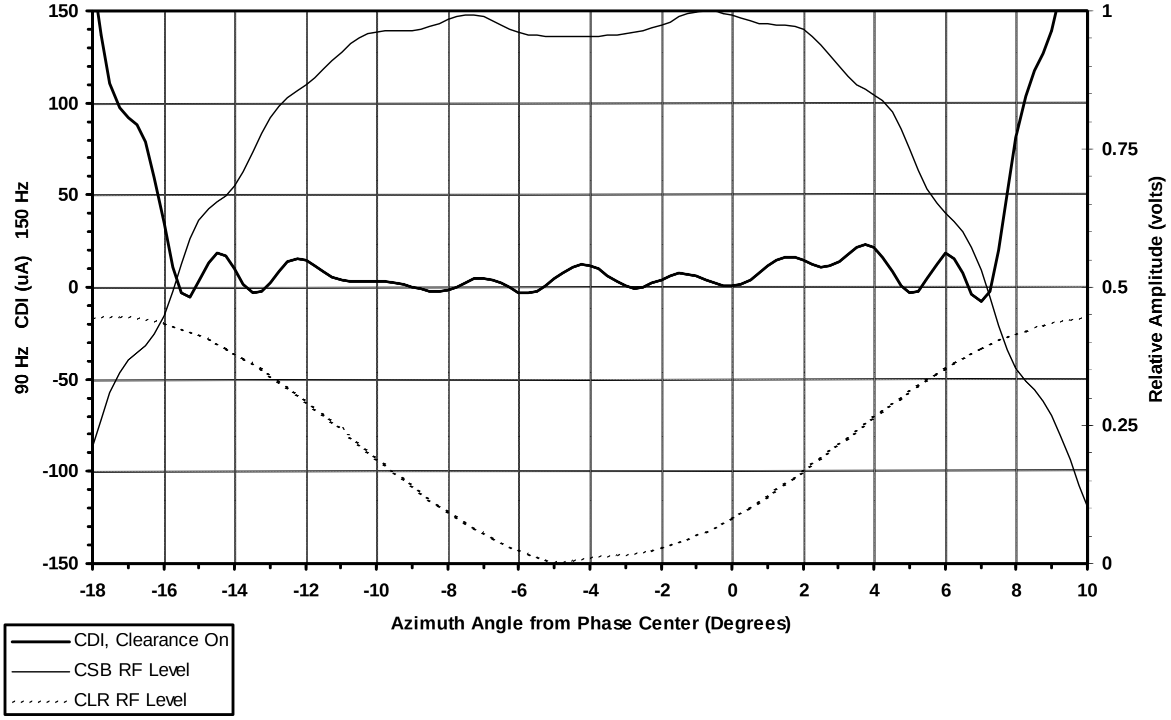


Figure A1-30. Clearance Normal

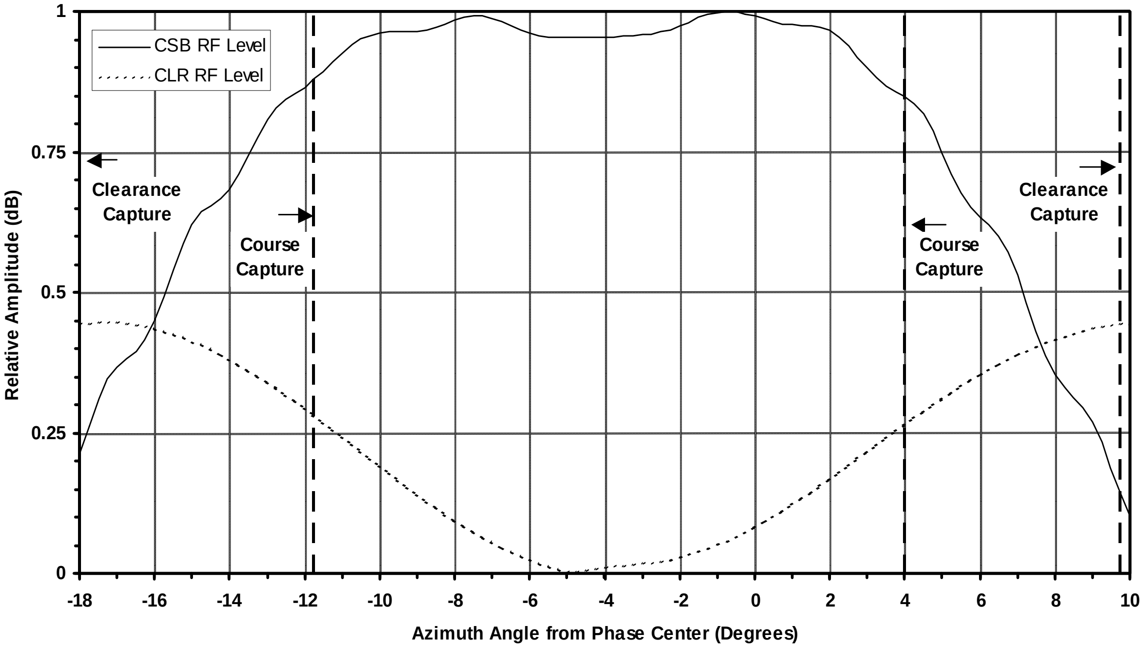


Figure A1-31. Course and Clearance Voltage Patterns, Showing Capture Regions

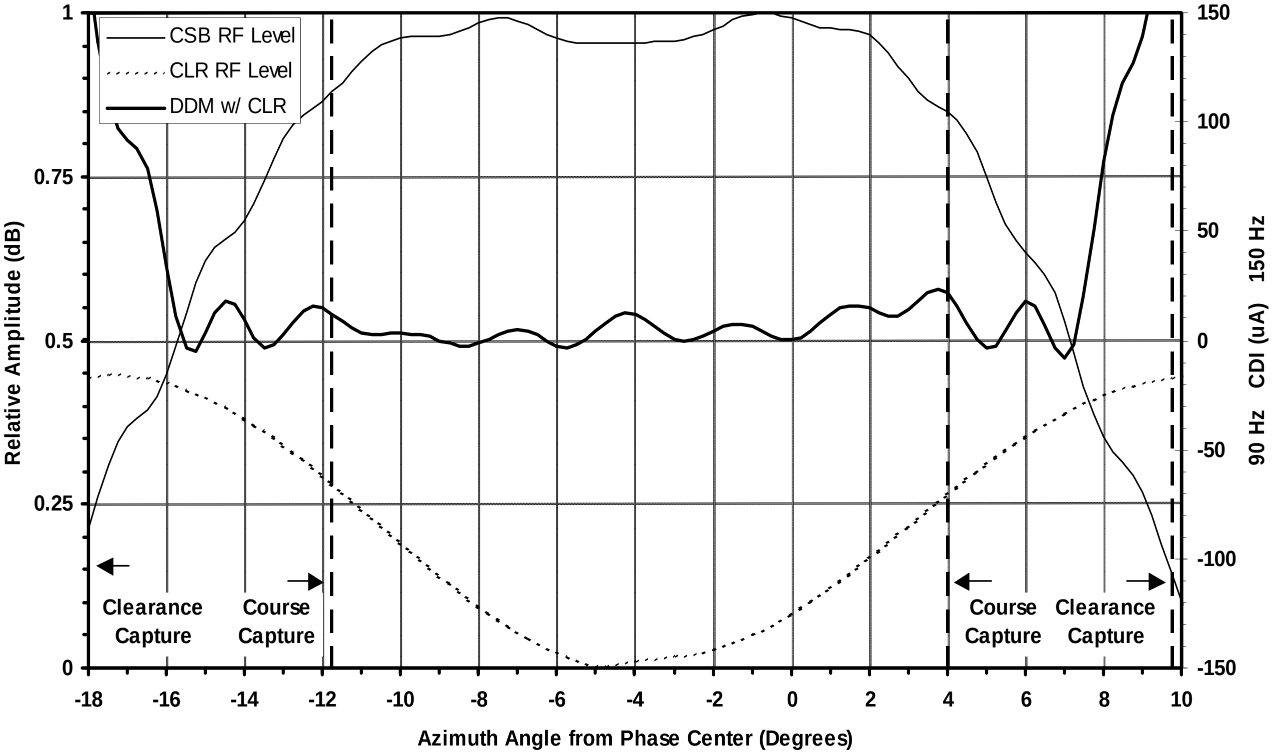


Figure A1-32. Course and Clearance Voltage Patterns and DDM w/ CLR, Showing Capture Regions

For an aircraft approaching the airport on the localizer centerline the signals from the clearance antenna serve no useful purpose. The course array provides clearances-below-path within the course antenna proportional guidance area. However, to obtain 180 uA fly-up signal throughout the lowest coverage altitude when outside of the course area, clearances signals from the clearance antenna are necessary.

Four conditions may potentially exist that would require adjustment of the clearance power or the physical position of the antenna. They are:

1) Clearance Power Low
2) Clearance Power High
3) Clearance Antenna Rotated Clockwise
4) Clearance Antenna Rotated Counterclockwise

The most significant issue is the power setting for the clearance transmitter and the effect it has at the capture points. Level runs made on the centerline, and the tilt in most cases, will be successful even if the clearance power setting is not optimum for meeting the tolerances for the runs made beyond the localizer limits. Not enough clearance power can result in soft areas in the clearance below-the-path runs that will not be detected until typically well into the flight inspection.

Clearance Power Low - If the clearance power is too low, the first indication will be 90 Hz fly-down “horns” on either side of the transverse structure at the capture points, see Figure A1-33. In this particular case, the below-path clearance checks that are made from ILS PT. A to ILS PT. C within the localizer edges, or to ILS PT. B outside of the localizer, could have a point where the fly-up signal is slightly below the tolerance. In clearance low RF level alarm condition, there should not be any point on a transverse structure recording where the CDI indicates greater than 48 uA of fly-down signal within the glide slope service volume of +/- 8 degrees.

Clearance Power High - If the clearance power is too high, the first indication will be a narrowing of the transverse structure. The transverse shape will look like a “U” rather than a trough shape having a significant flat area, see Figure A1-34. Too much clearance power will reduce azimuth coverage due to difficulty meeting clearance above-the-path tolerances beyond the localizer limits. Restrictions will result when the airborne receiver captures the strong clearance signal before the course signal has a chance to reach the 150uA point. If the power setting is significantly stronger than desired, even the level runs made on the localizer edges could be biased upward by clearance transmitter signal.

For examples of errors in the physical alignment, or rotation, of the clearance antenna, refer to Figures A1-35 and A1-36. Alignment errors are evident when one side of the transverse structure is biased upward when the clearance signal is added and a 90 Hz fly-down horn is evident on the opposite side. The clearance antenna should be adjusted with reduced power so that a 90 Hz fly-down “horn” is evident on both sides. By comparing the magnitude of the horns the antenna can be precisely adjusted until the horns are of equal magnitude. Once this has been accomplished a nominal power can be set.

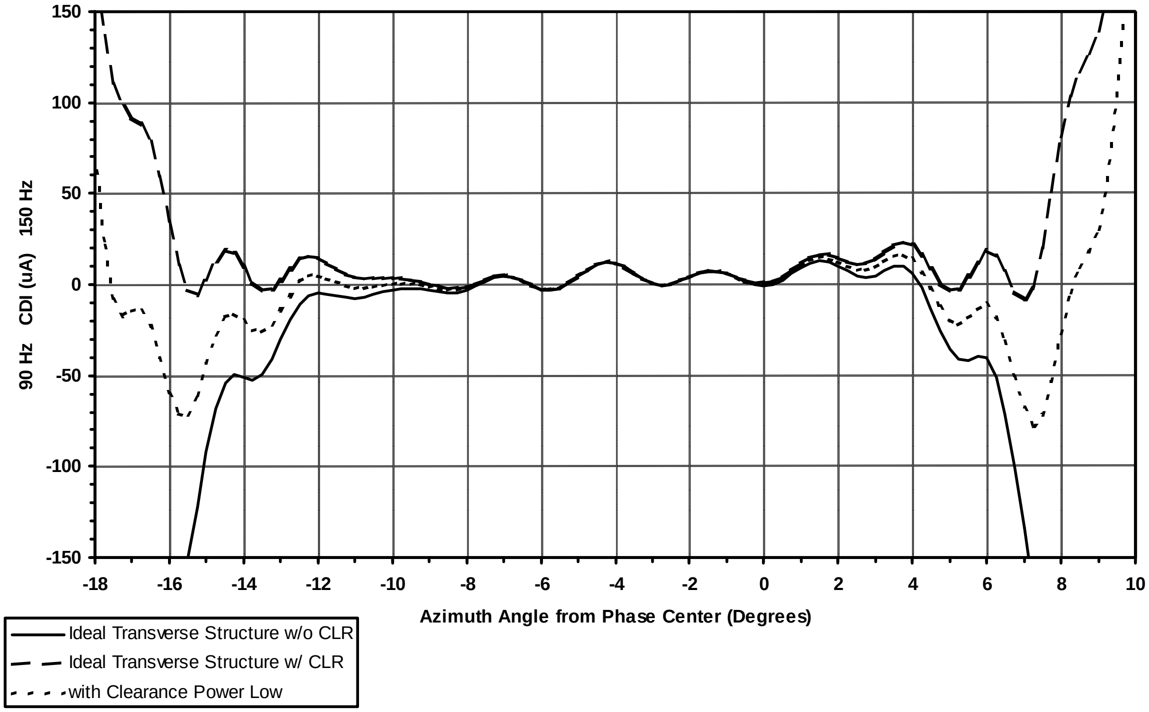


Figure A1-33. Clearance Power Low

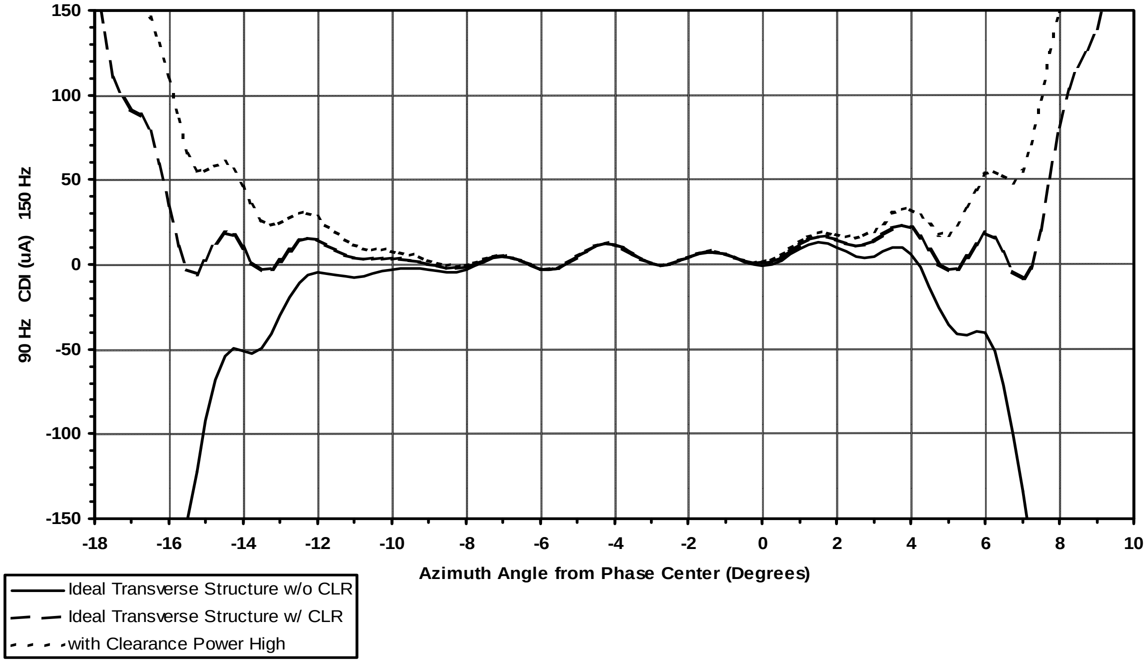


Figure A1-34. Clearance Power High

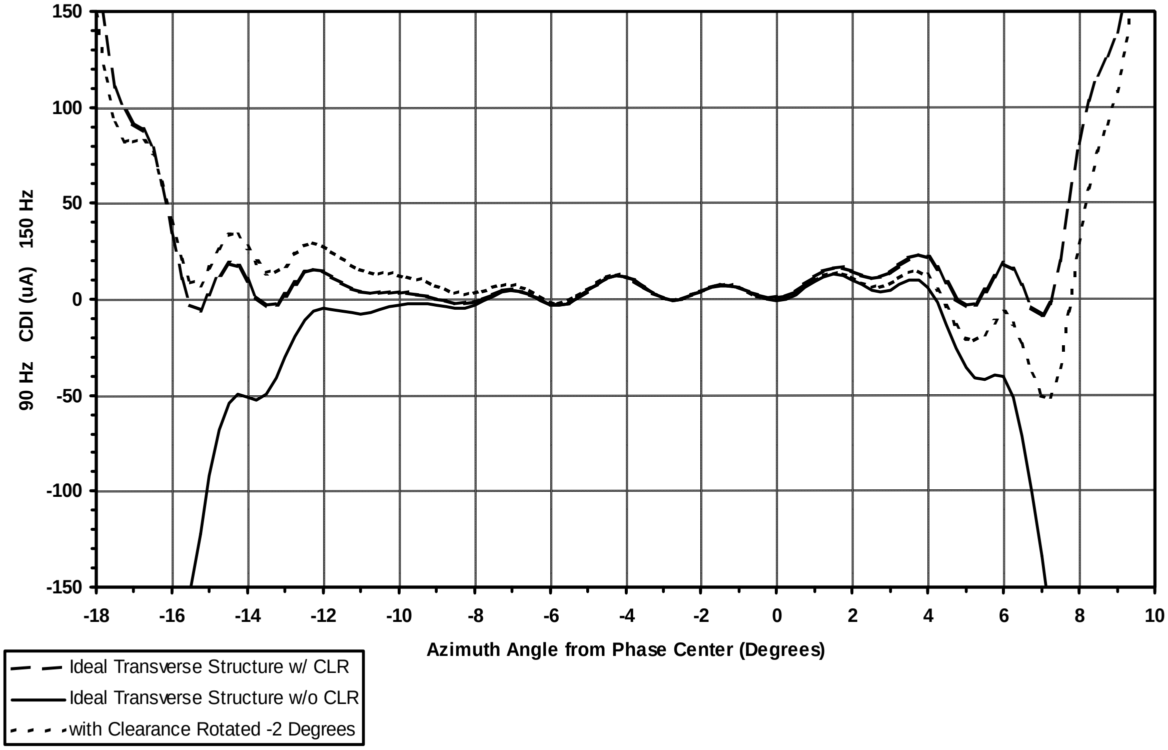


Figure A1-35. Clearance Antenna Rotated - 2 Degrees.

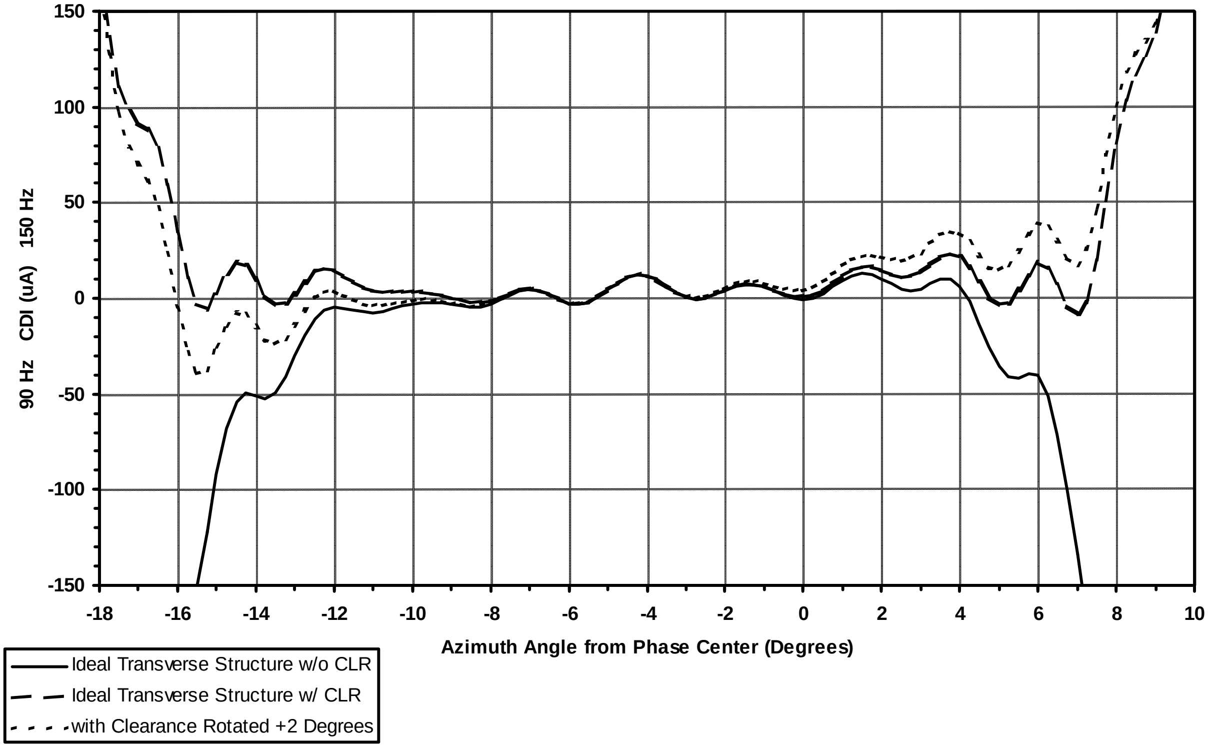


Figure A1-36. Clearance Antenna Rotated +2 Degrees.

A.9 COURSE ANTENNA INDIVIDUAL PEDESTAL ADJUSTMENTS.- The computed affect of individual pedestal adjustments are presented in the following figures:

A1-37 through A1-54, Front Antenna Pedestal F1 through F18, respectively, moved 0.3 ft TOWARD the threshold.

A1-55 through A1-72, Front Antenna Pedestal F1 through F12, respectively, moved 0.3 feet AWAY FROM the threshold.

A1-73 through A1-90, Rear Antenna Pedestal R1 through R12, respectively, moved 0.3 feet TOWARD the threshold.

A1-91 through A1-108, Rear Antenna Pedestal R1 through R12, respectively, moved 0.3 feet AWAY FROM the threshold.

See Section A7 entitled “Course Antenna Pedestal Adjustments” for further theory and details.

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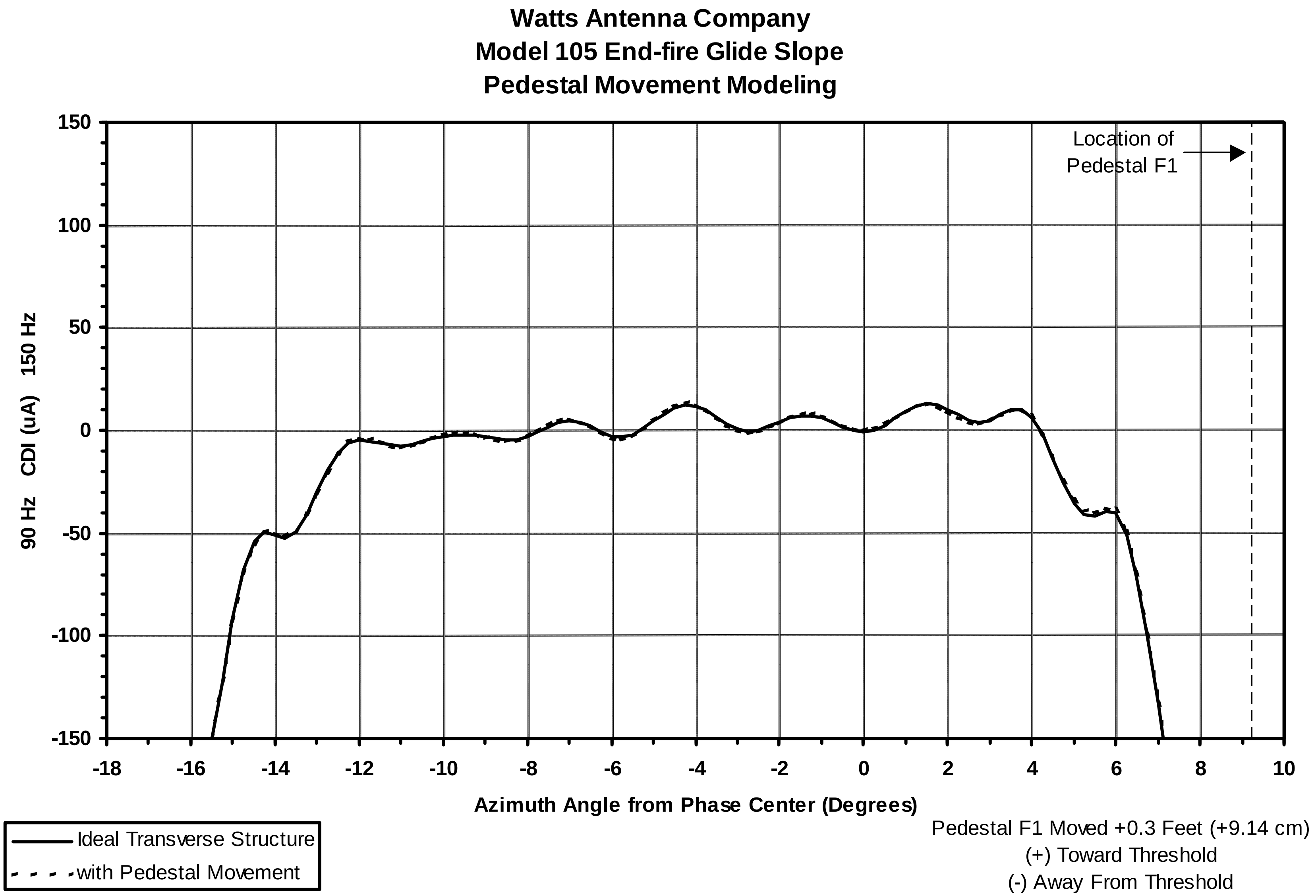


Pedestal F1 Moved +0.3 Feet (+9.14 cm)
(+) Toward Threshold
(-) Away From Threshold

Figure A1-37. Pedestal F1 Moved 0.3 Feet Toward Threshold

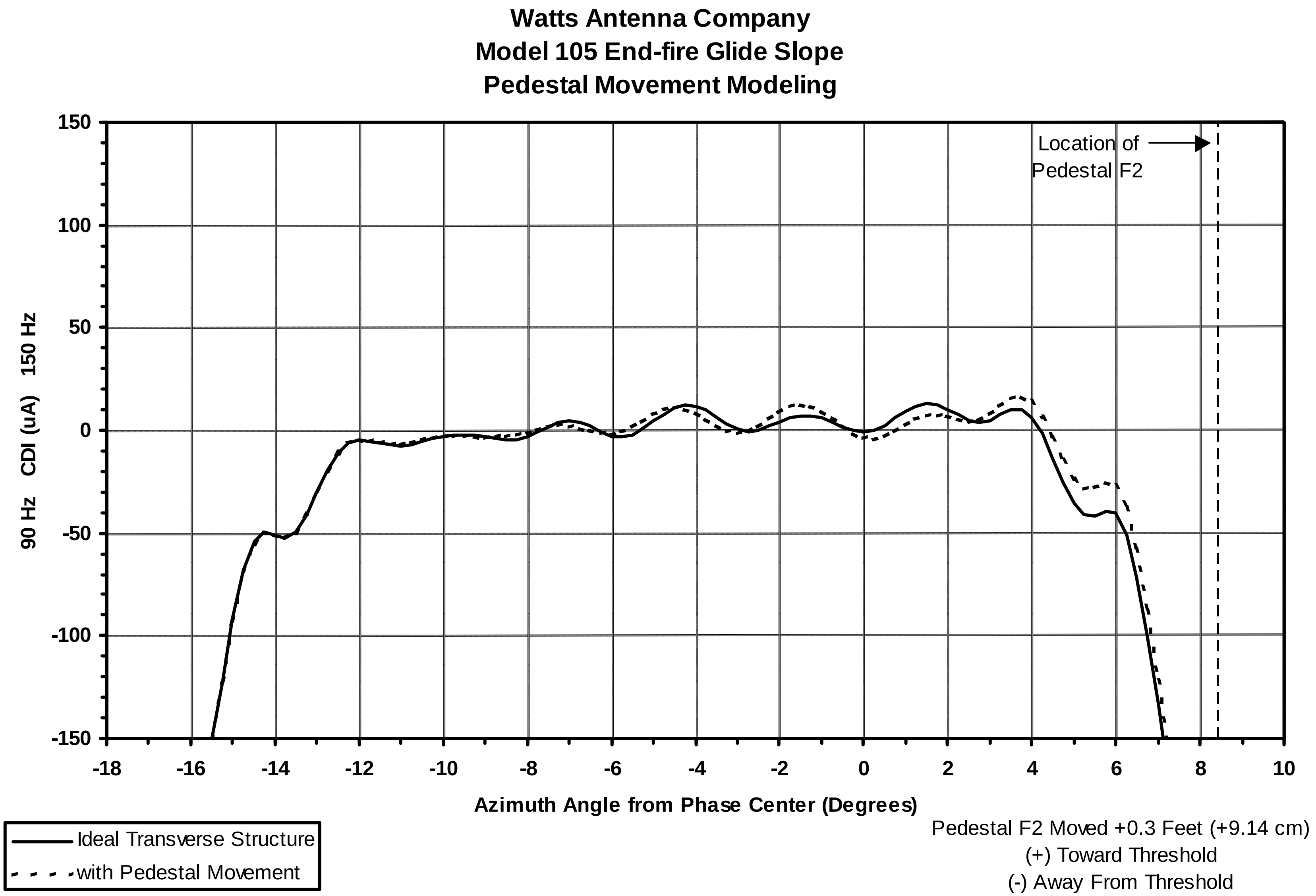
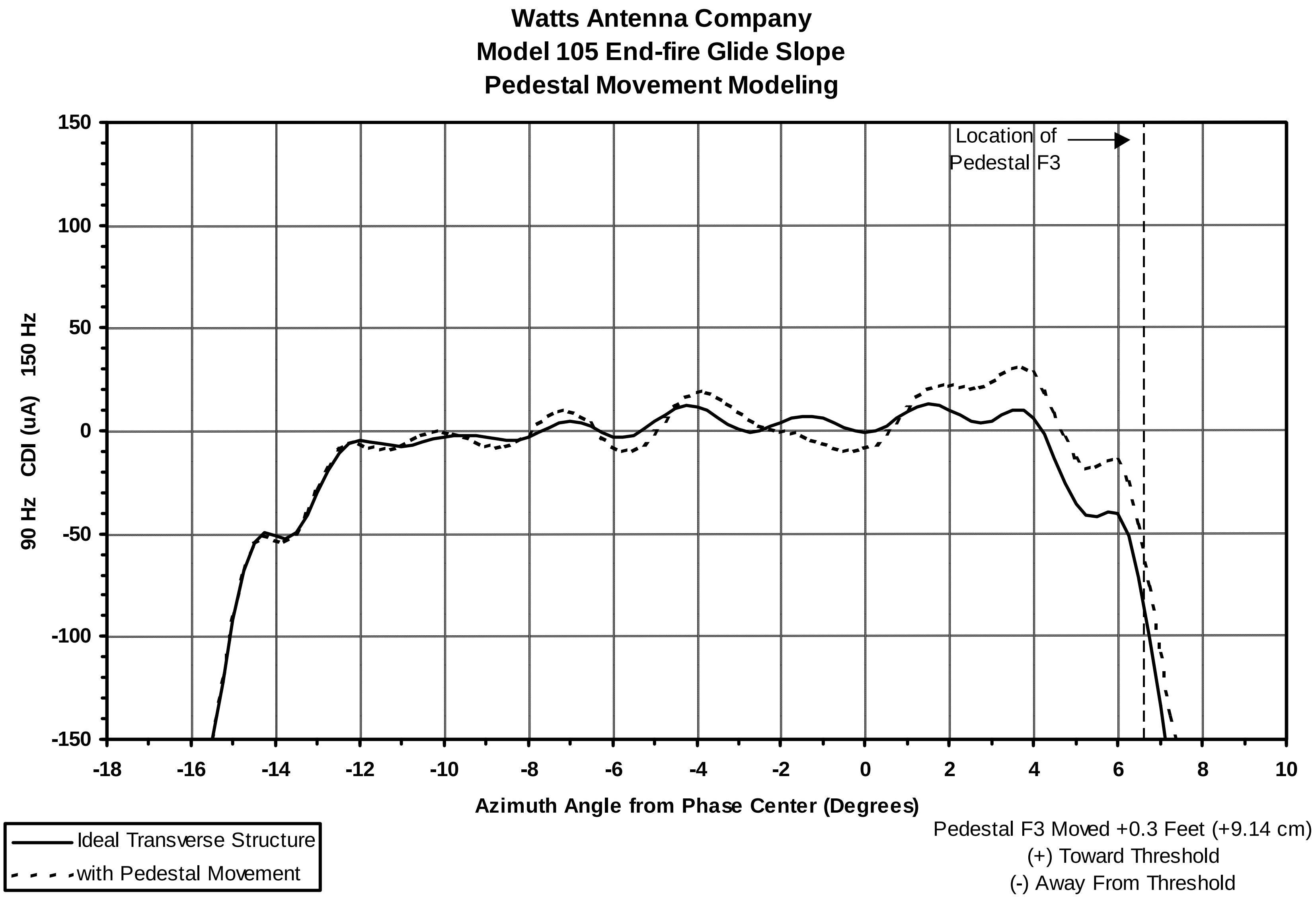


Figure A1-38. Pedestal F2 Moved 0.3 Feet Toward Threshold



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Model 105 End-fire Glide Slope
Pedestal Movement Modeling

Pedestal F3 Moved +0.3 Feet (+9.14 cm)
(+) Toward Threshold
(-) Away From Threshold

Figure A1-39. Pedestal F3 Moved 0.3 Feet Toward Threshold

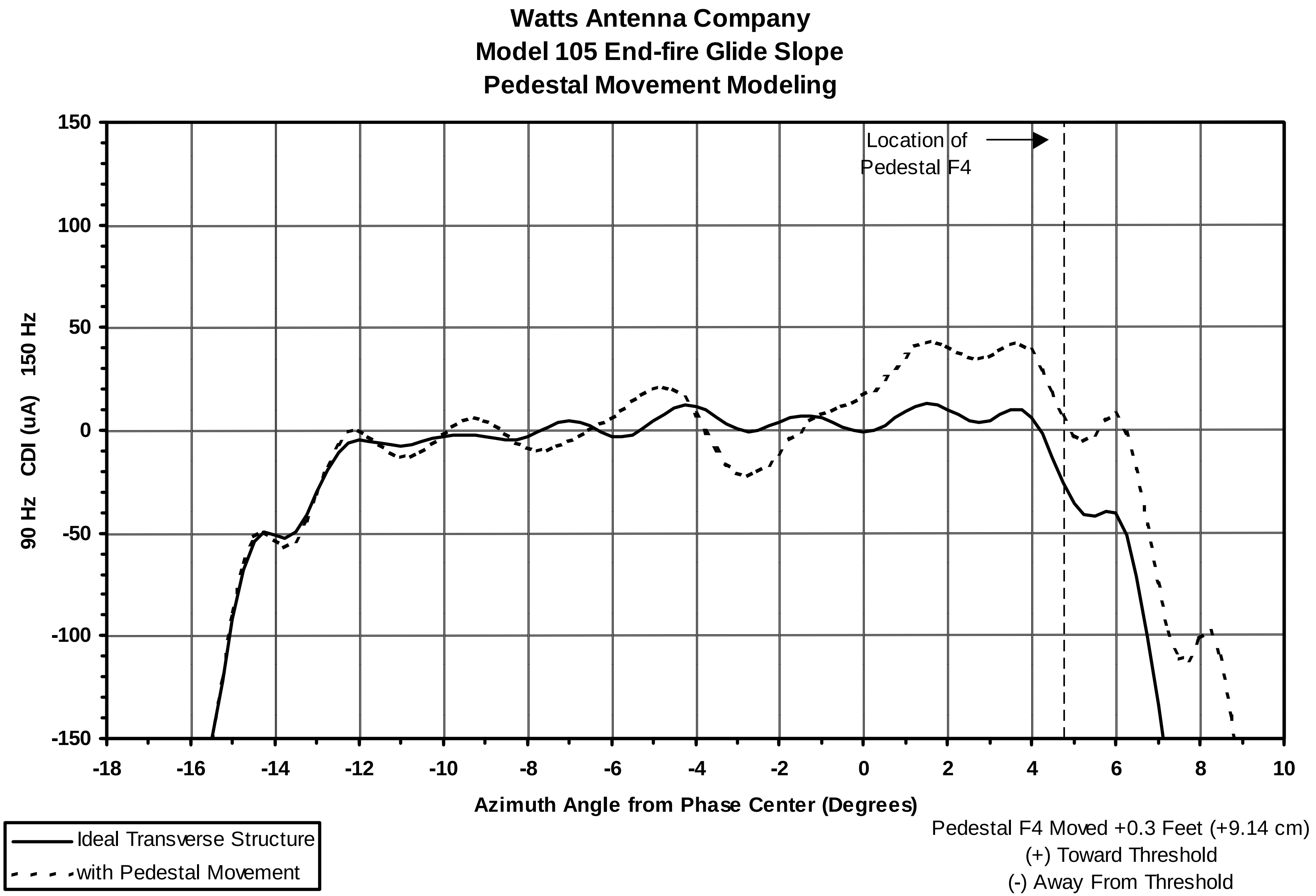


Figure A1-40. Pedestal F4 Moved 0.3 Feet Toward Threshold

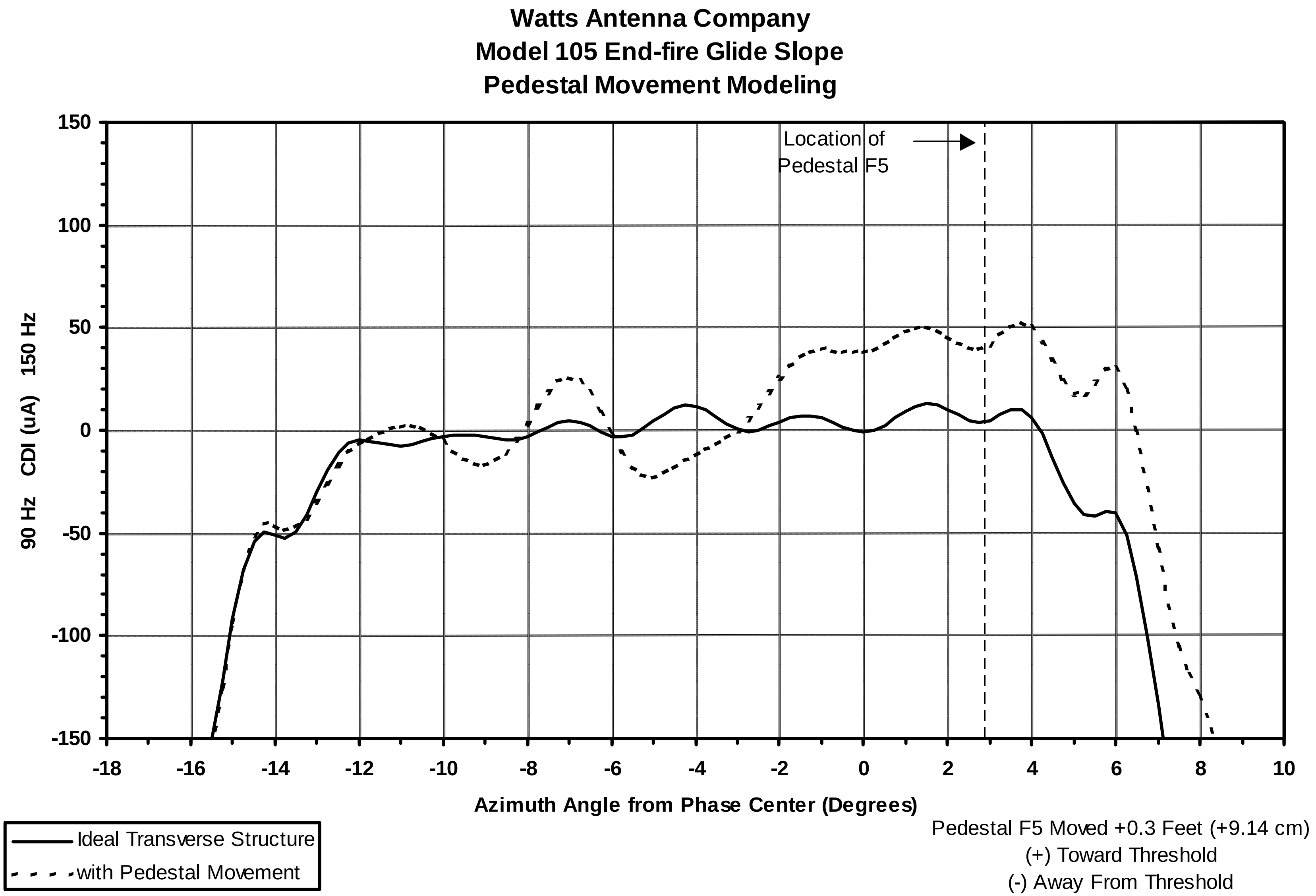


Figure A1-41. Pedestal F5 Moved 0.3 Feet Toward Threshold

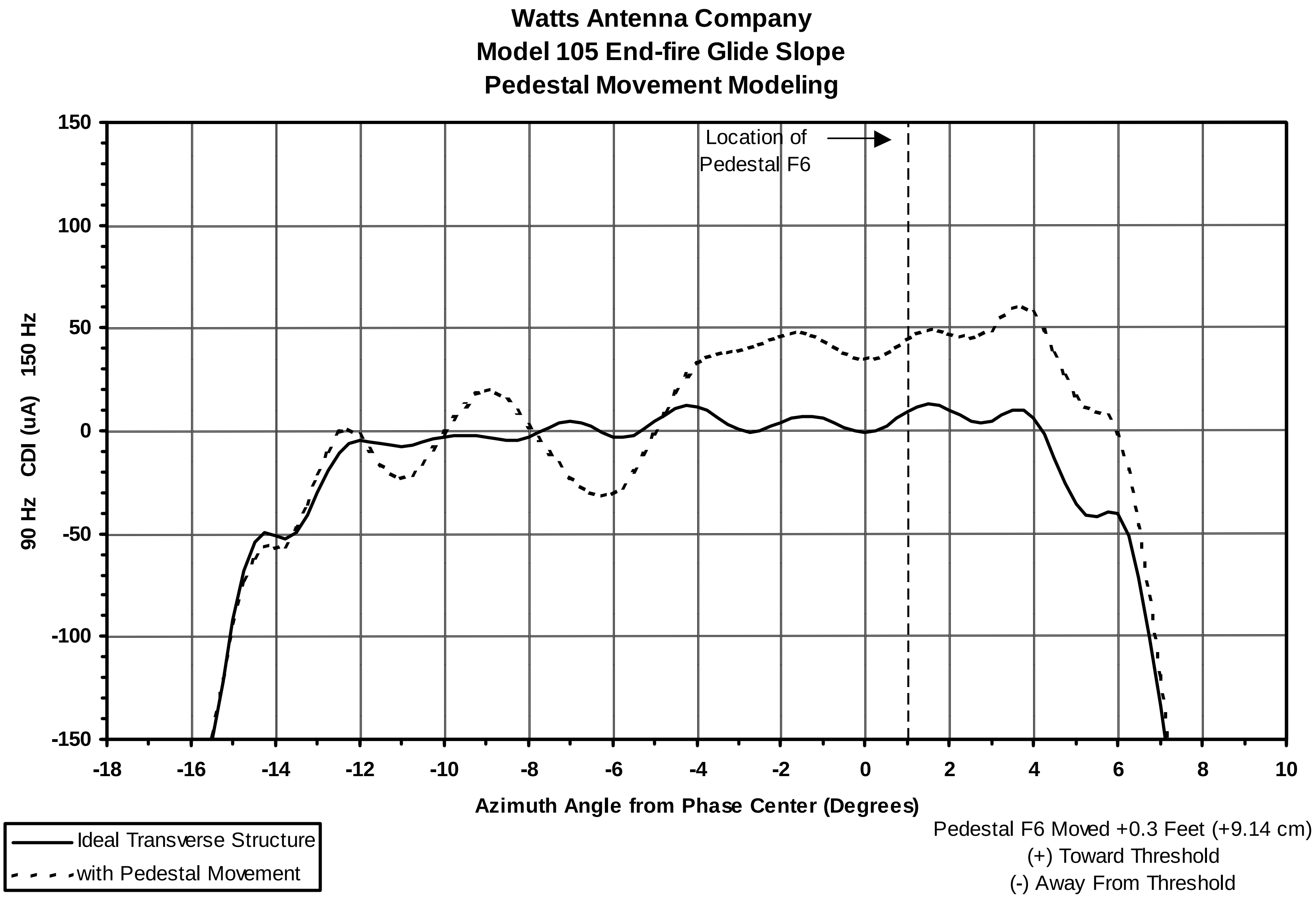


Figure A1-42. Pedestal F6 Moved 0.3 Feet Toward Threshold

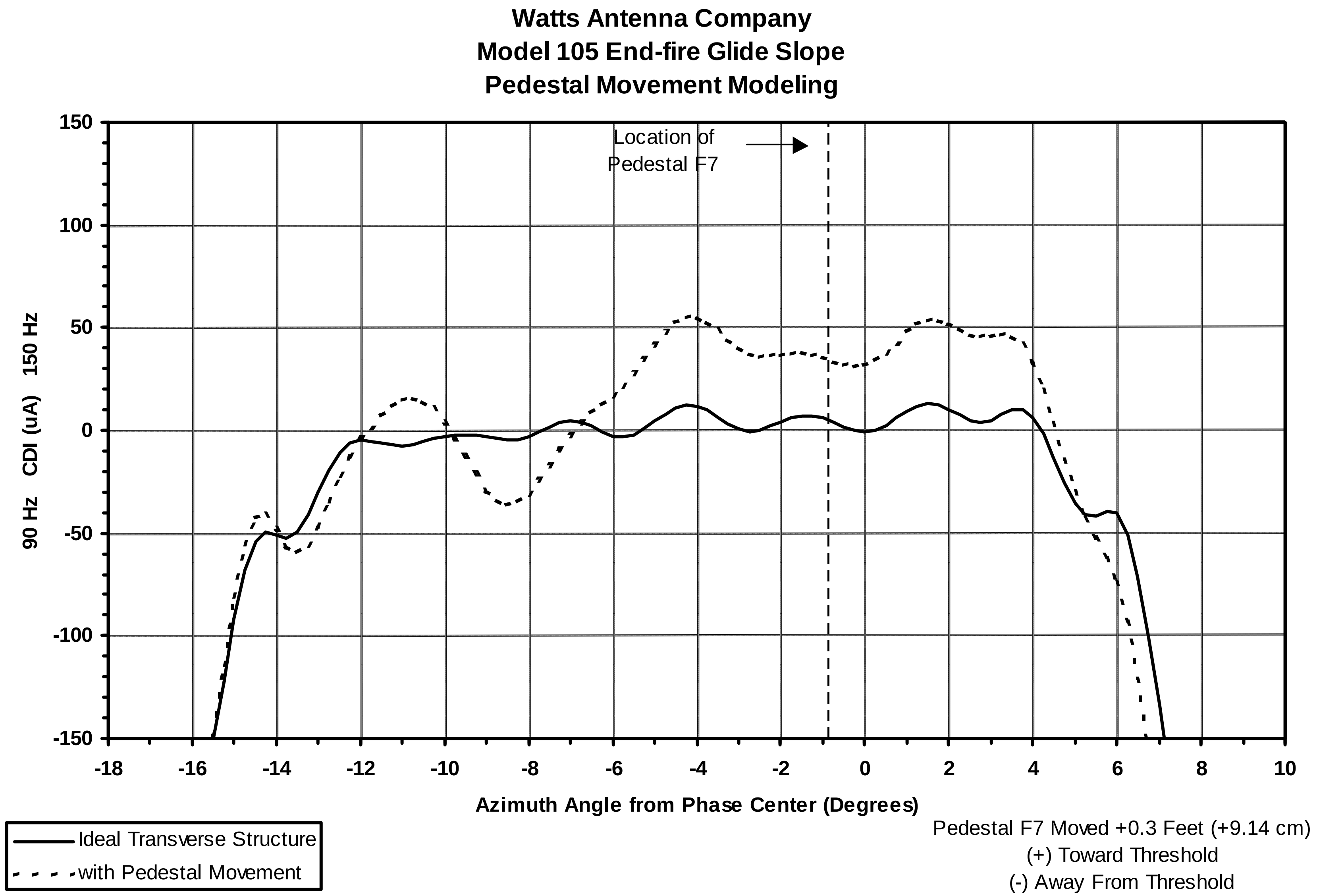


Figure A1-43. Pedestal F7 Moved 0.3 Feet Toward Threshold

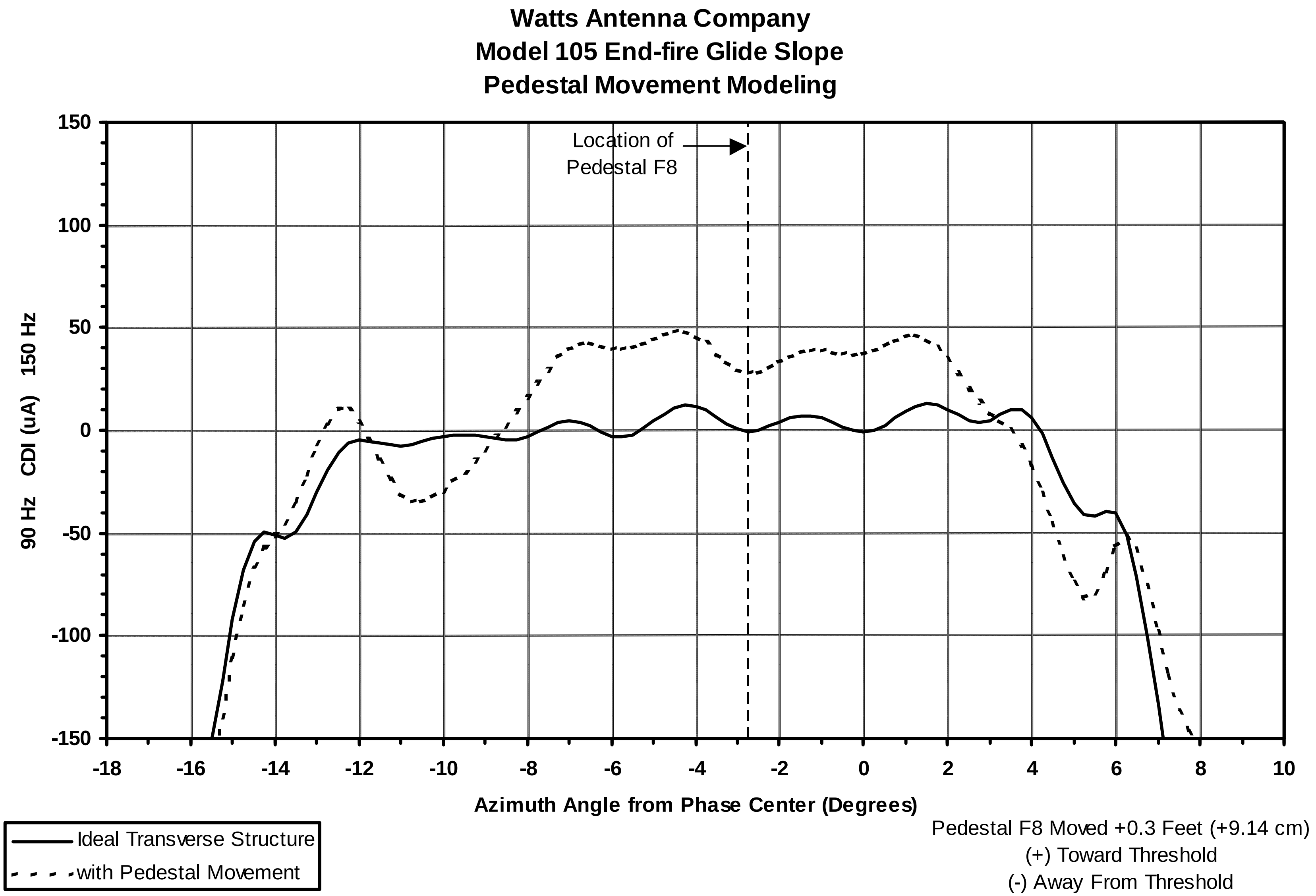


Figure A1-44. Pedestal F8 Moved 0.3 Feet Toward Threshold

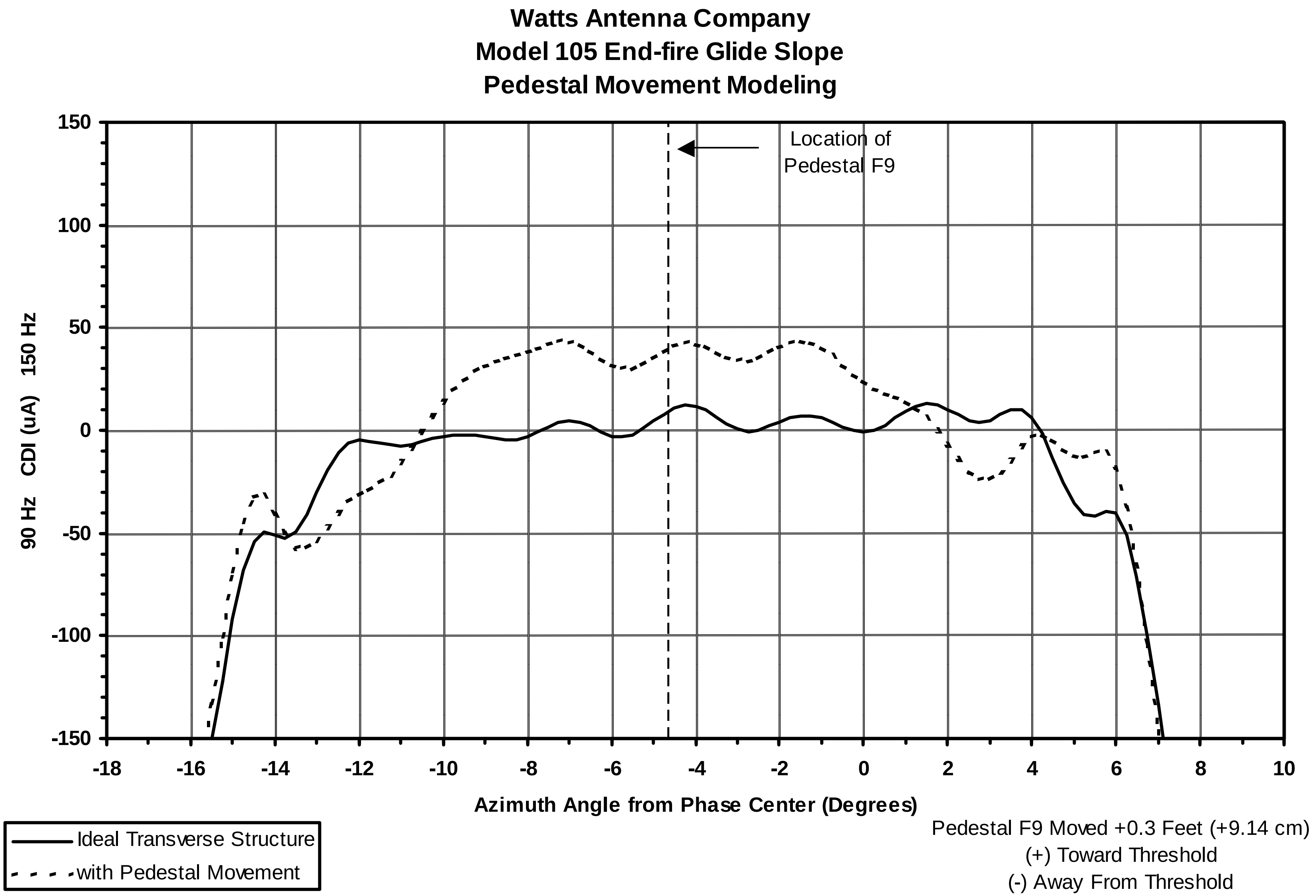


Figure A1-45. Pedestal F9 Moved 0.3 Feet Toward Threshold

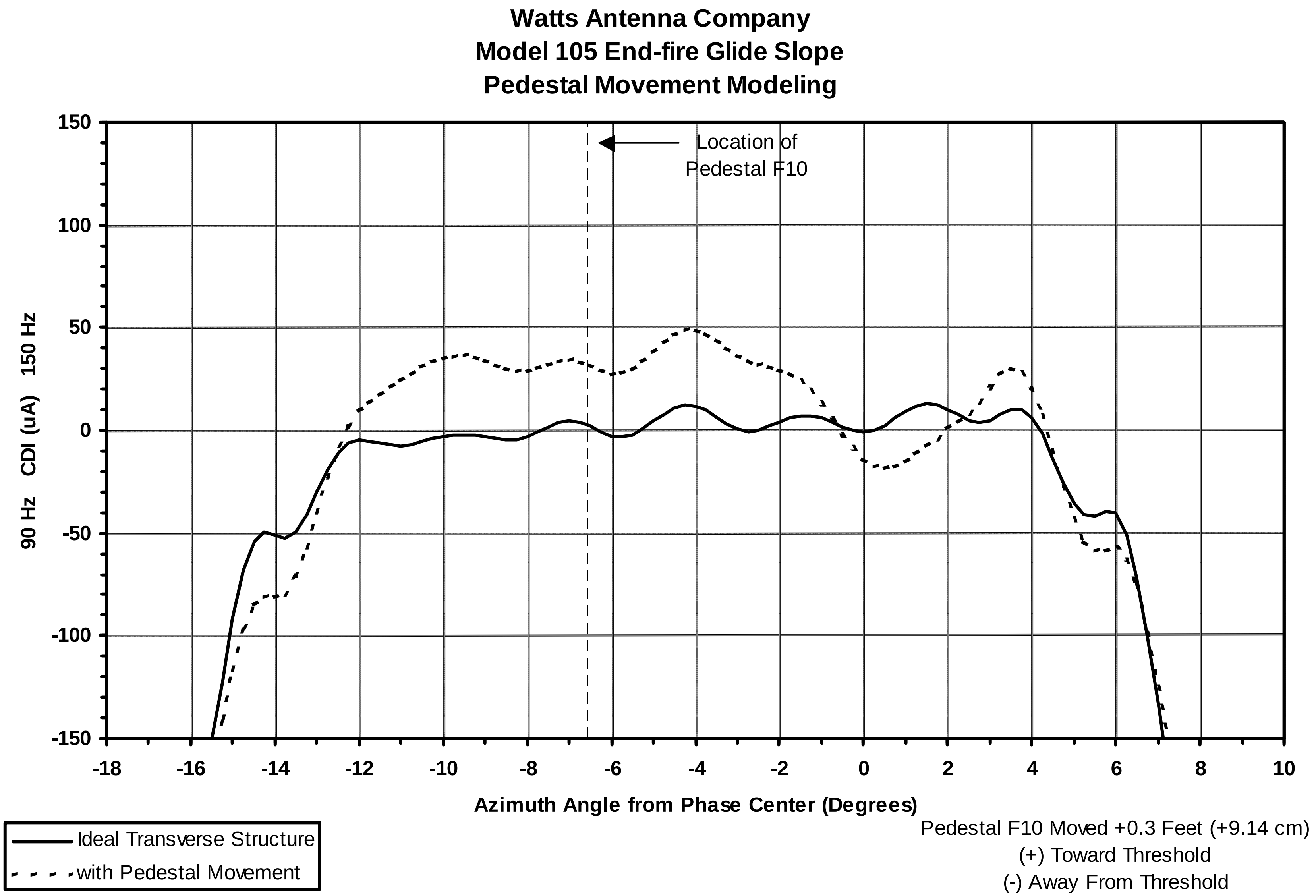


Figure A1-46. Pedestal F10 Moved 0.3 Feet Toward Threshold

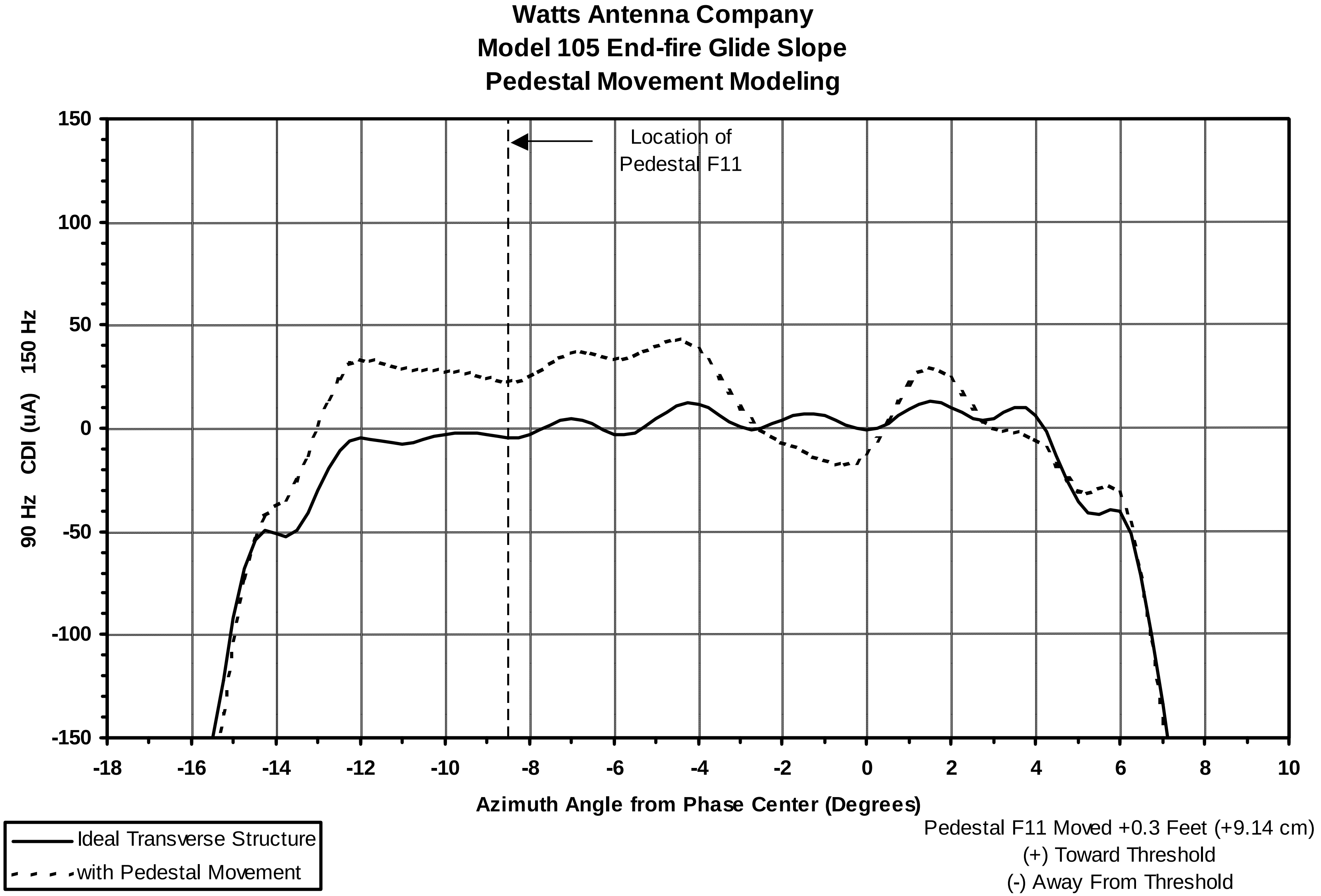


Figure A1-47. Pedestal F11 Moved 0.3 Feet Toward Threshold

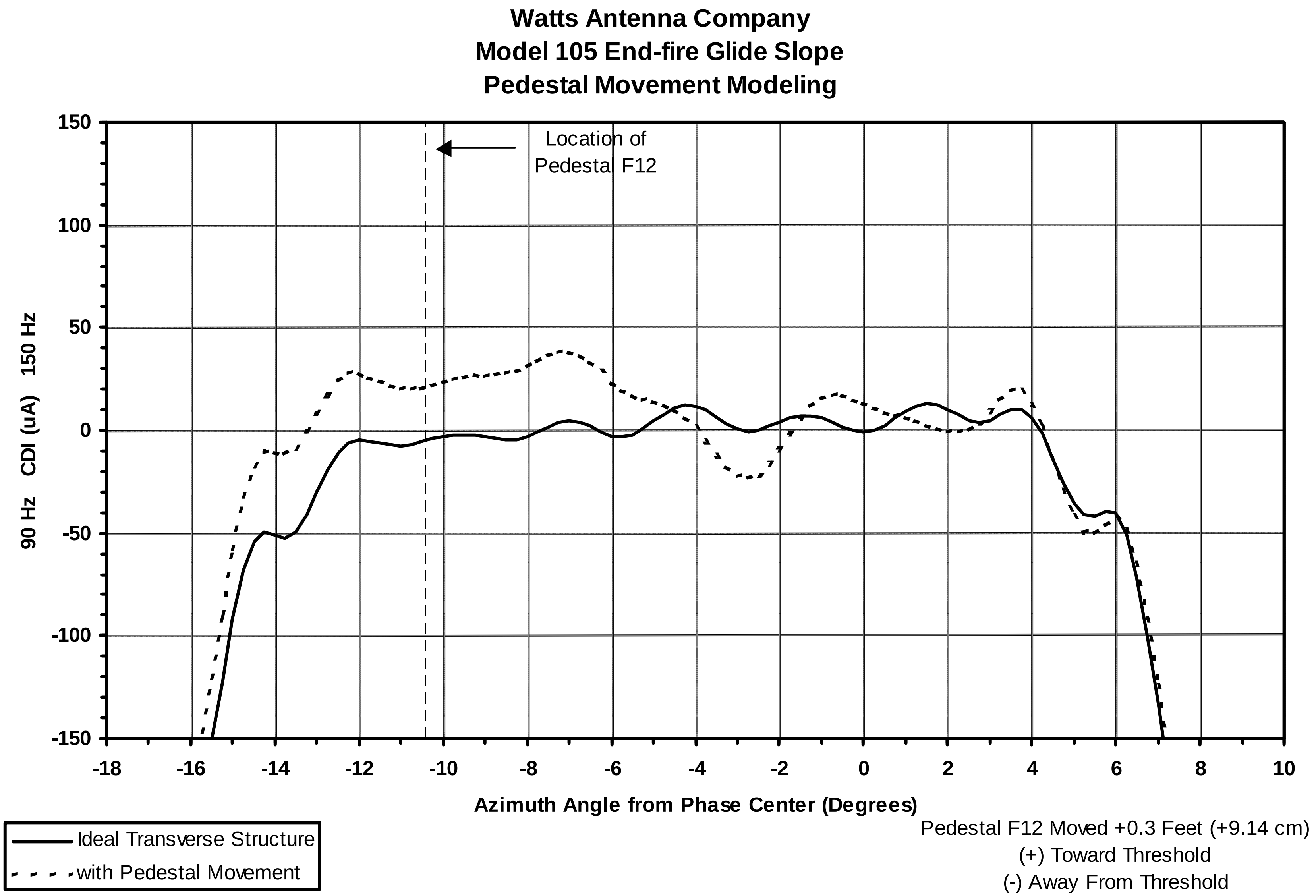


Figure A1-48. Pedestal F12 Moved 0.3 Feet Toward Threshold

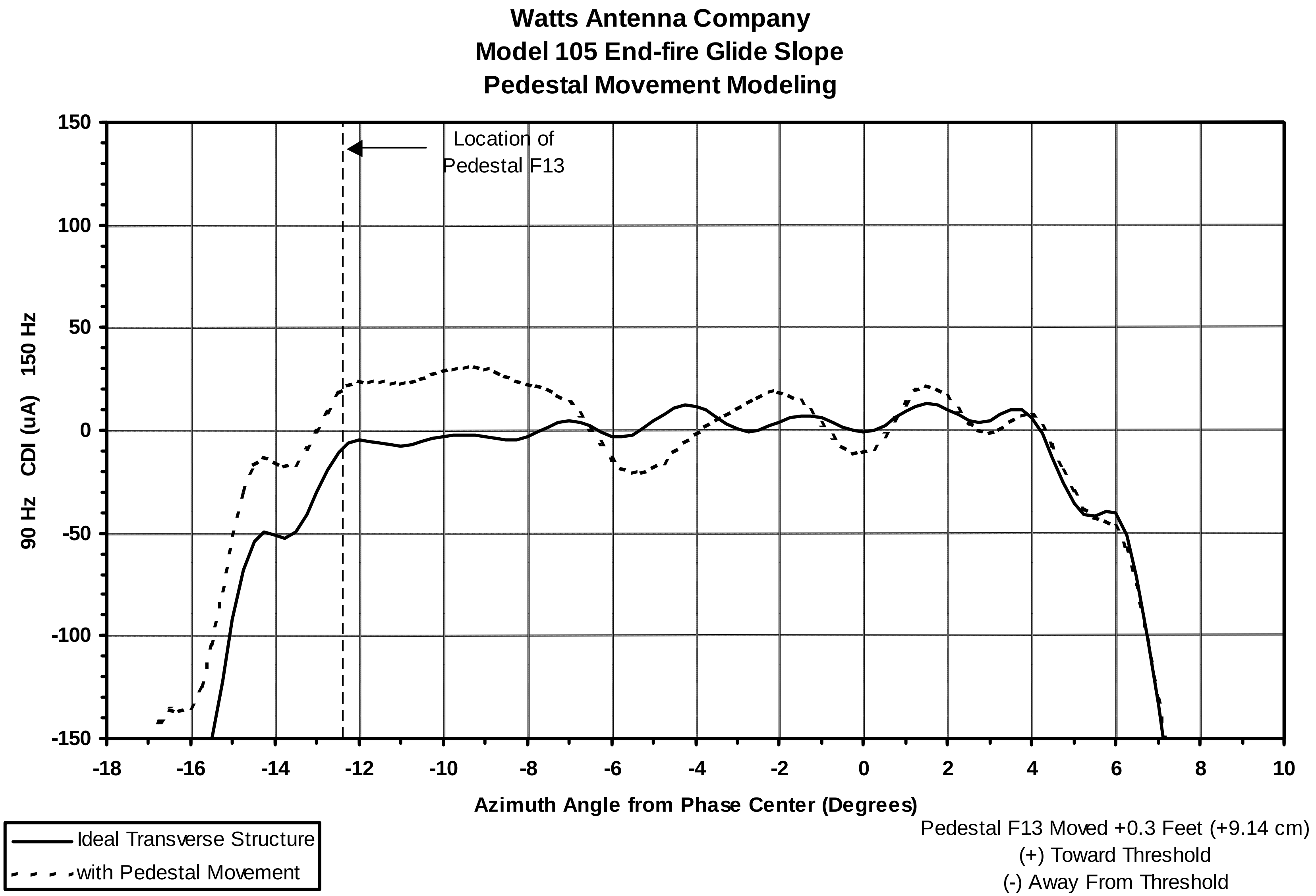


Figure A1-49. Pedestal F13 Moved 0.3 Feet Toward Threshold

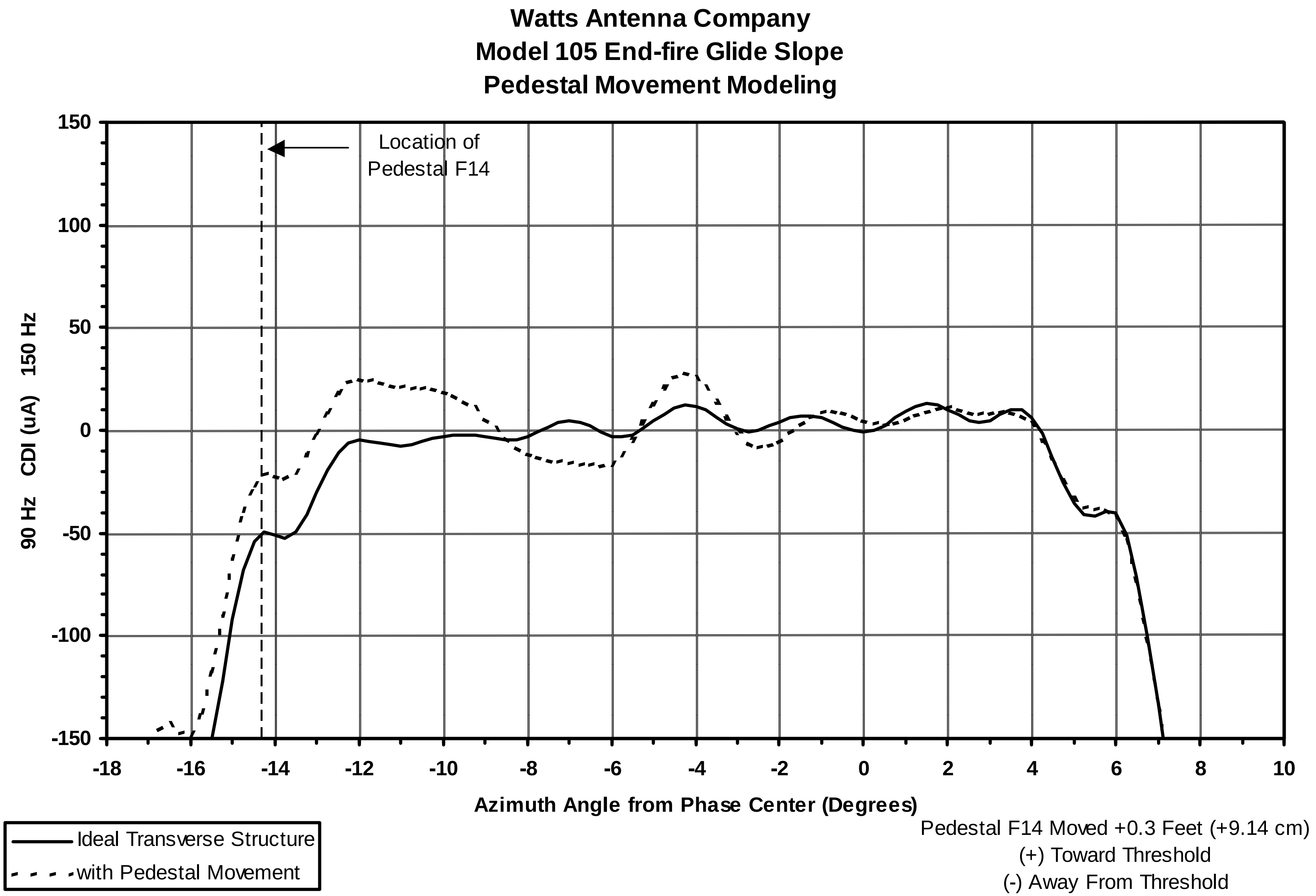


Figure A1-50. Pedestal F14 Moved 0.3 Feet Toward Threshold

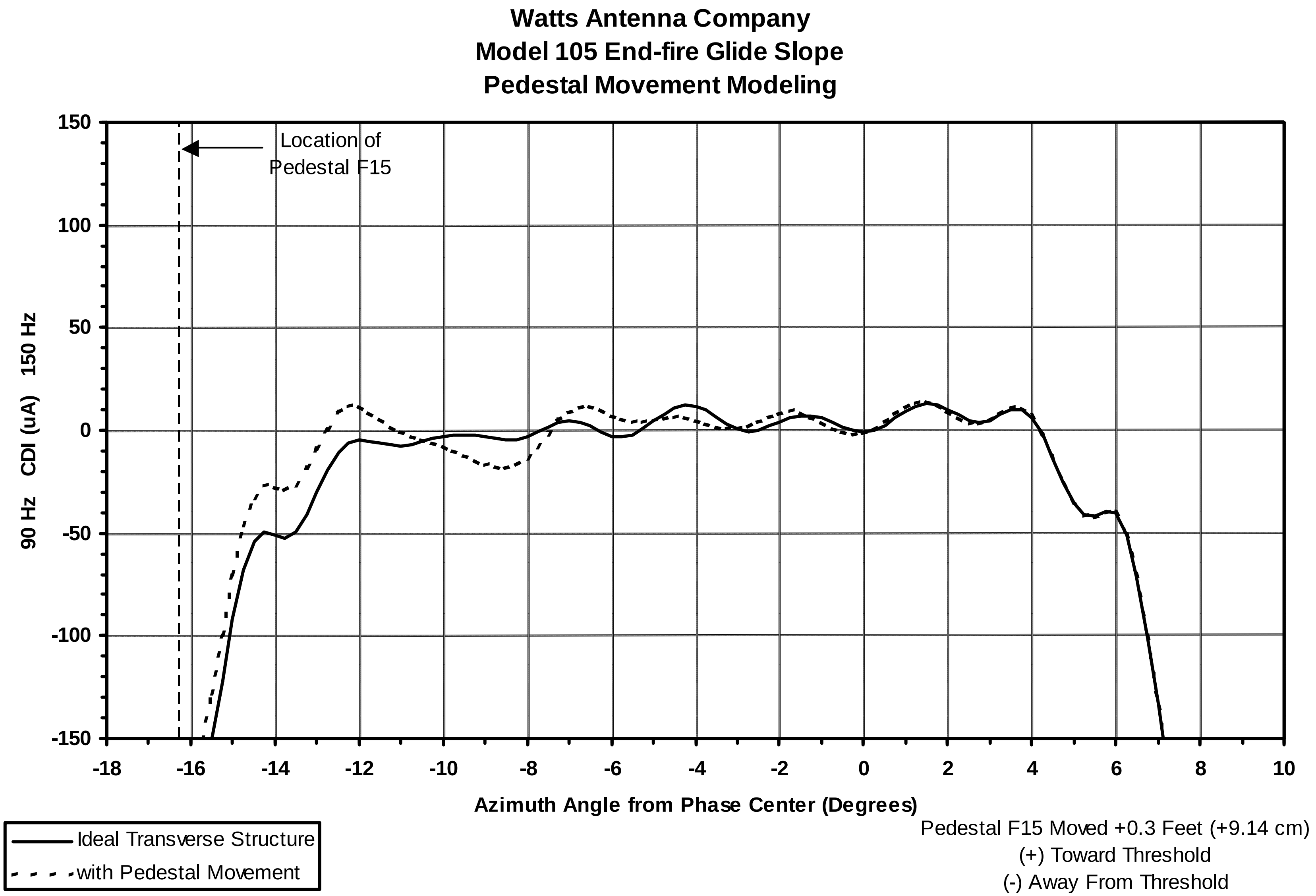


Figure A1-51. Pedestal F15 Moved 0.3 Feet Toward Threshold

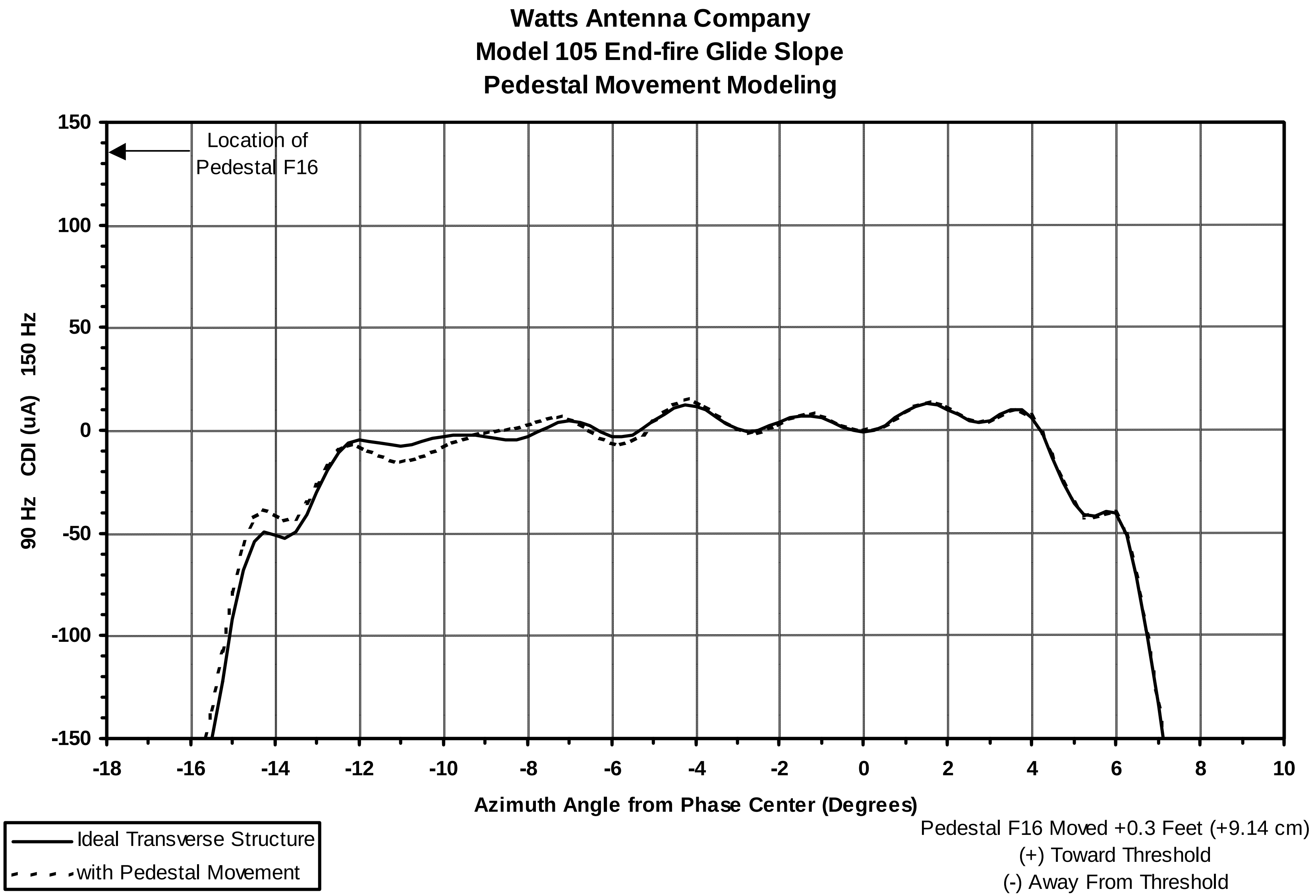


Figure A1-52. Pedestal F16 Moved 0.3 Feet Toward Threshold

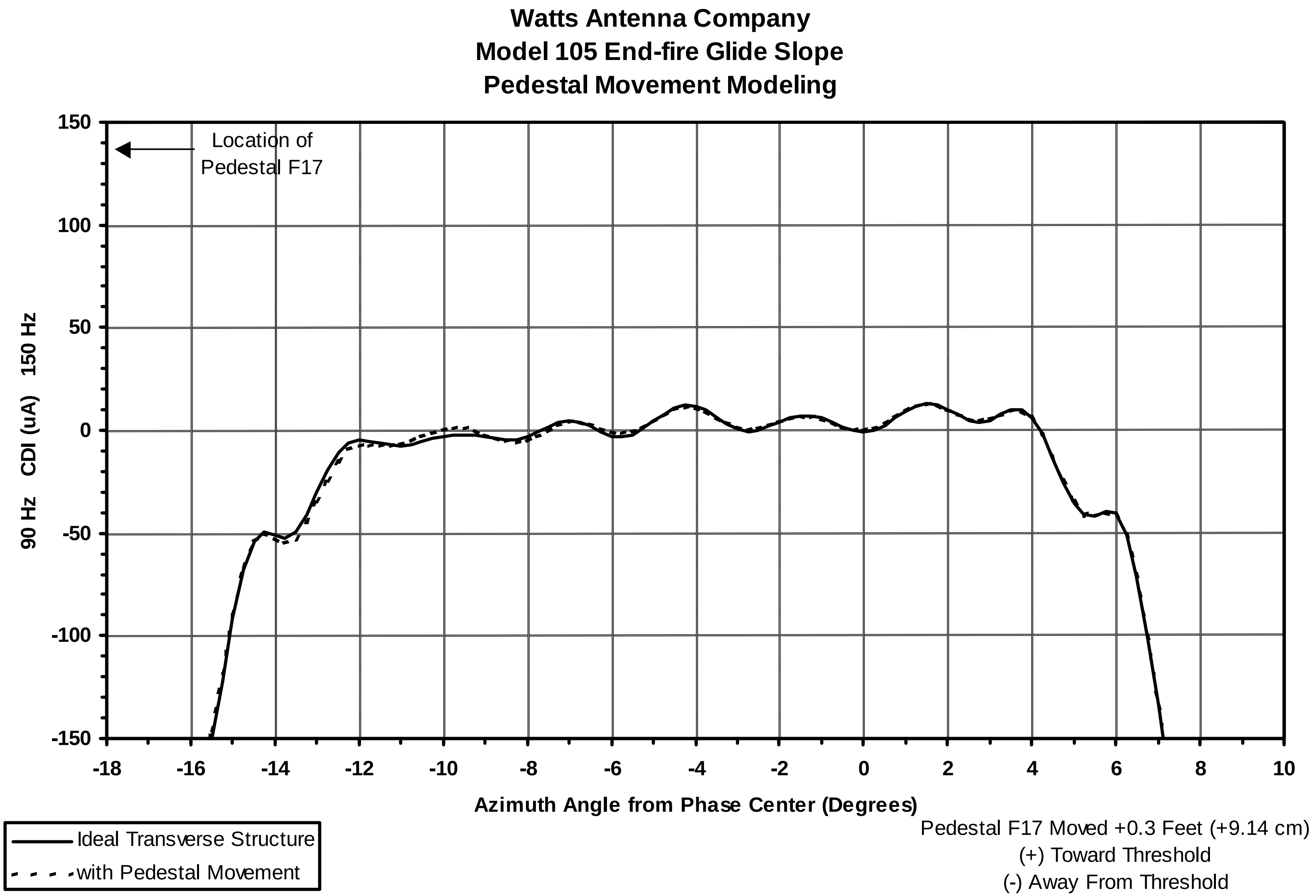


Figure A1-53. Pedestal F17 Moved 0.3 Feet Toward Threshold

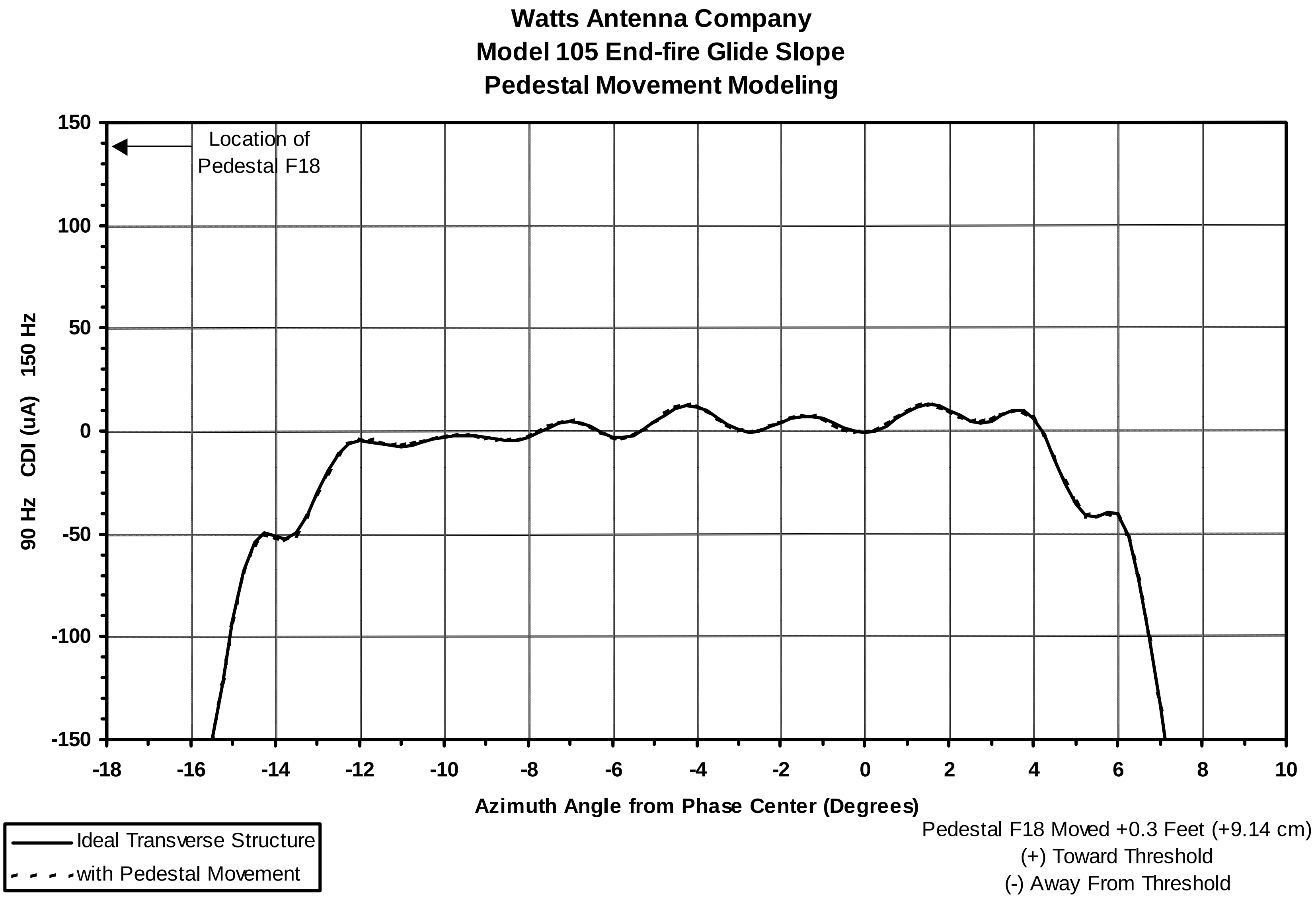


Figure A1-54. Pedestal F18 Moved 0.3 Feet Toward Threshold

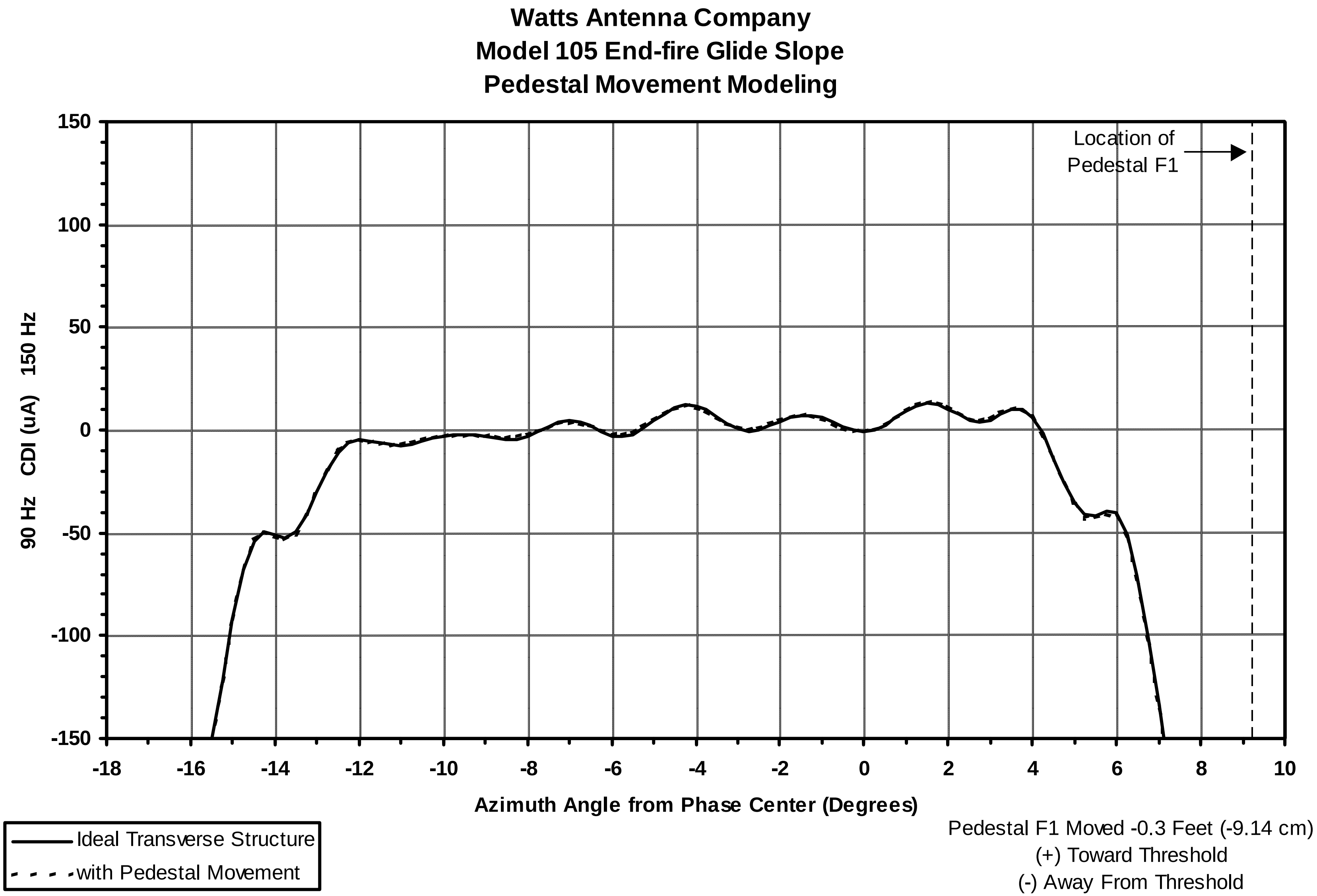


Figure A1-55. Pedestal F1 Moved 0.3 Feet Away From Threshold

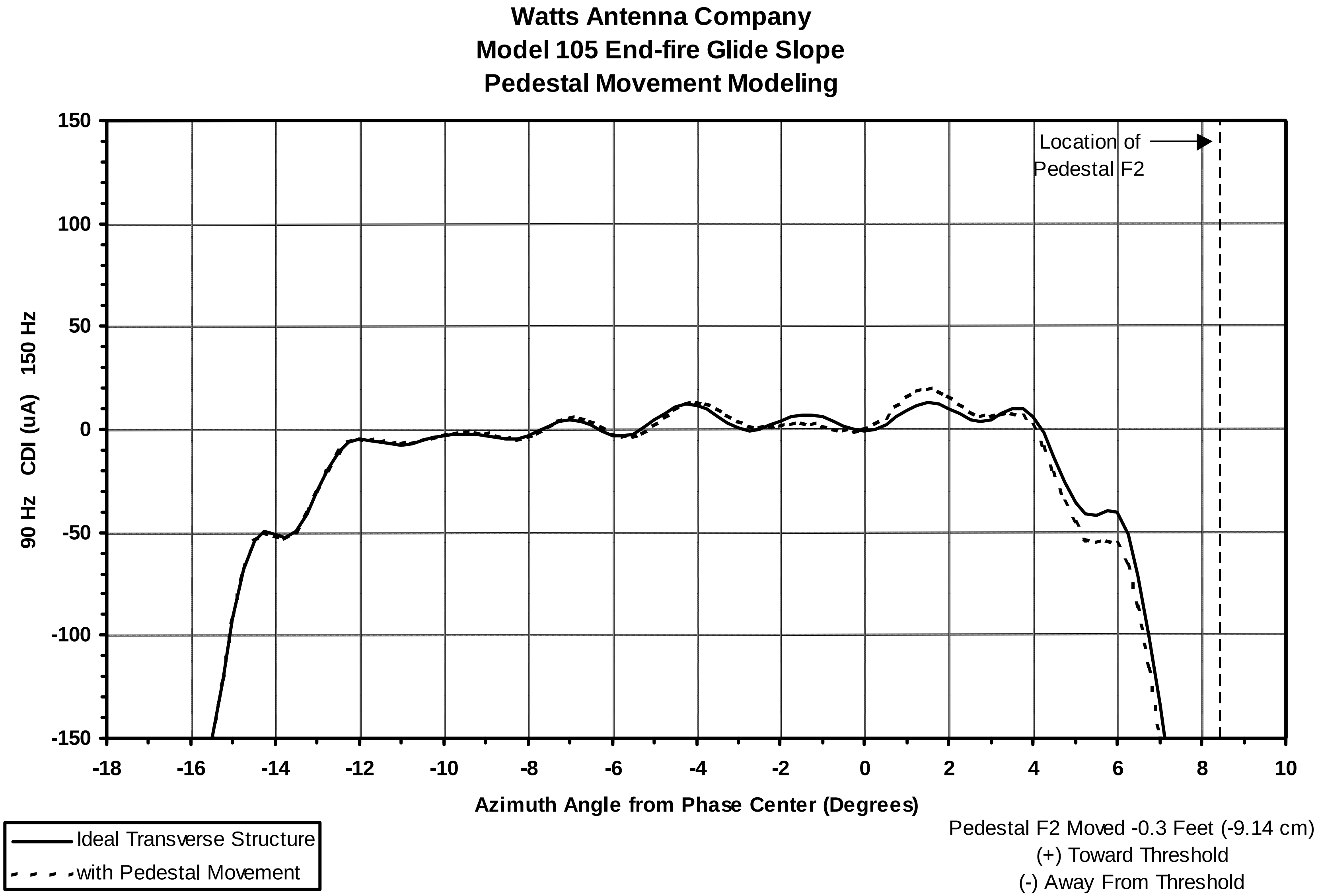


Figure A1-56. Pedestal F2 Moved 0.3 Feet Away From Threshold

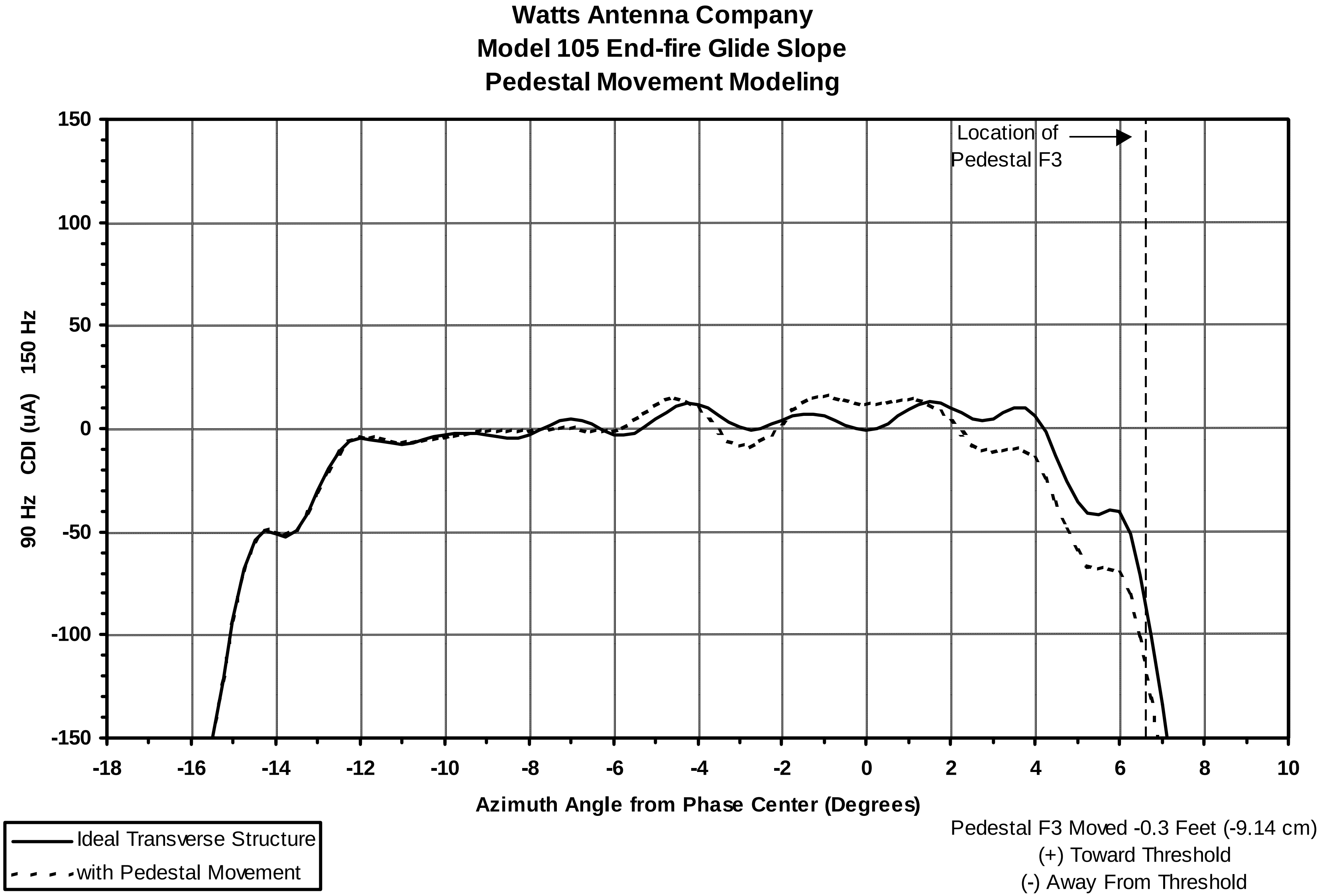


Figure A1-57. Pedestal F3 Moved 0.3 Feet Away From Threshold

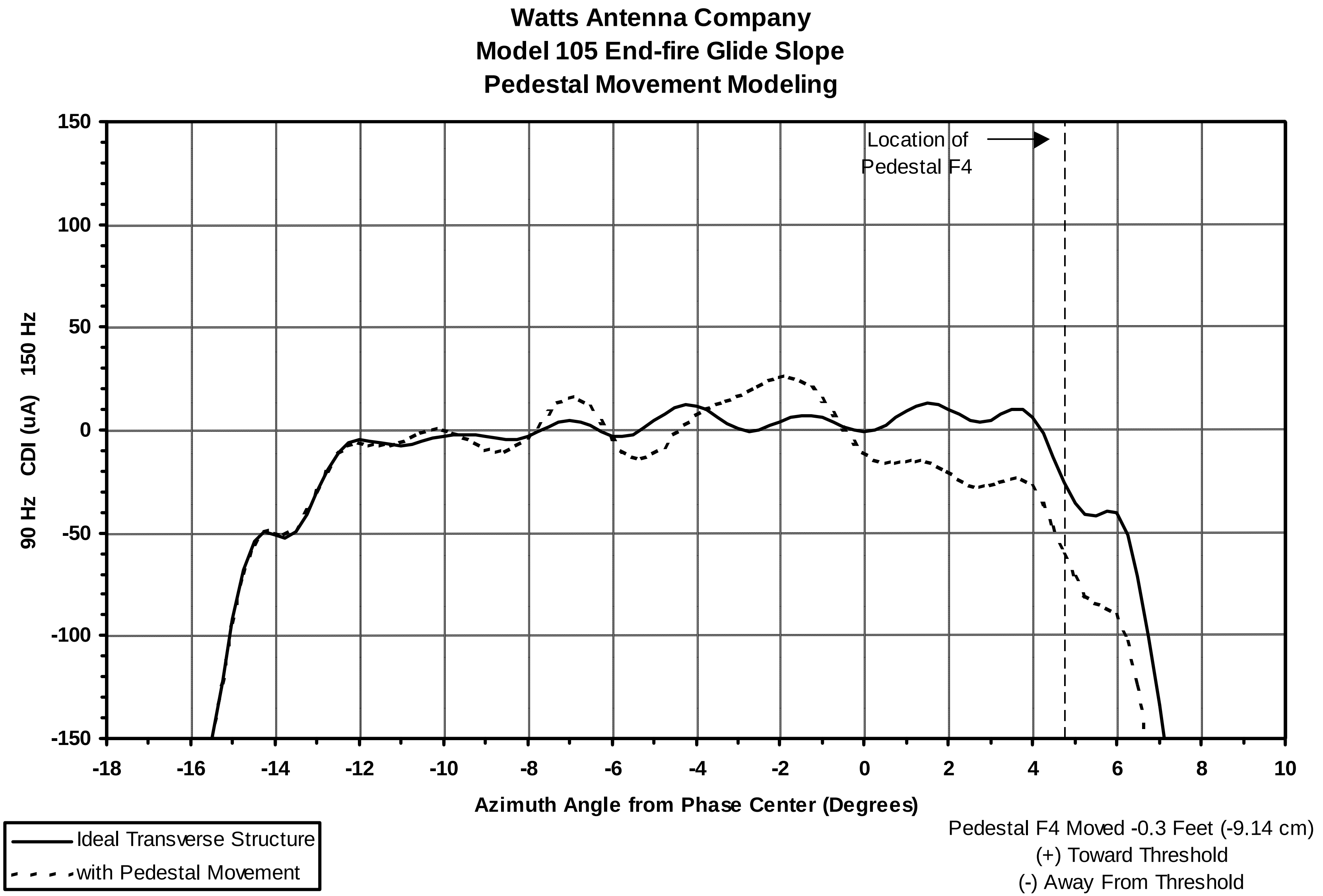


Figure A1-58. Pedestal F4 Moved 0.3 Feet Away From Threshold

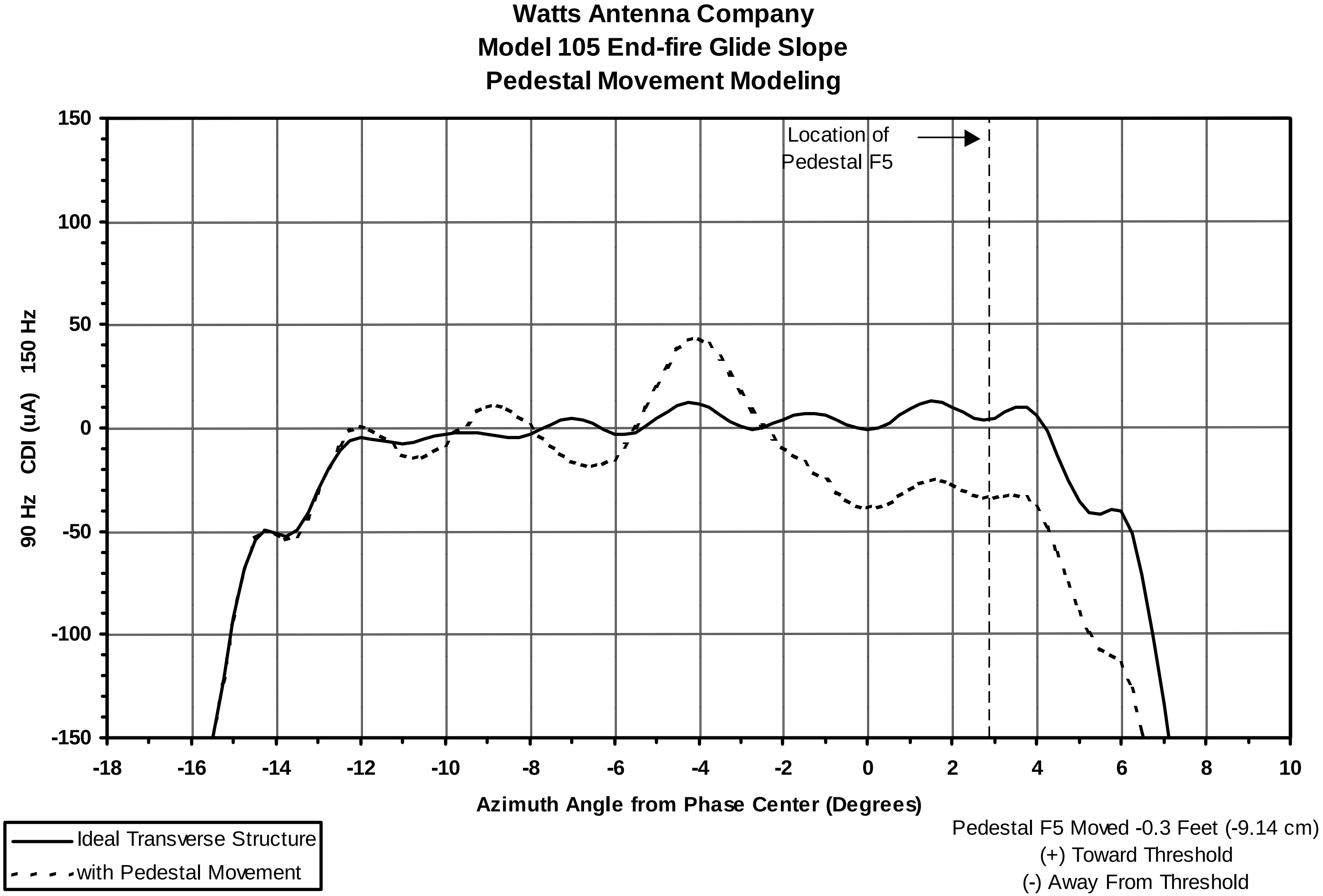


Figure A1-59. Pedestal F5 Moved 0.3 Feet Away From Threshold

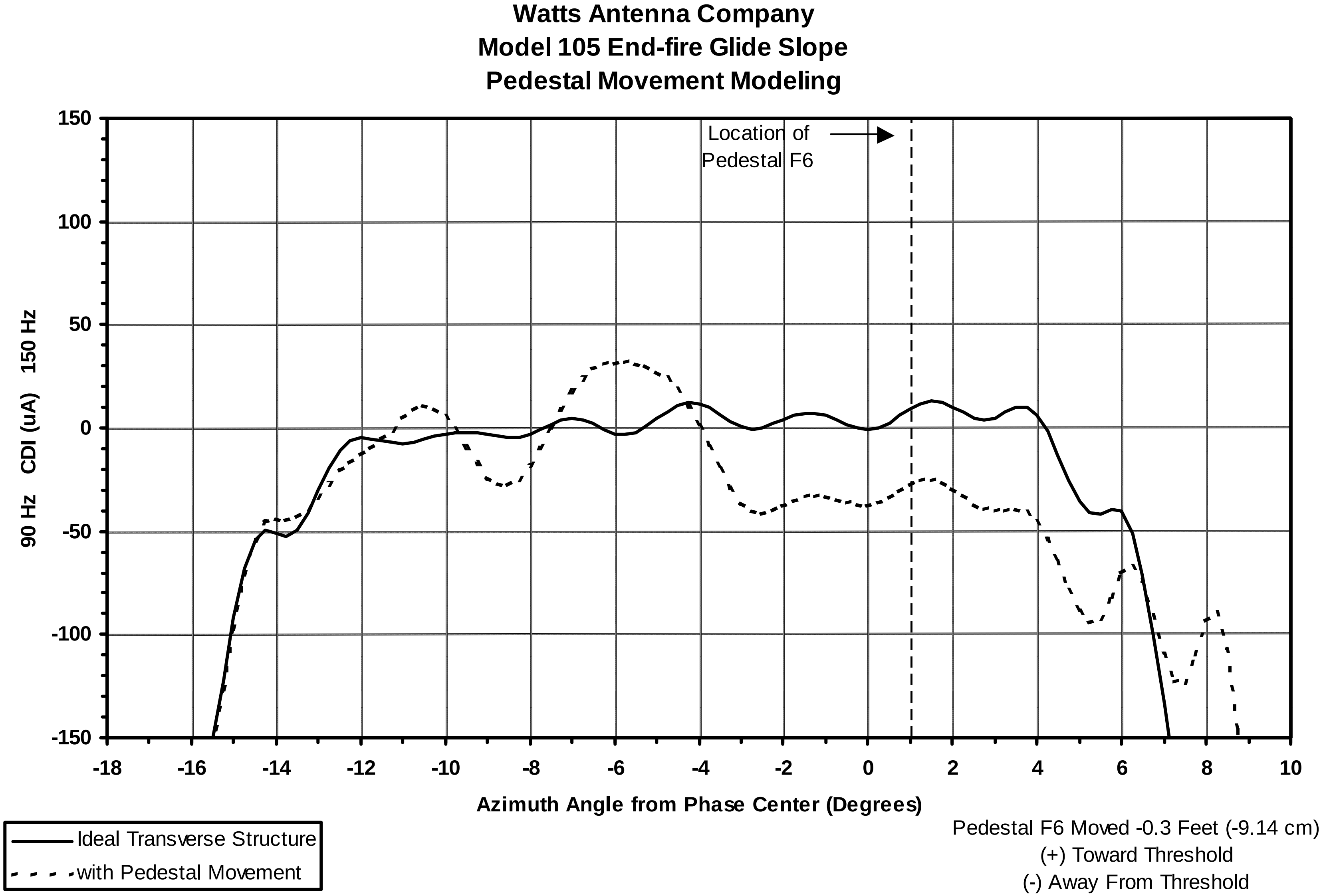


Figure A1-60. Pedestal F6 Moved 0.3 Feet Away From Threshold

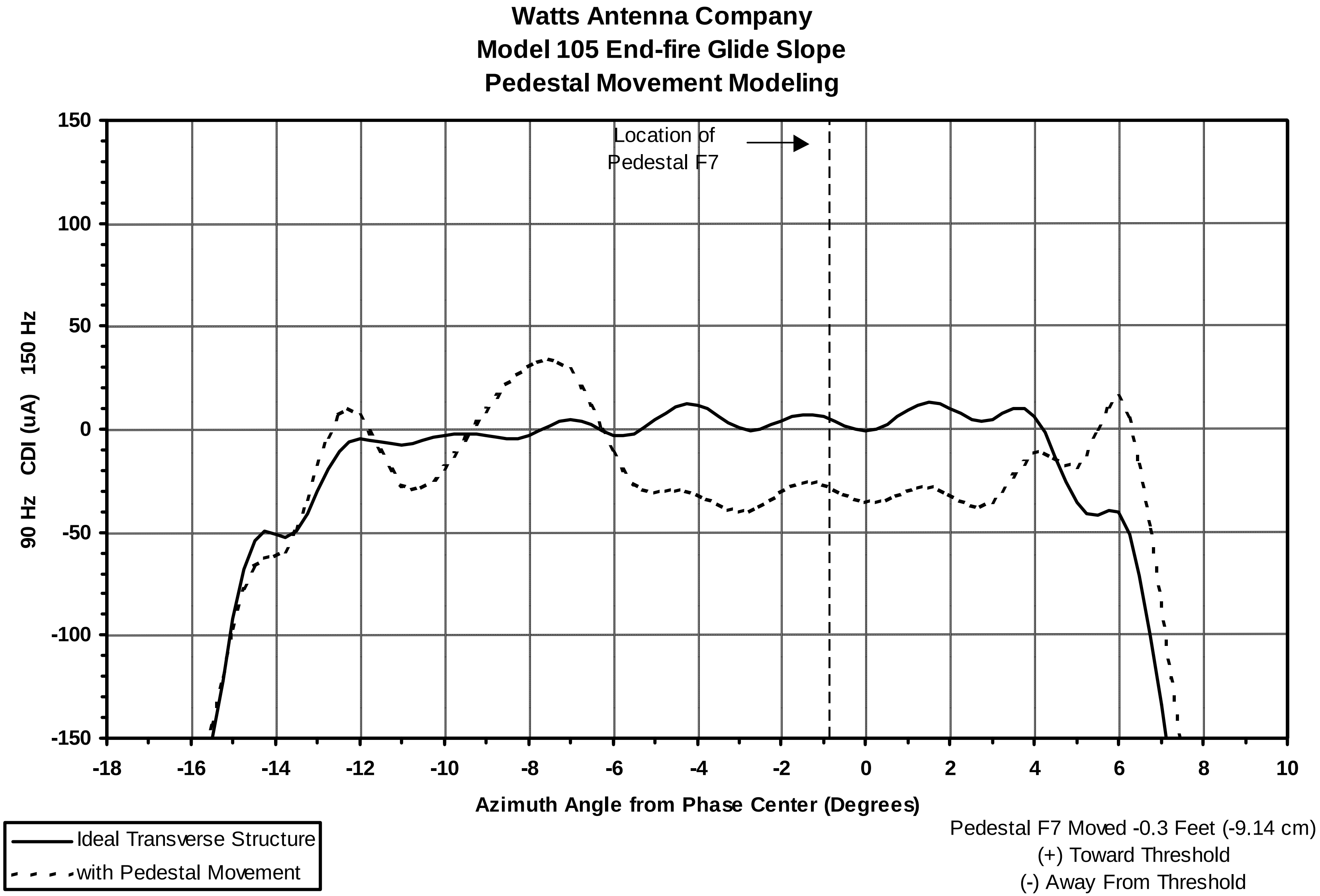


Figure A1-61. Pedestal F7 Moved 0.3 Feet Away From Threshold

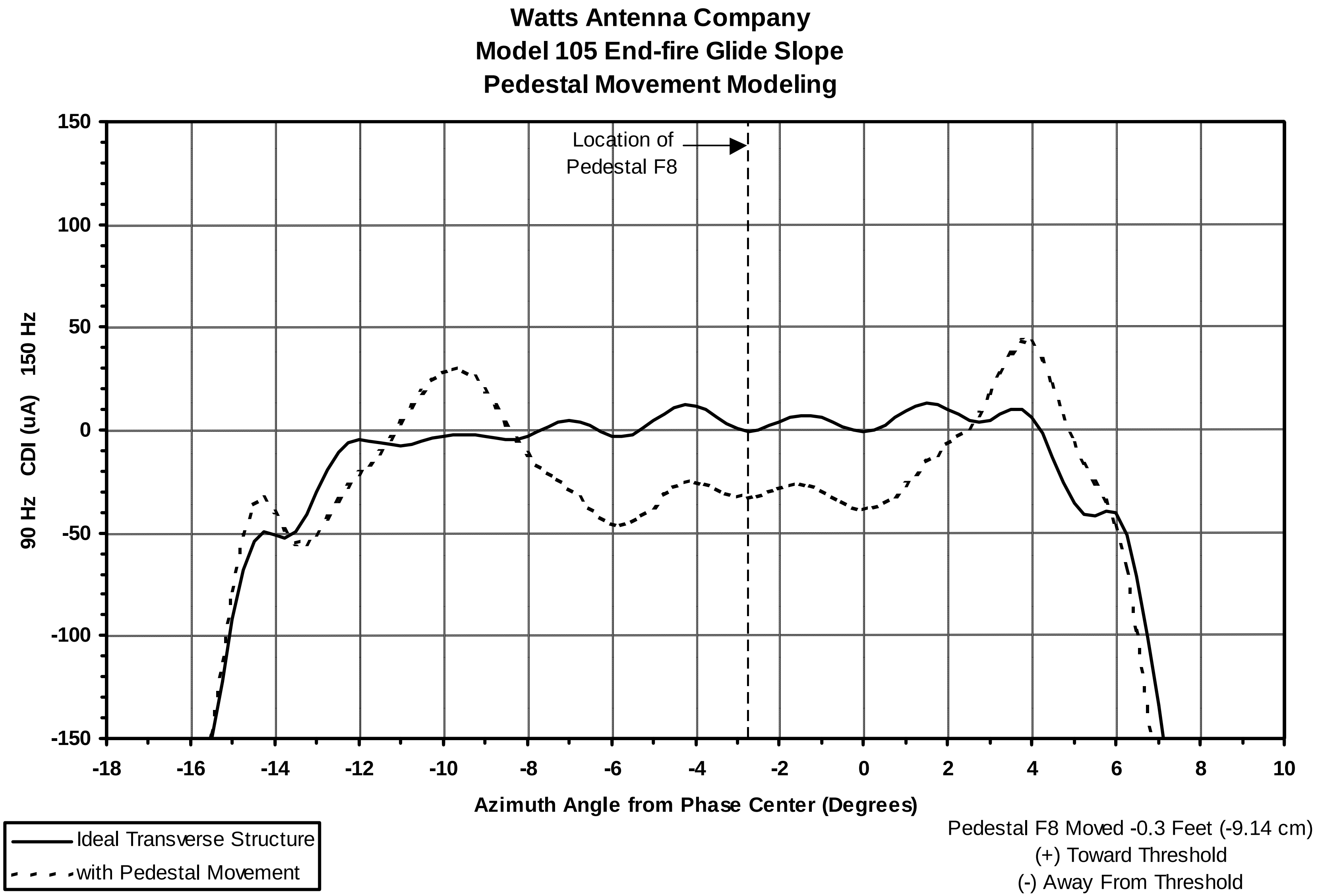


Figure A1-62. Pedestal F8 Moved 0.3 Feet Away From Threshold

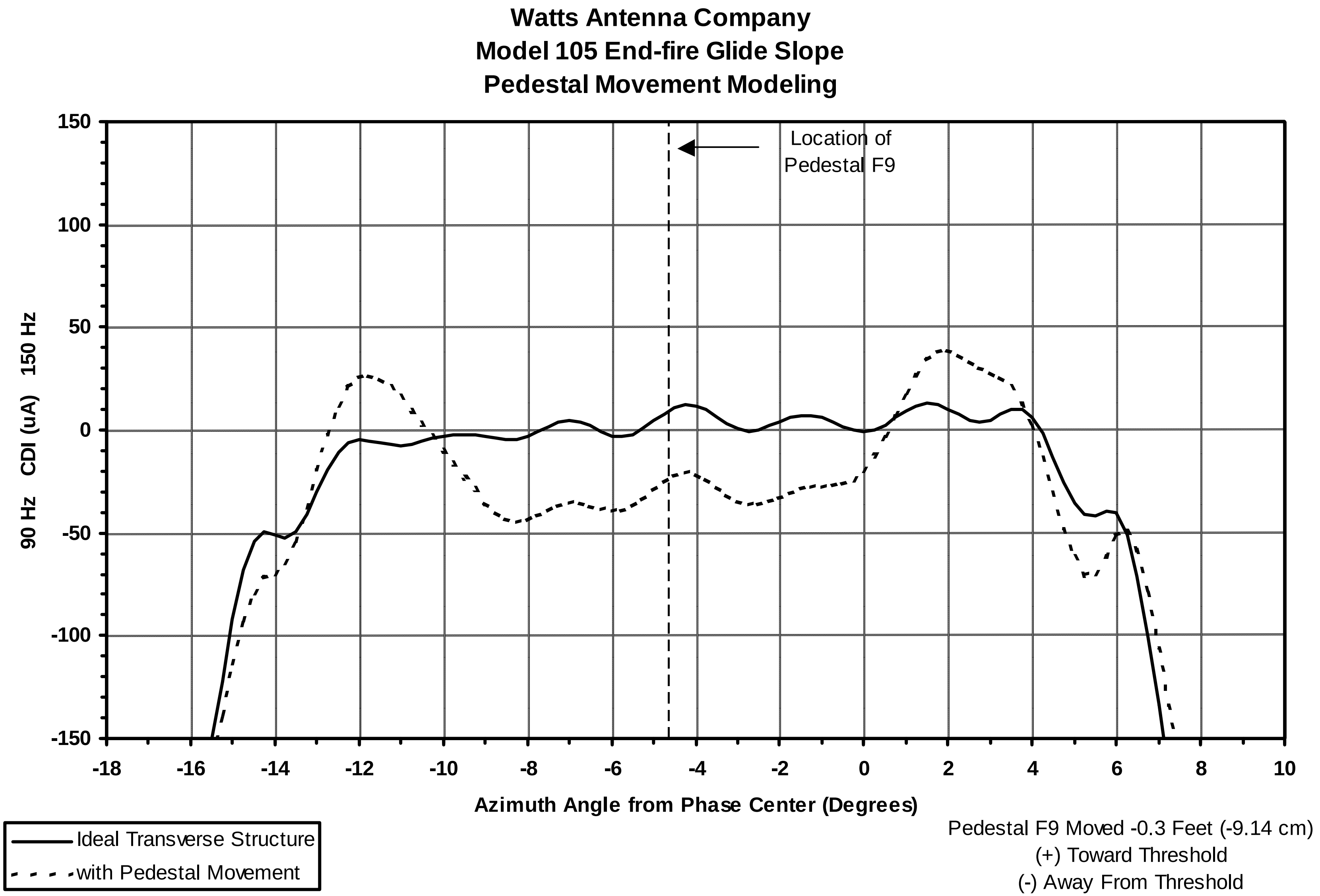


Figure A1-63. Pedestal F9 Moved 0.3 Feet Away From Threshold

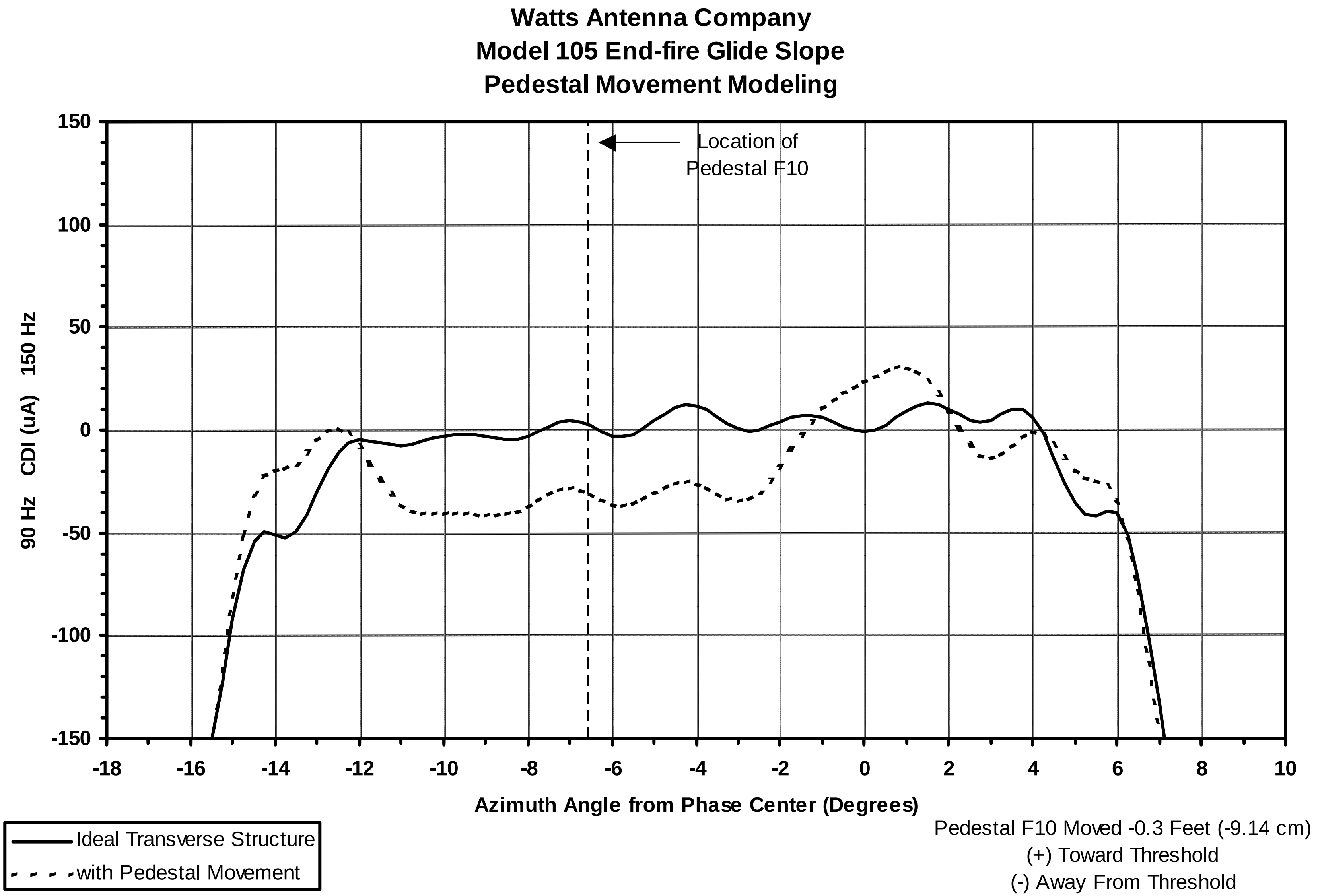


Figure A1-64. Pedestal F10 Moved 0.3 Feet Away From Threshold

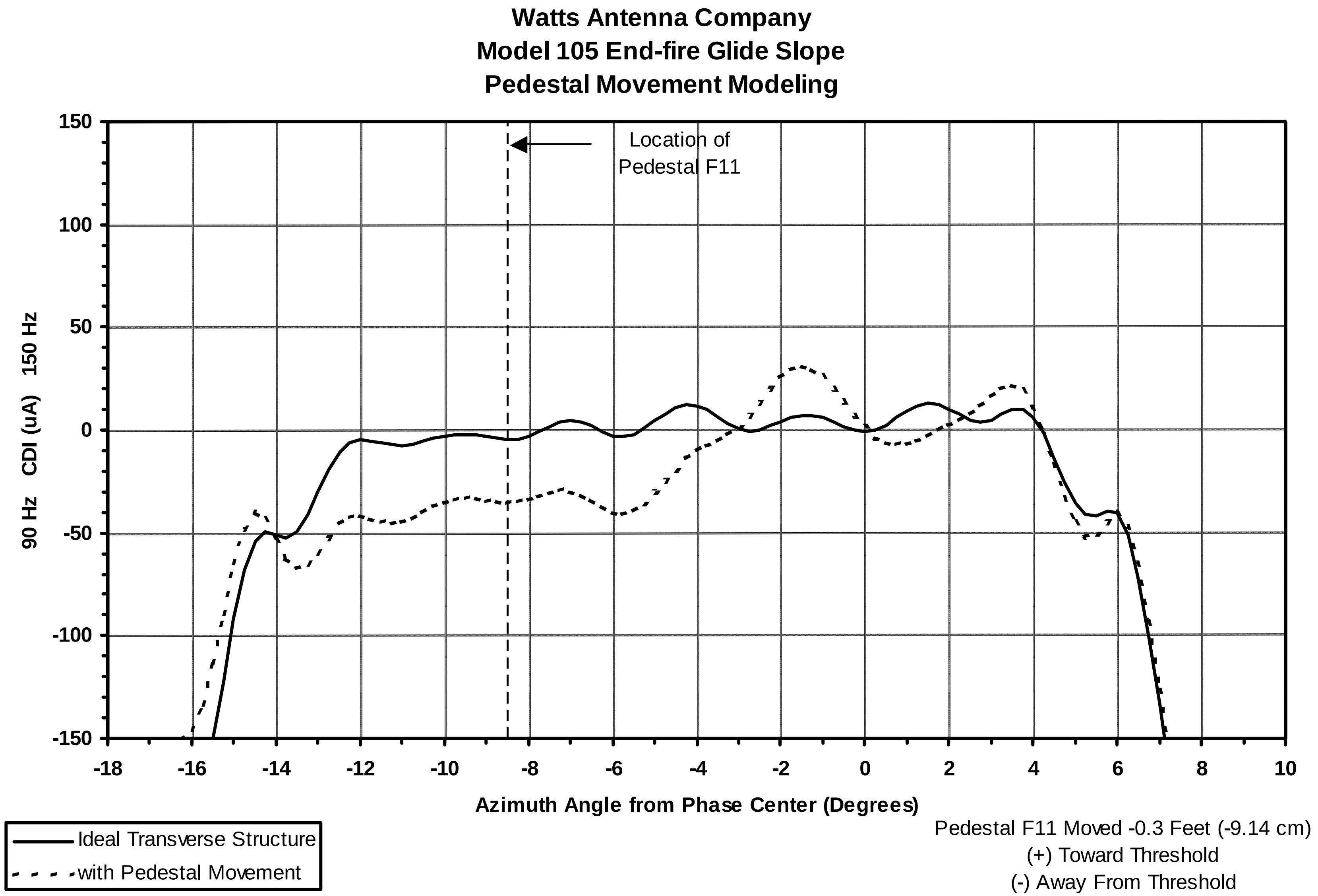


Figure A1-65. Pedestal F11 Moved 0.3 Feet Away From Threshold

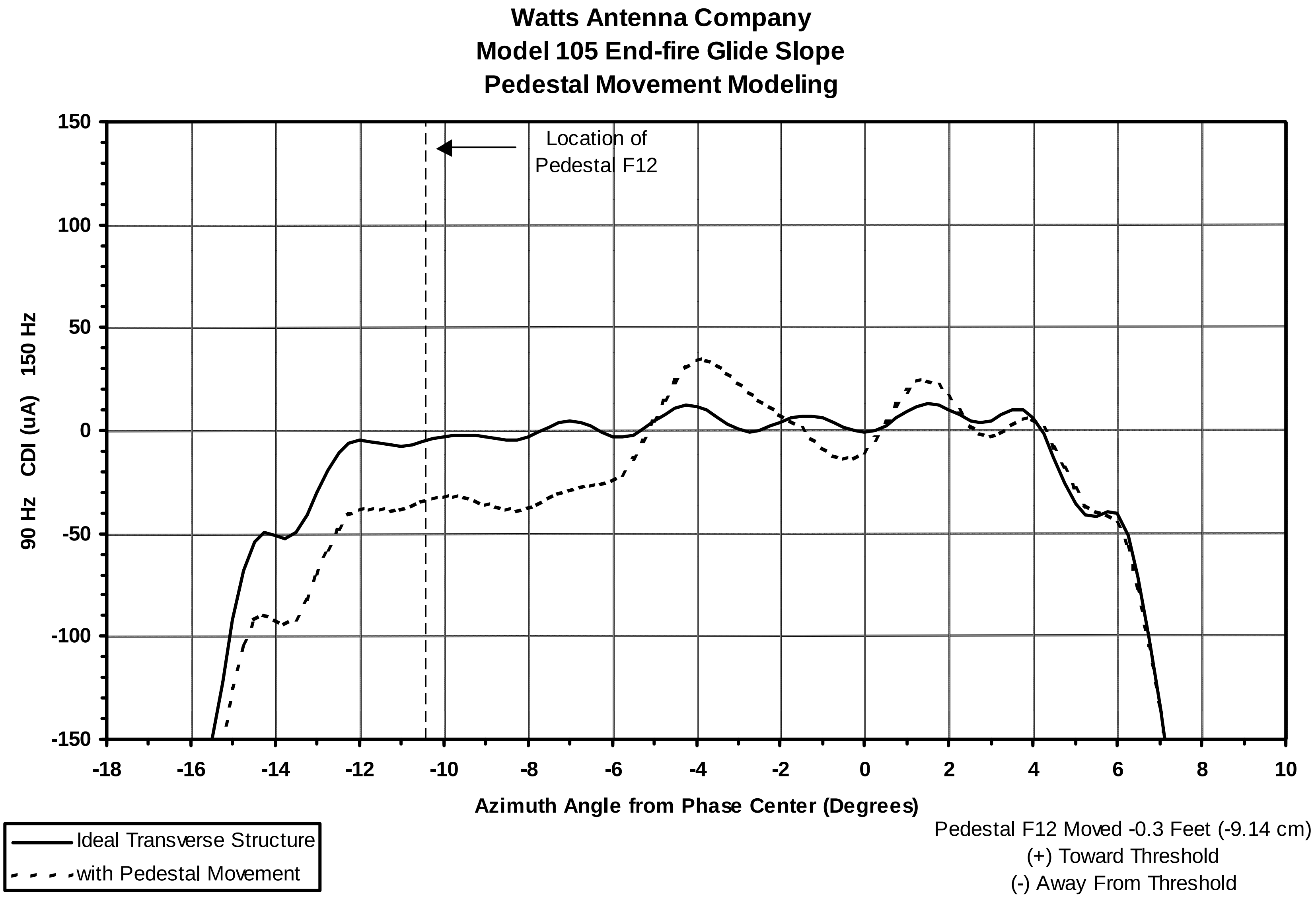


Figure A1-66. Pedestal F12 Moved 0.3 Feet Away From Threshold

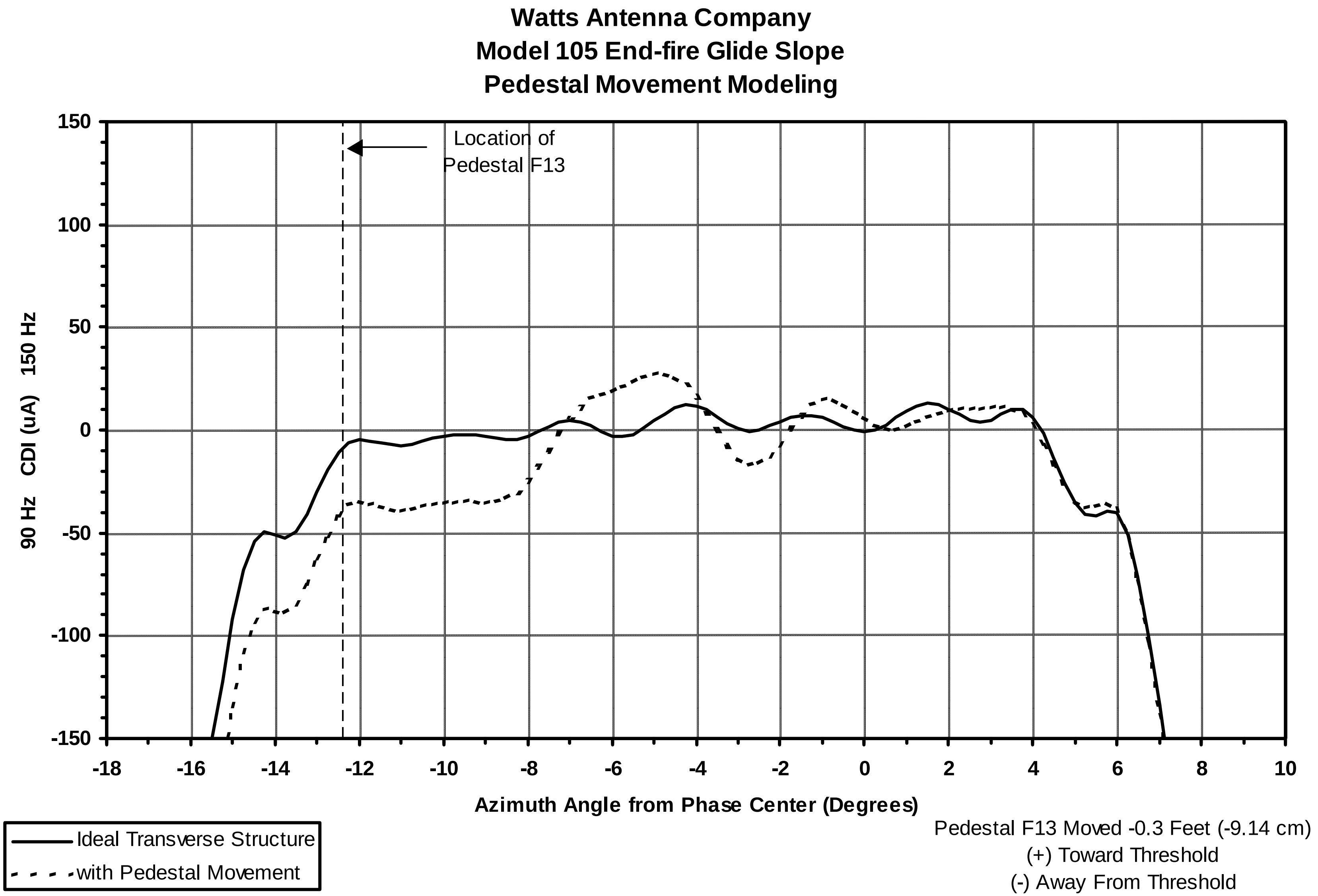


Figure A1-67. Pedestal F13 Moved 0.3 Feet Away From Threshold

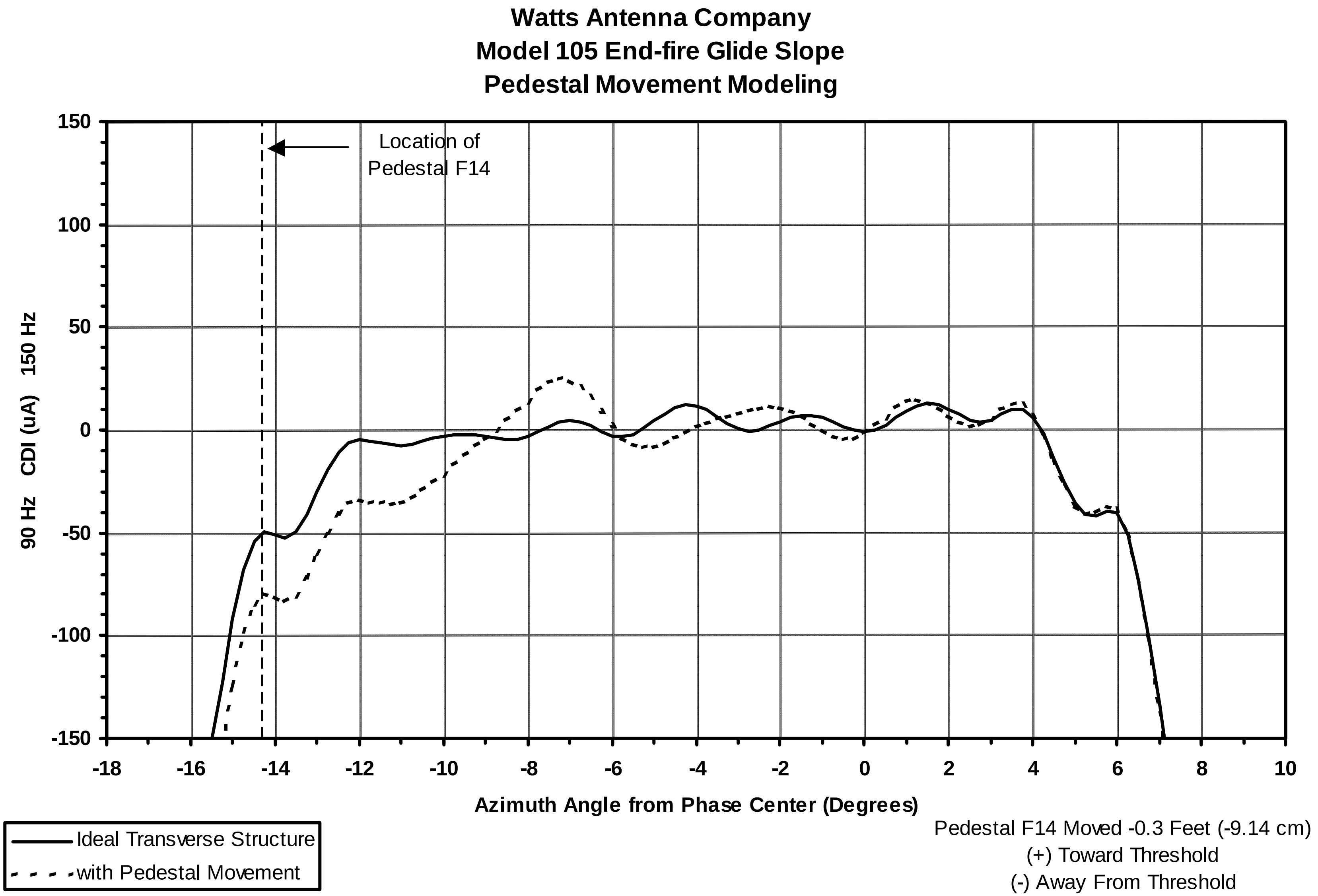


Figure A1-68. Pedestal F14 Moved 0.3 Feet Away From Threshold

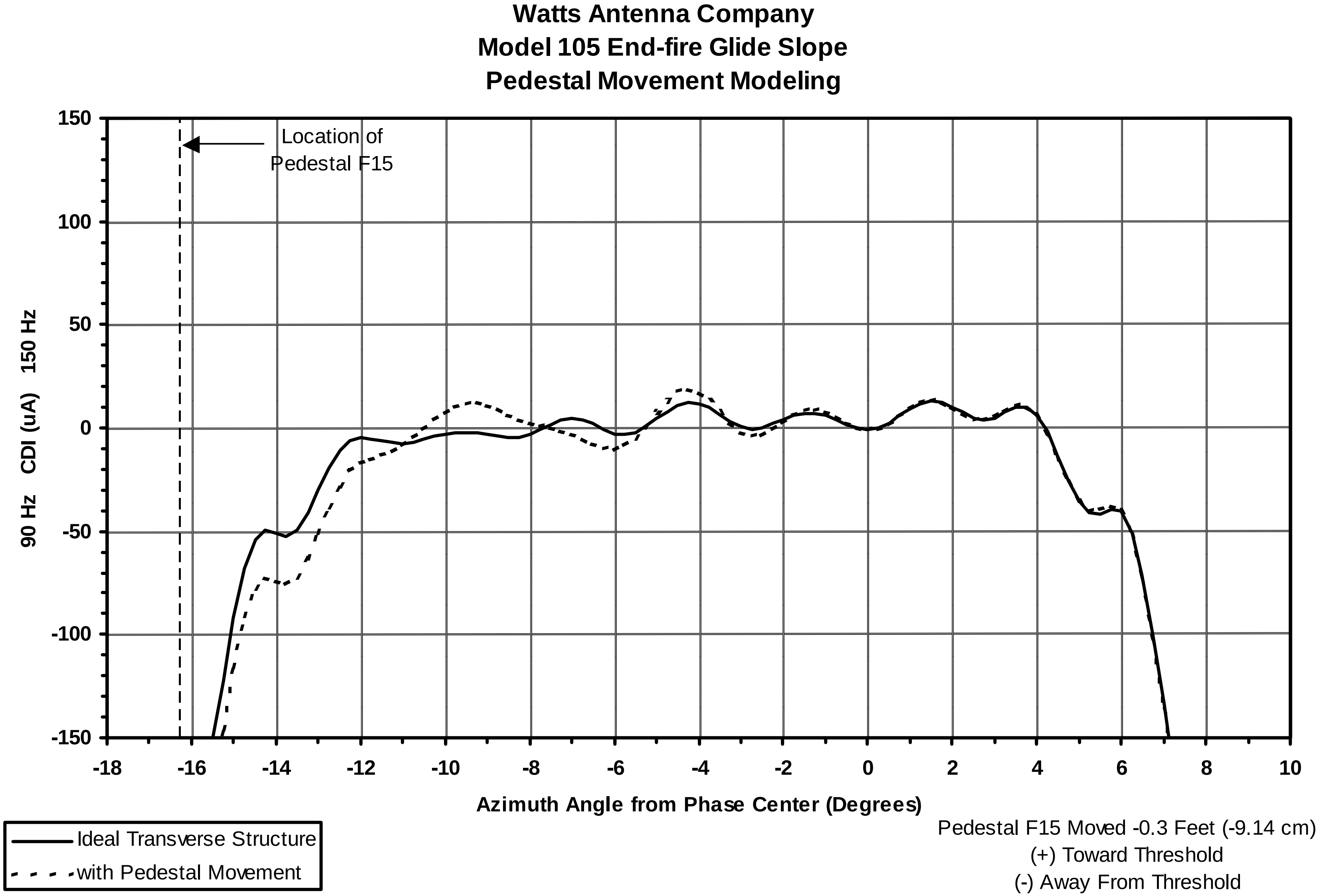


Figure A1-69. Pedestal F15 Moved 0.3 Feet Away From Threshold

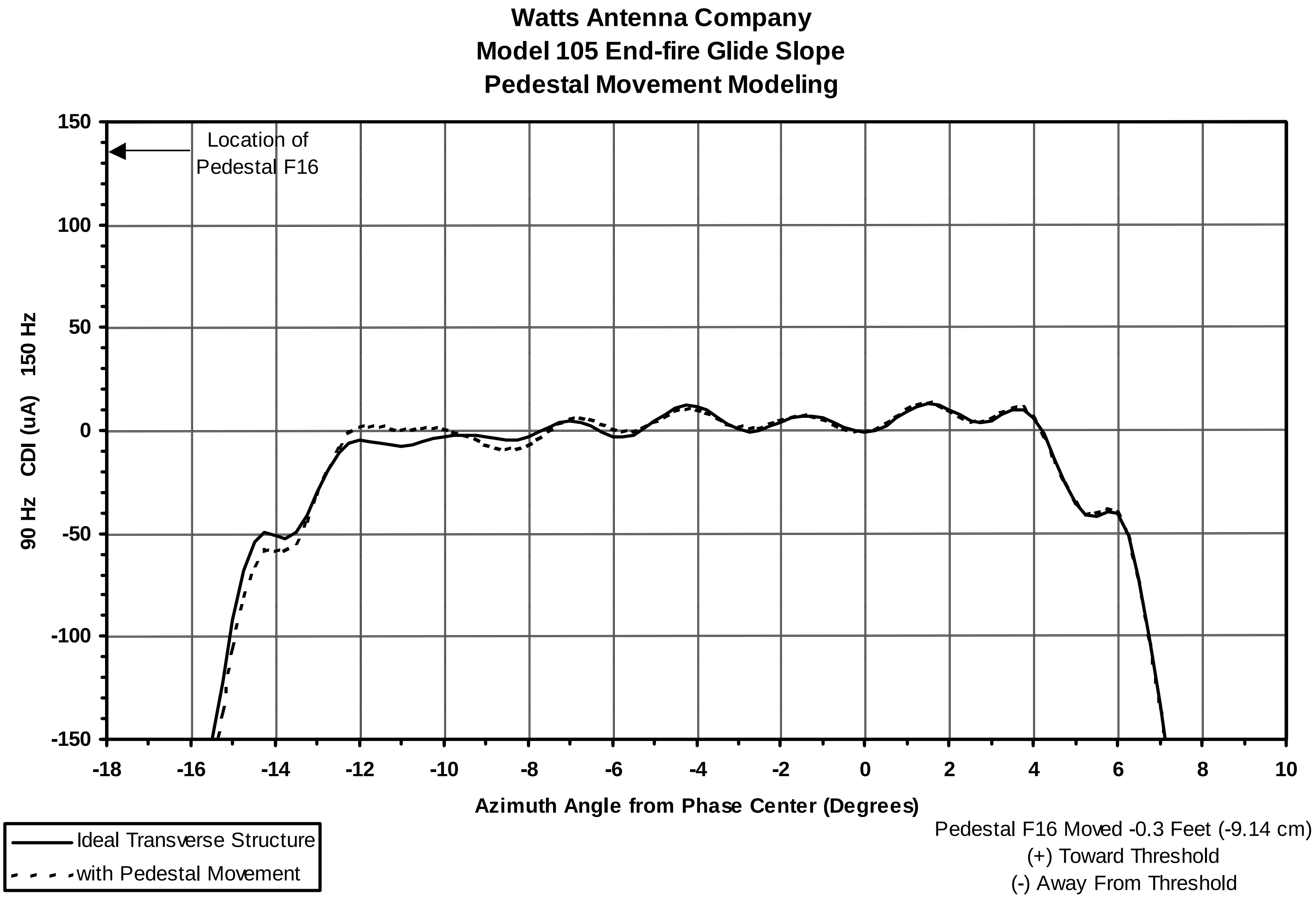


Figure A1-70. Pedestal F16 Moved 0.3 Feet Away From Threshold

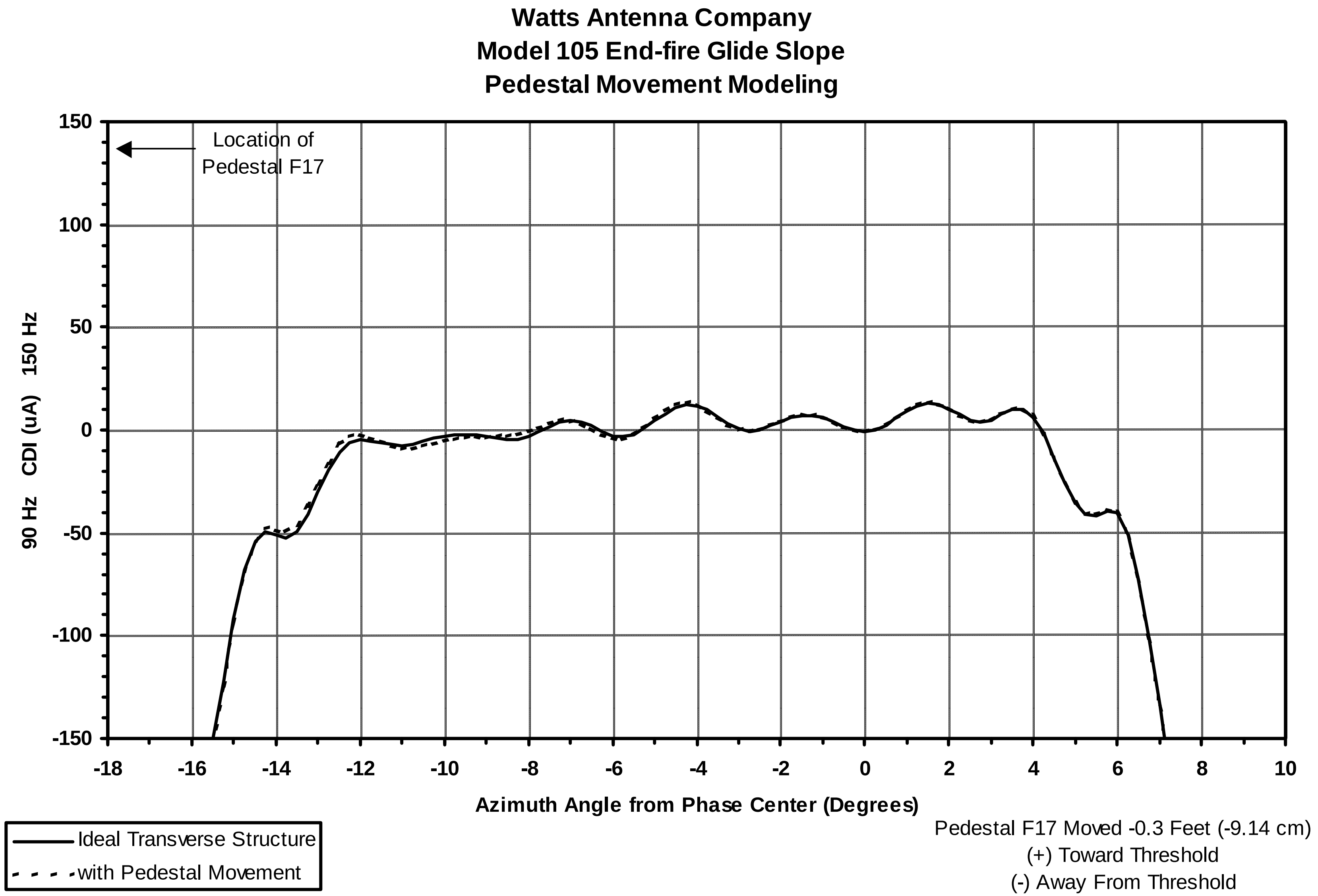


Figure A1-71. Pedestal F17 Moved 0.3 Feet Away From Threshold

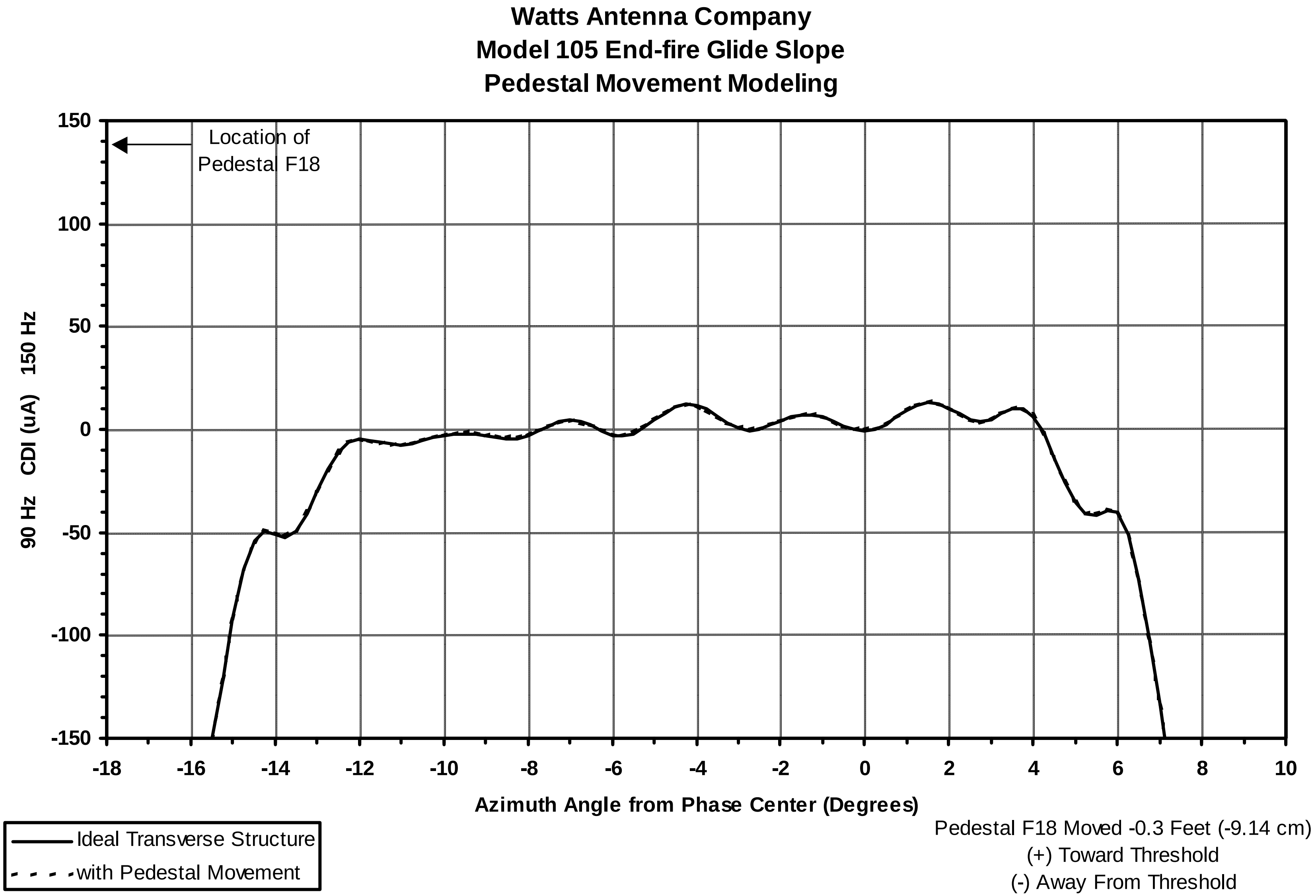


Figure A1-72. Pedestal F18 Moved 0.3 Feet Away From Threshold

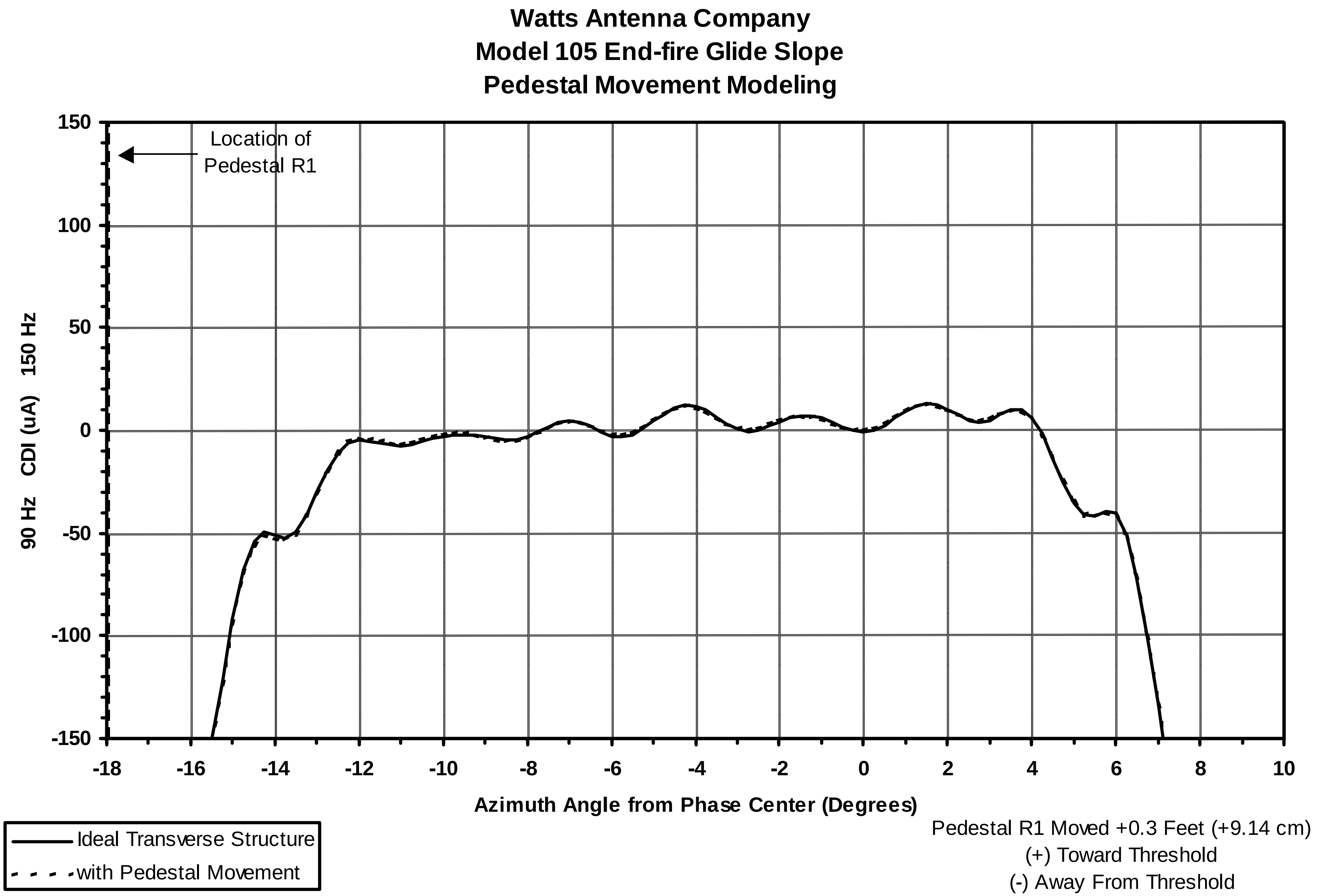


Figure A1-73. Pedestal R1 Moved 0.3 Feet Toward Threshold

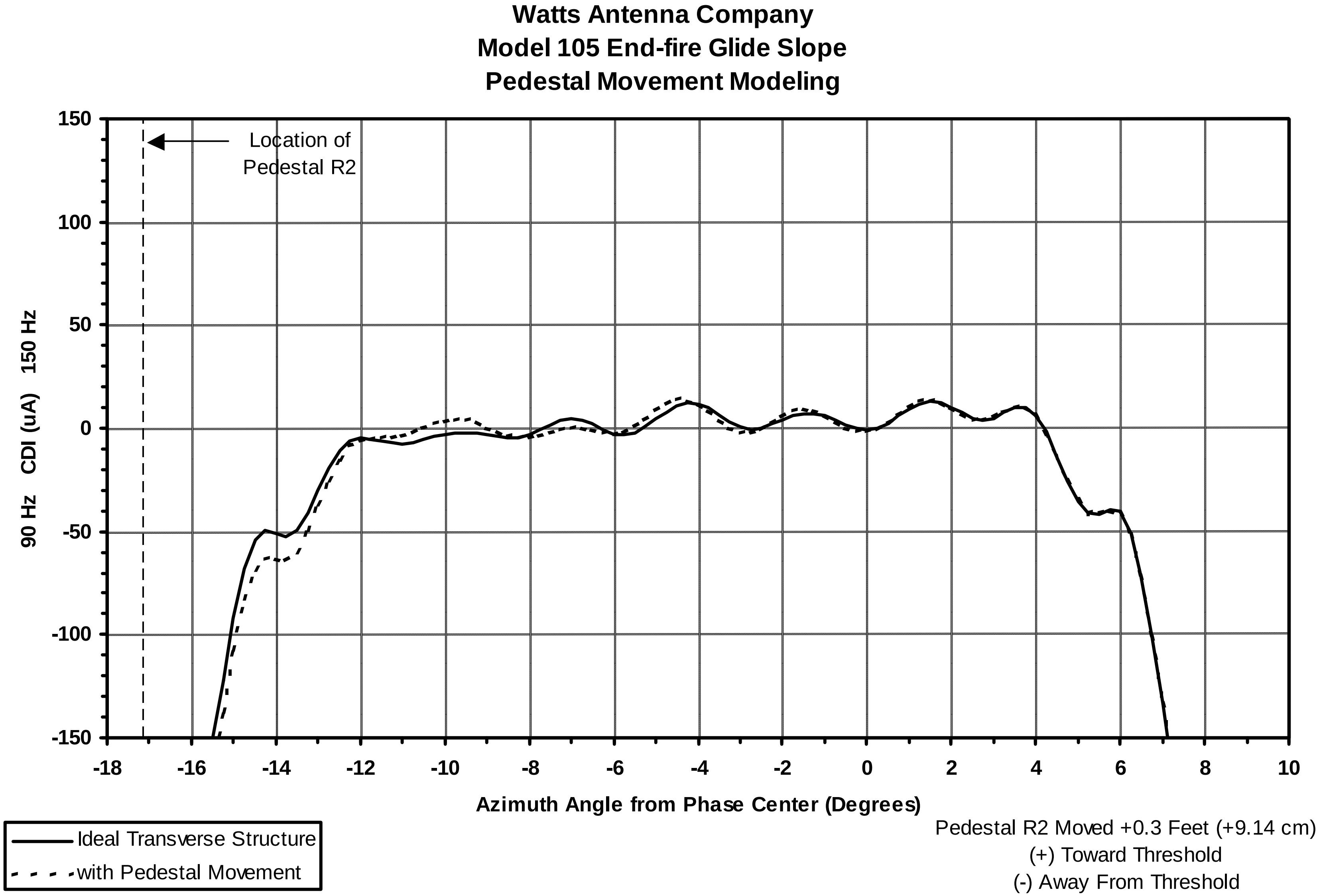


Figure A1-74. Pedestal R2 Moved 0.3 Feet Toward Threshold

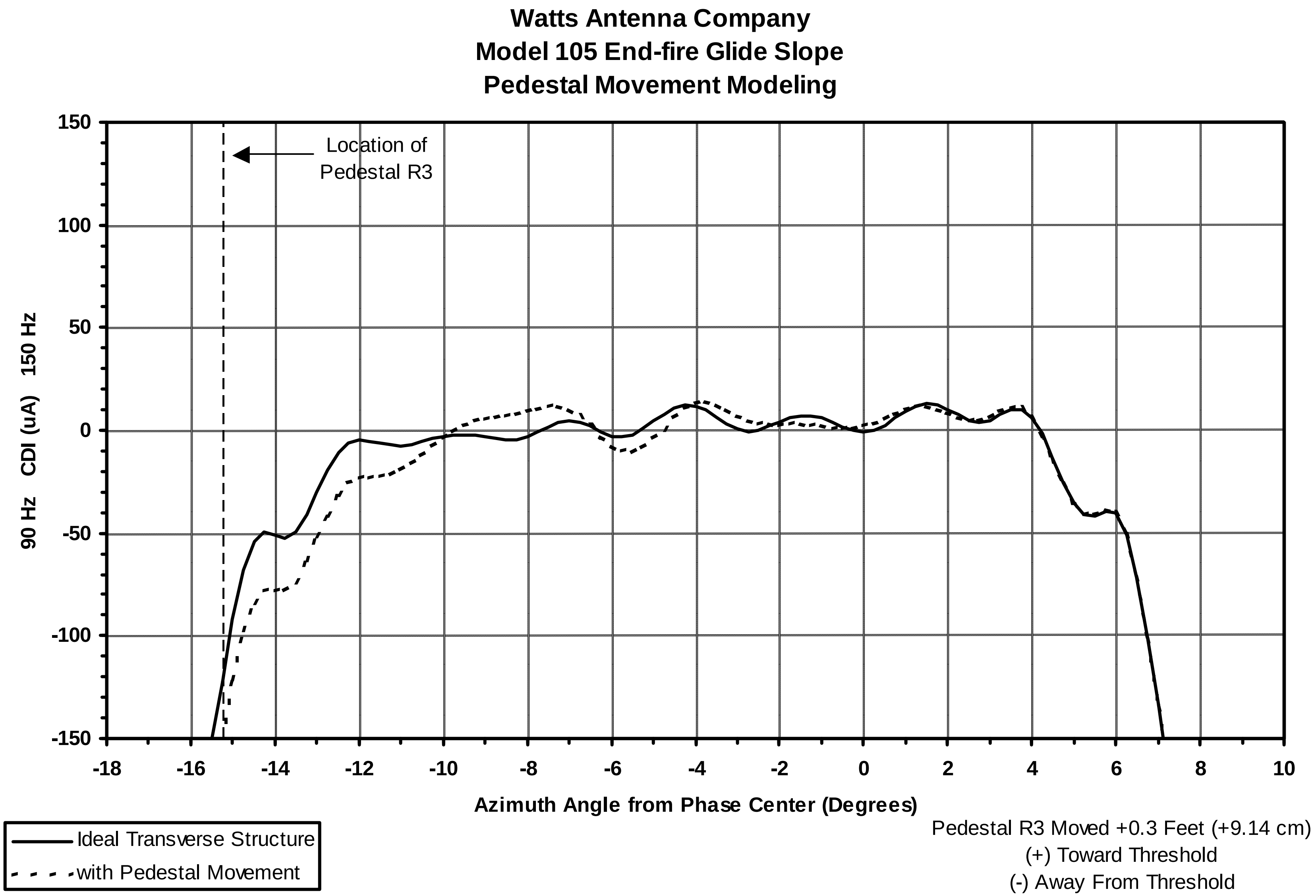


Figure A1-75. Pedestal R3 Moved 0.3 Feet Toward Threshold

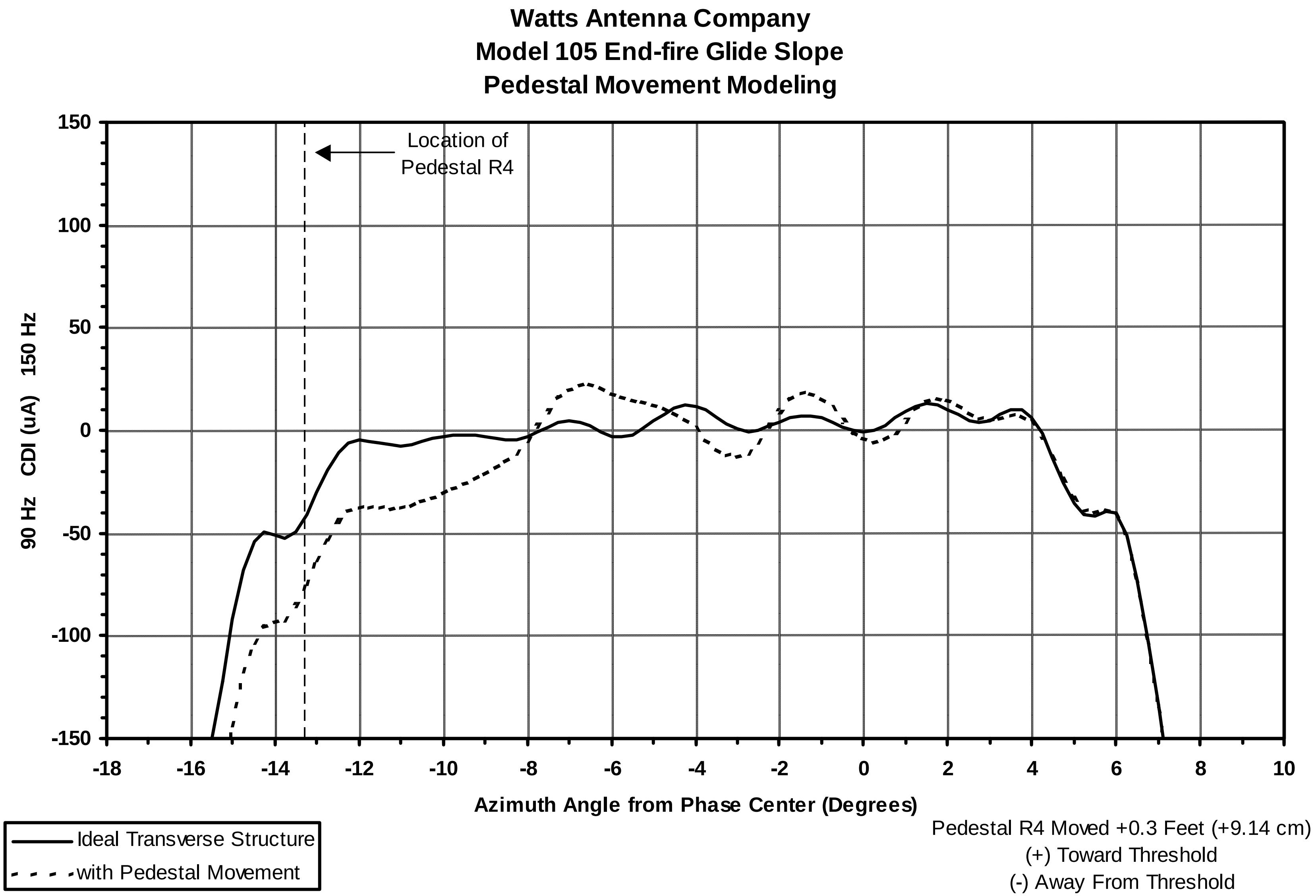


Figure A1-76. Pedestal R4 Moved 0.3 Feet Toward Threshold

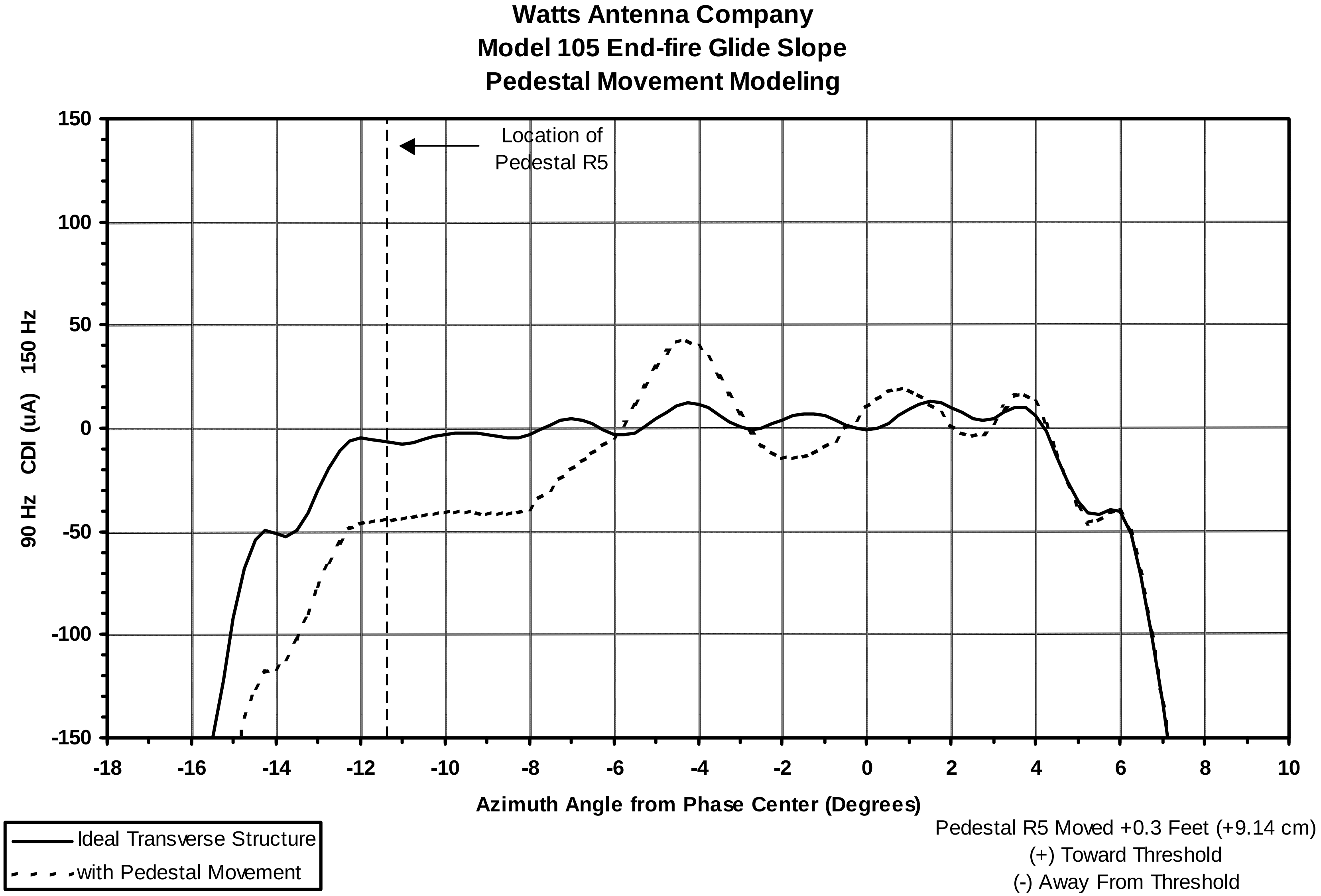


Figure A1-77. Pedestal R5 Moved 0.3 Feet Toward Threshold

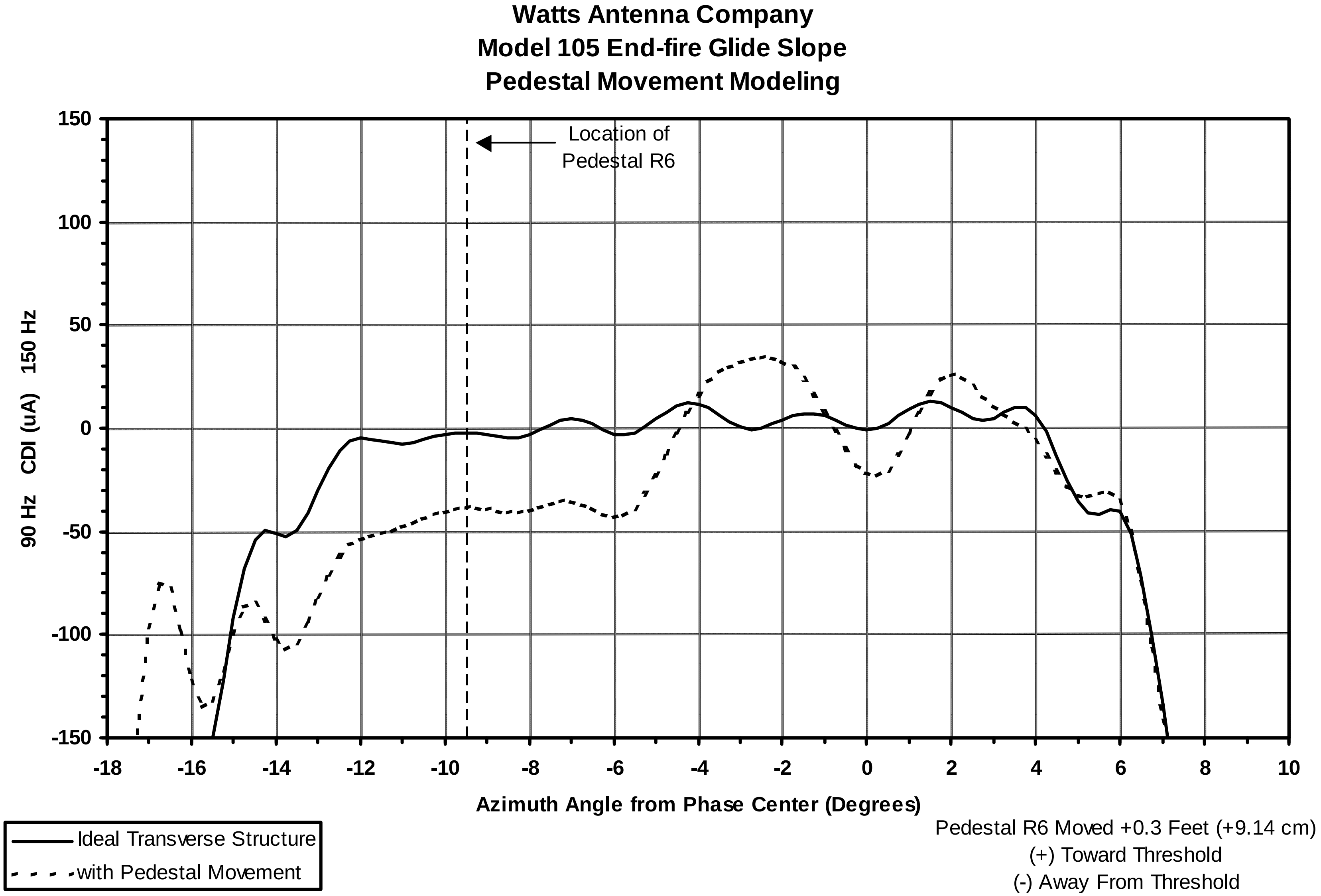
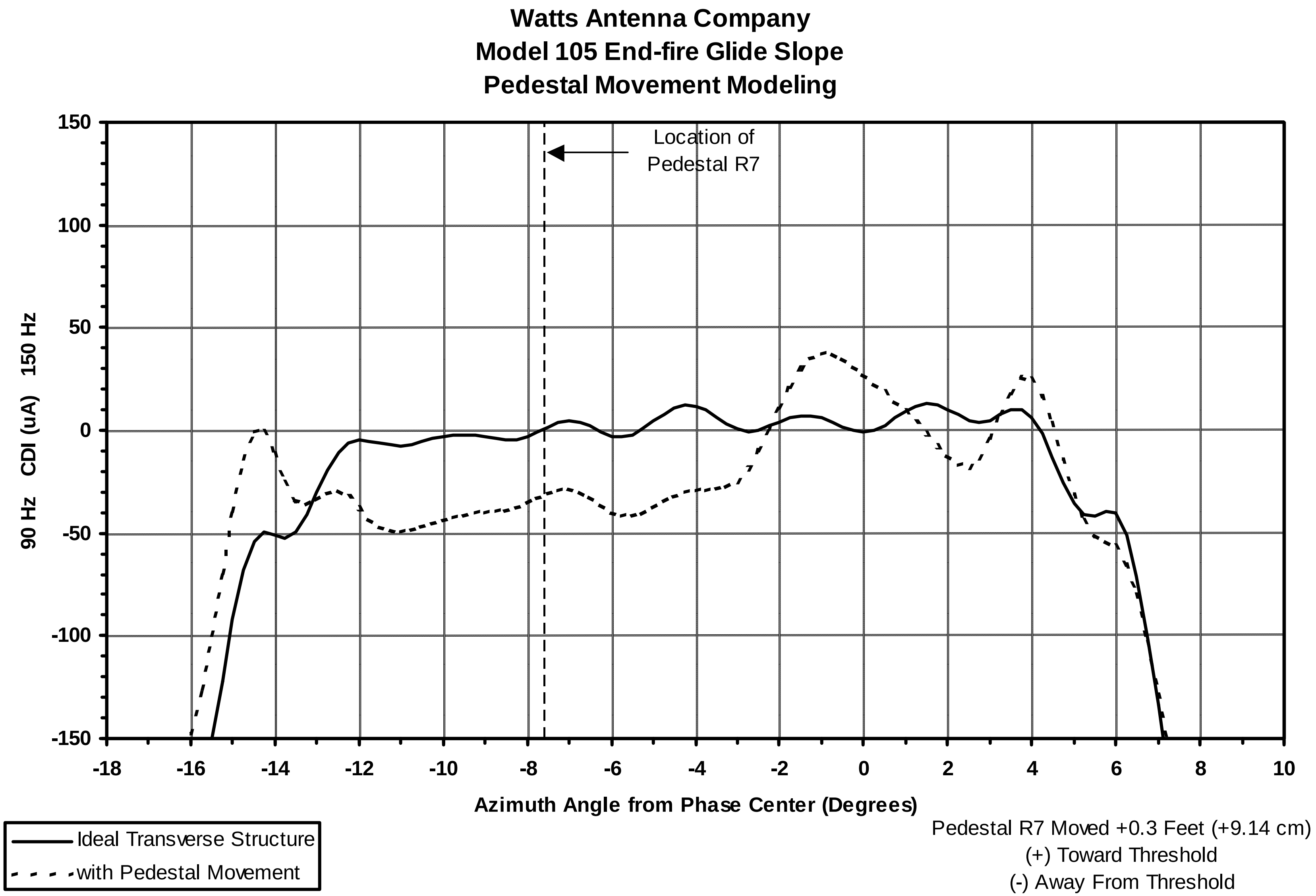


Figure A1-78. Pedestal R6 Moved 0.3 Feet Toward Threshold



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Pedestal R7 Moved +0.3 Feet (+9.14 cm)
(+) Toward Threshold
(-) Away From Threshold

Figure A1-79. Pedestal R7 Moved 0.3 Feet Toward Threshold

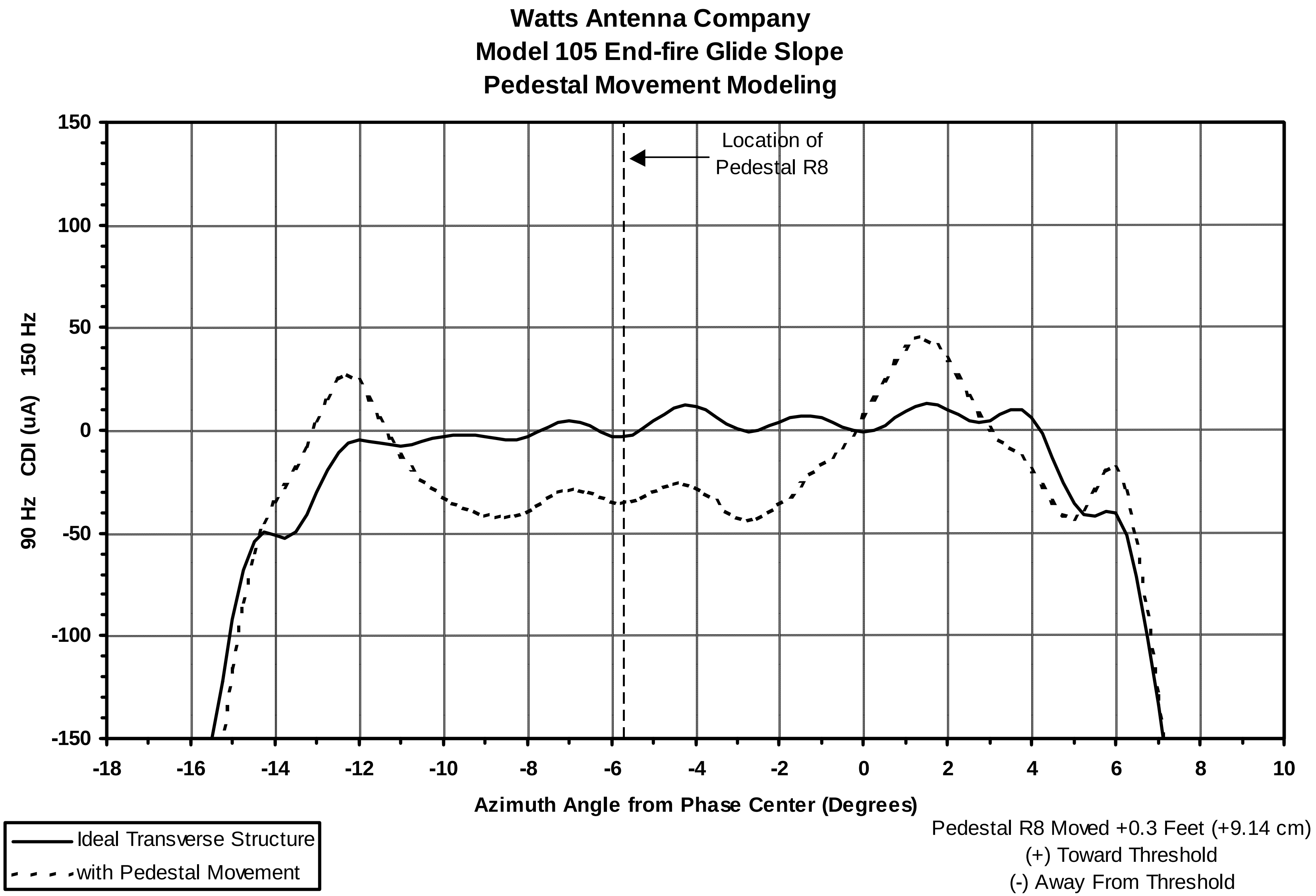

Figure A1-80. Pedestal R8 Moved 0.3 Feet Toward Threshold

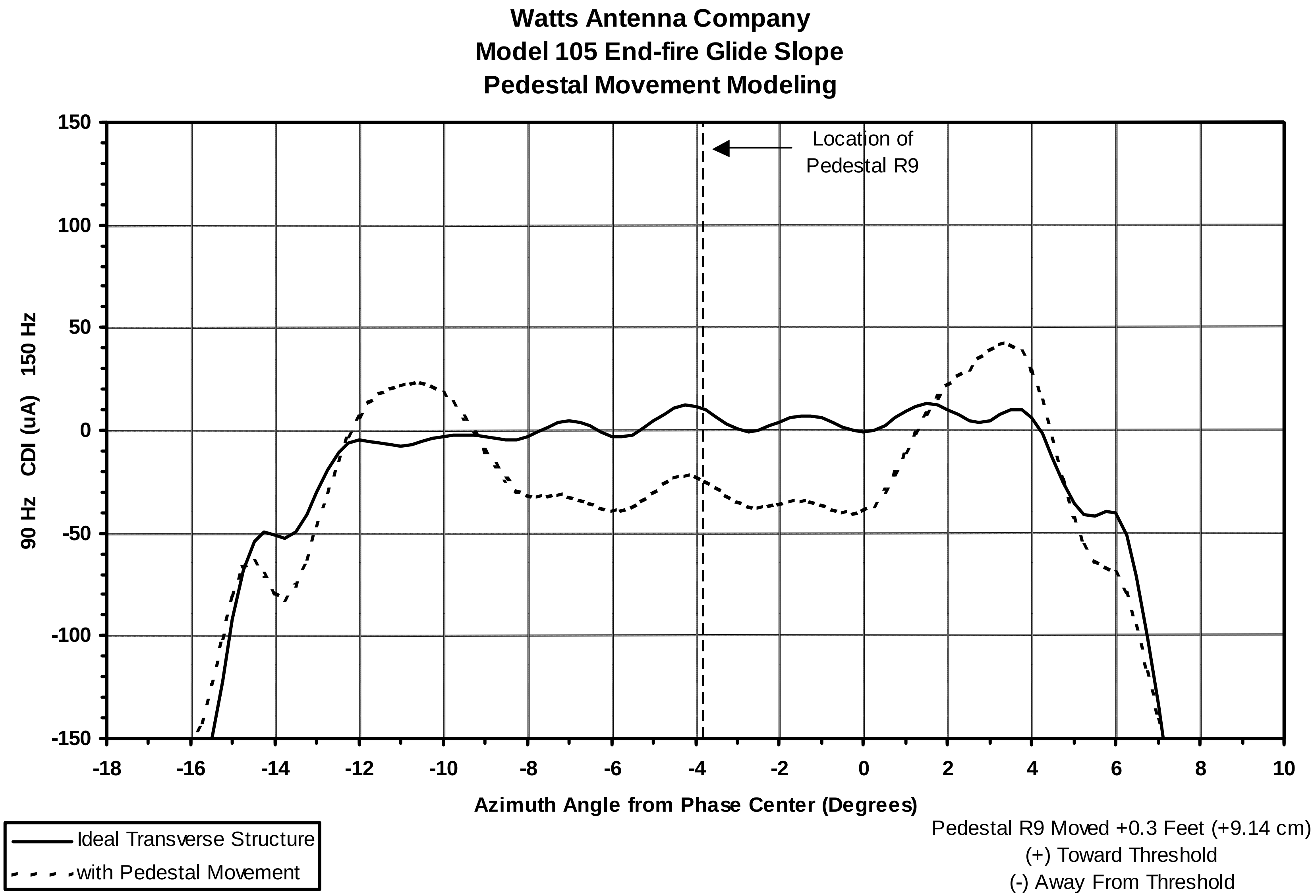

Figure A1-81. Pedestal R9 Moved 0.3 Feet Toward Threshold

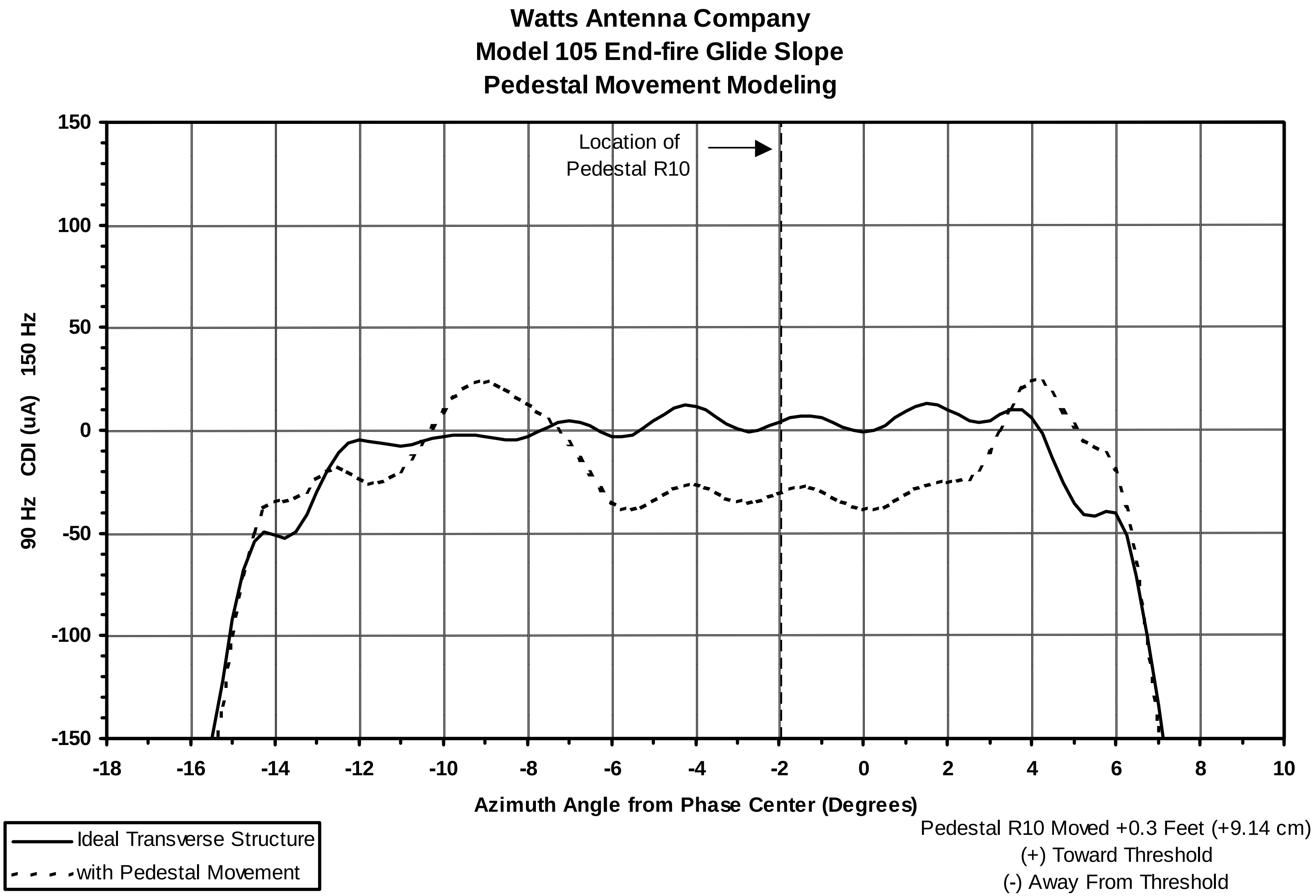

Figure A1-82. Pedestal R10 Moved 0.3 Feet Toward Threshold

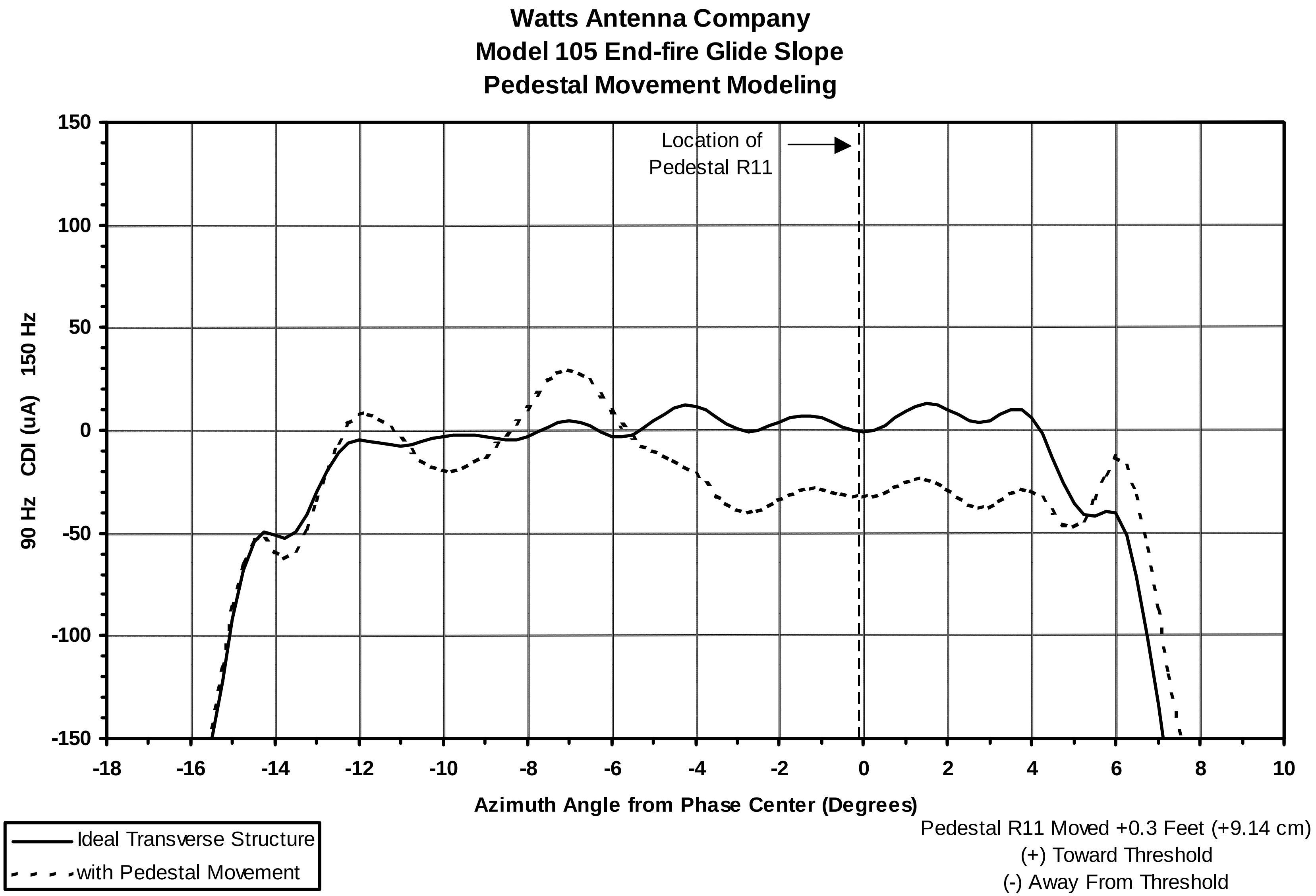

Figure A1-83. Pedestal R11 Moved 0.3 Feet Toward Threshold

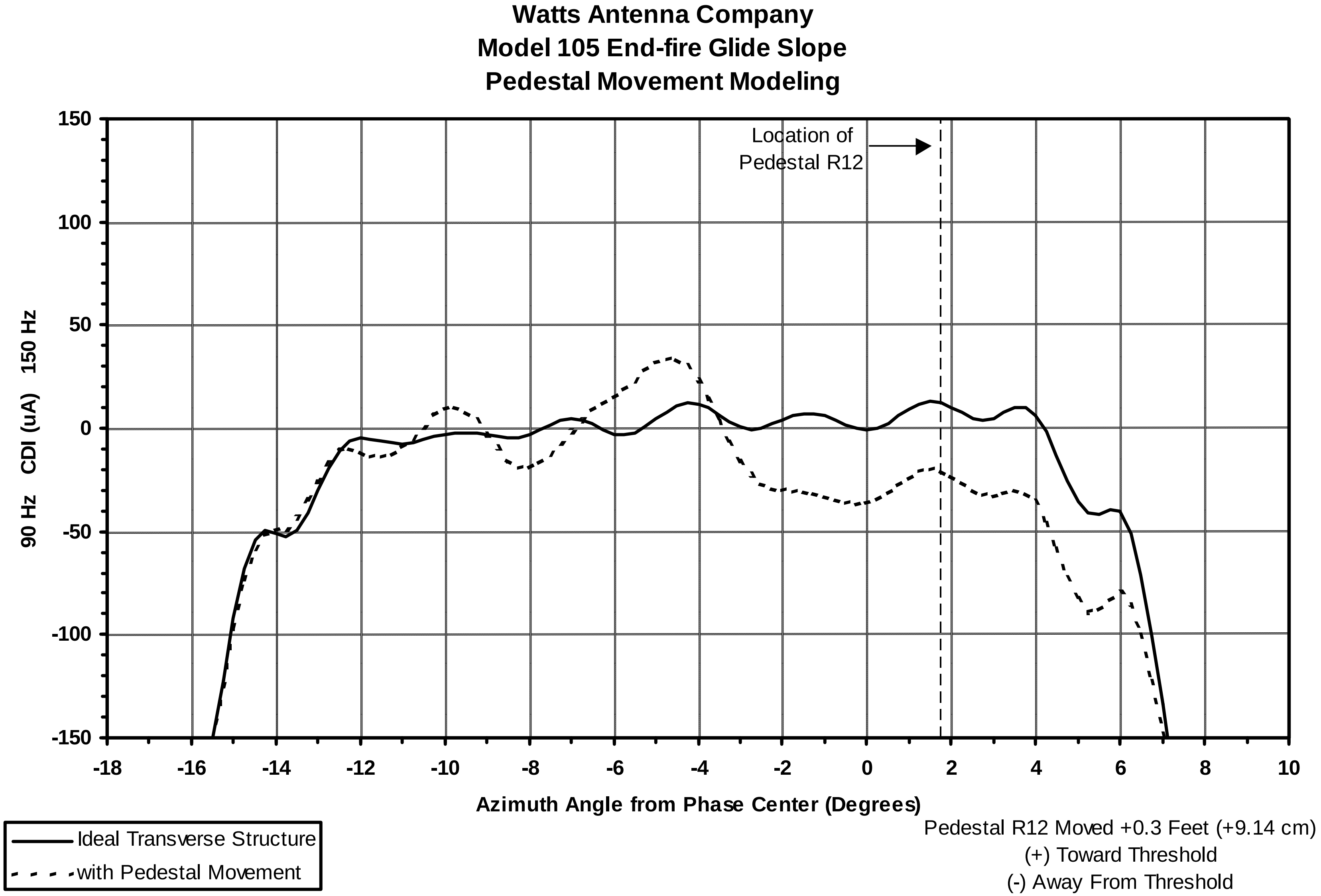

Figure A1-84. Pedestal R12 Moved 0.3 Feet Toward Threshold

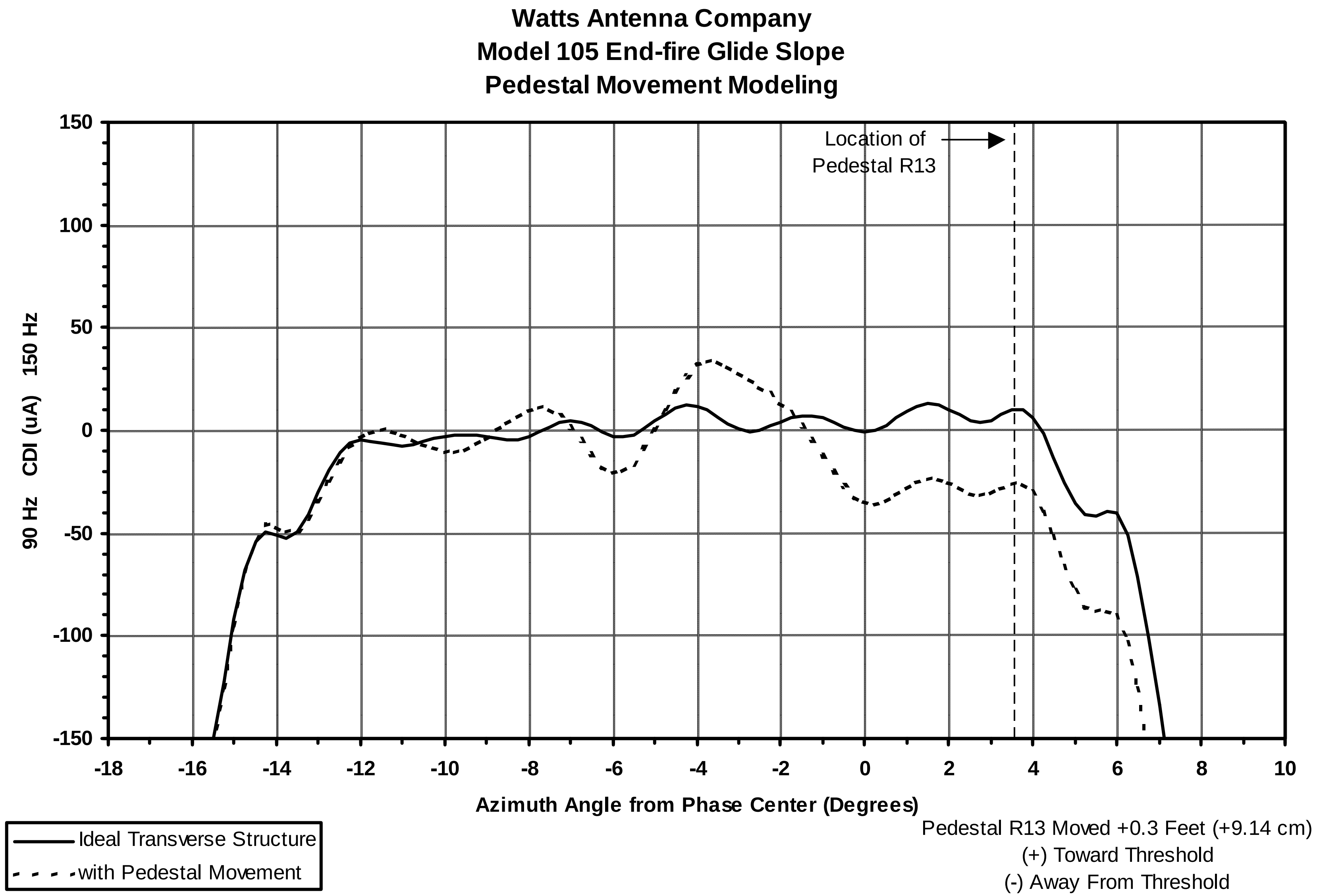

Figure A1-85. Pedestal R13 Moved 0.3 Feet Toward Threshold

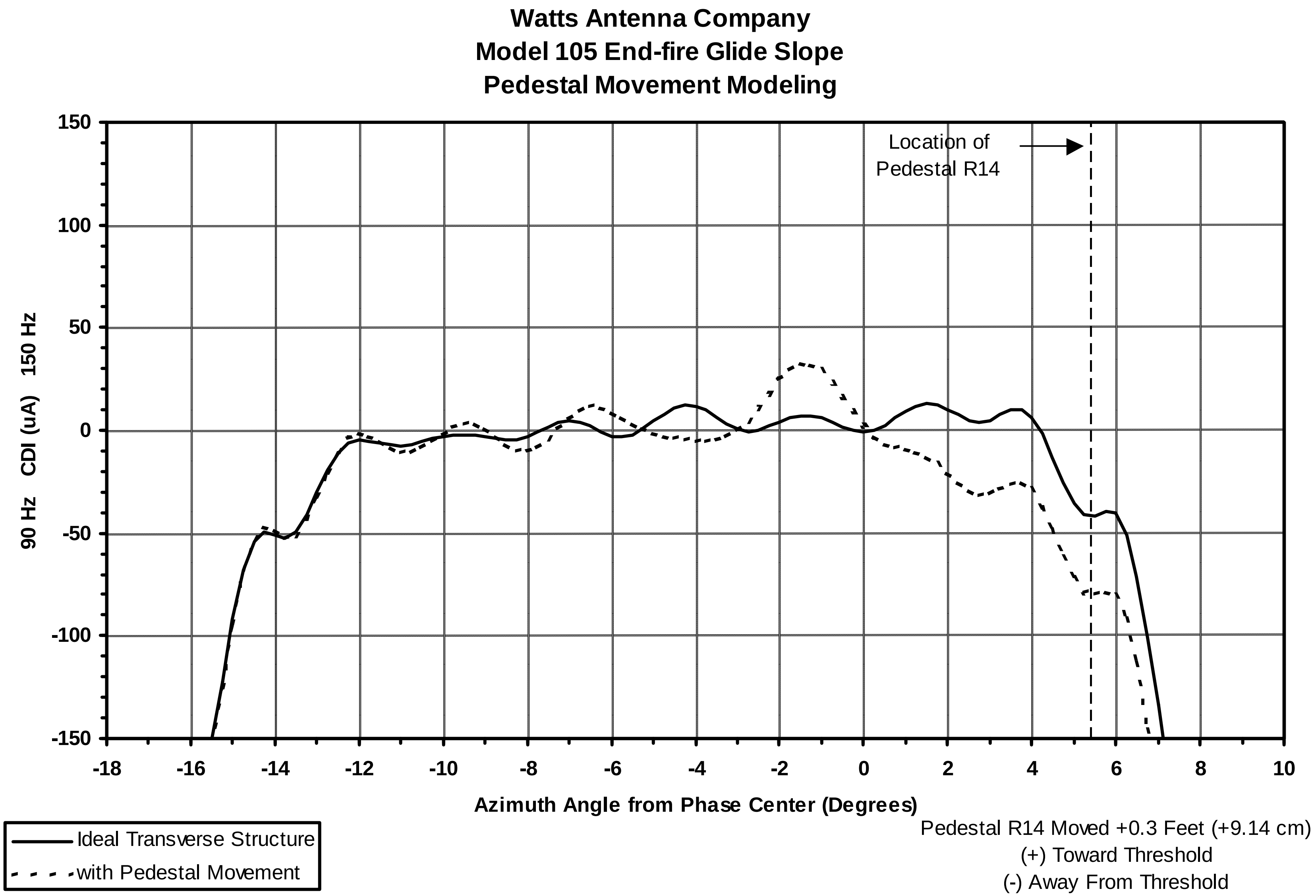

Figure A1-86. Pedestal R14 Moved 0.3 Feet Toward Threshold

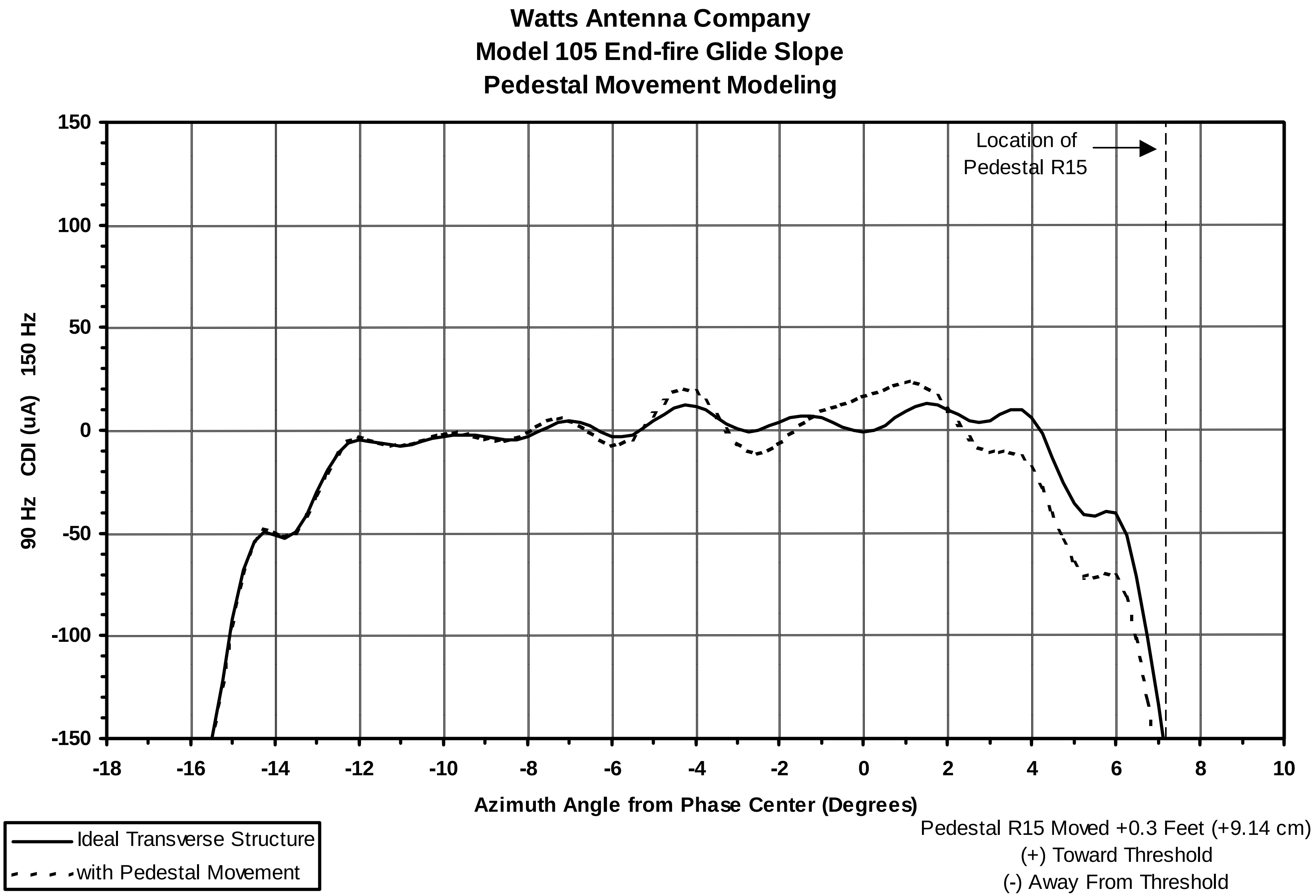

Figure A1-87. Pedestal R15 Moved 0.3 Feet Toward Threshold

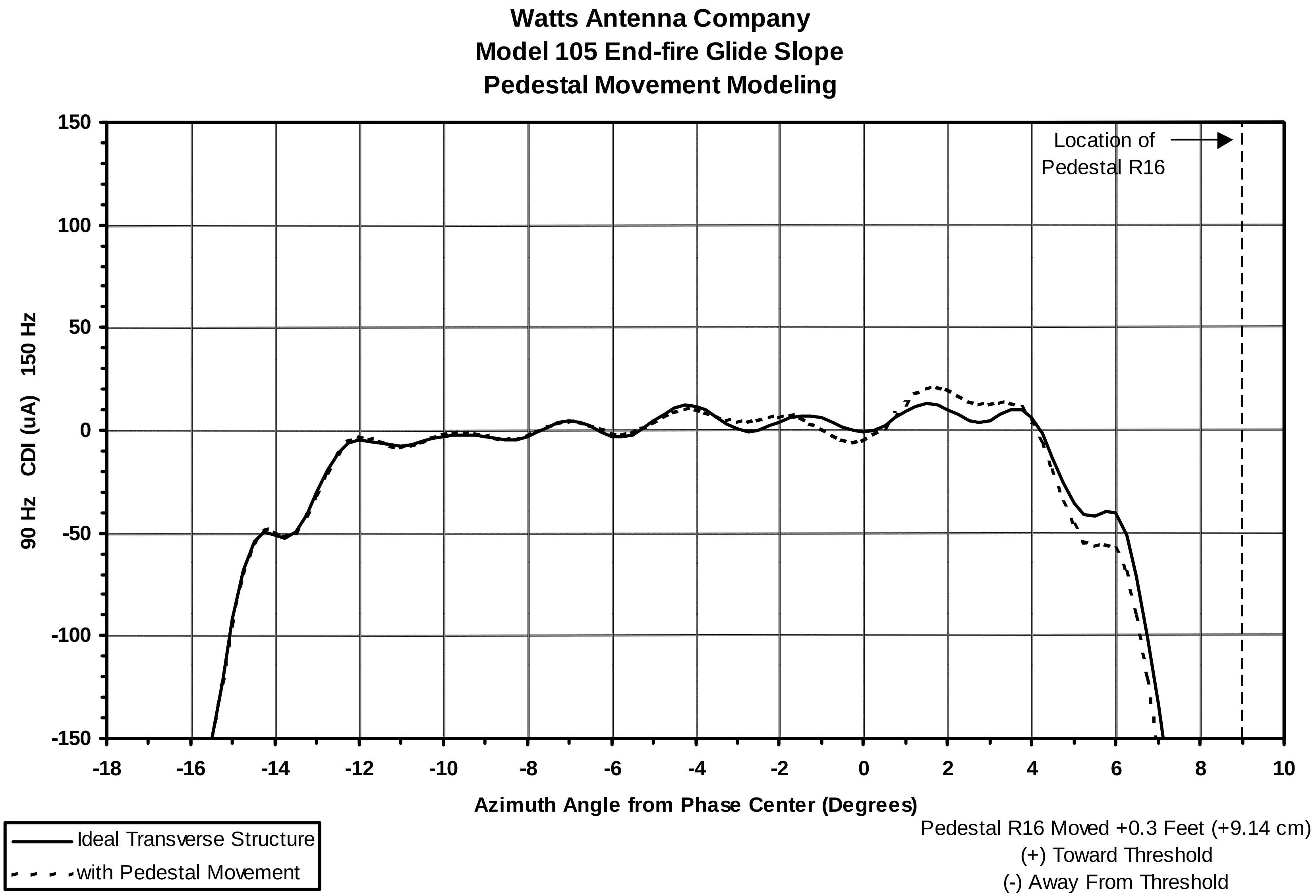

Figure A1-88. Pedestal R16 Moved 0.3 Feet Toward Threshold

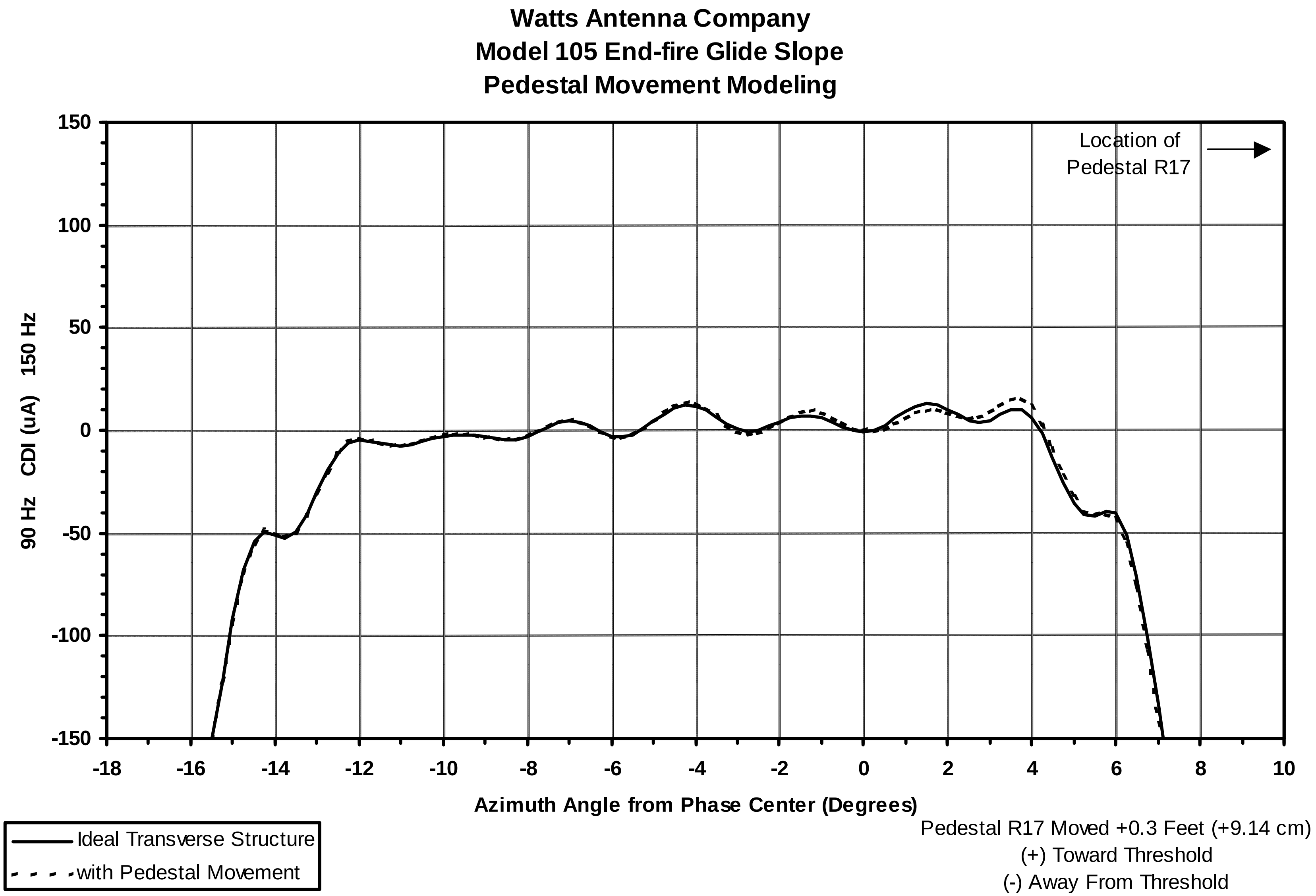

Figure A1-89. Pedestal R17 Moved 0.3 Feet Toward Threshold

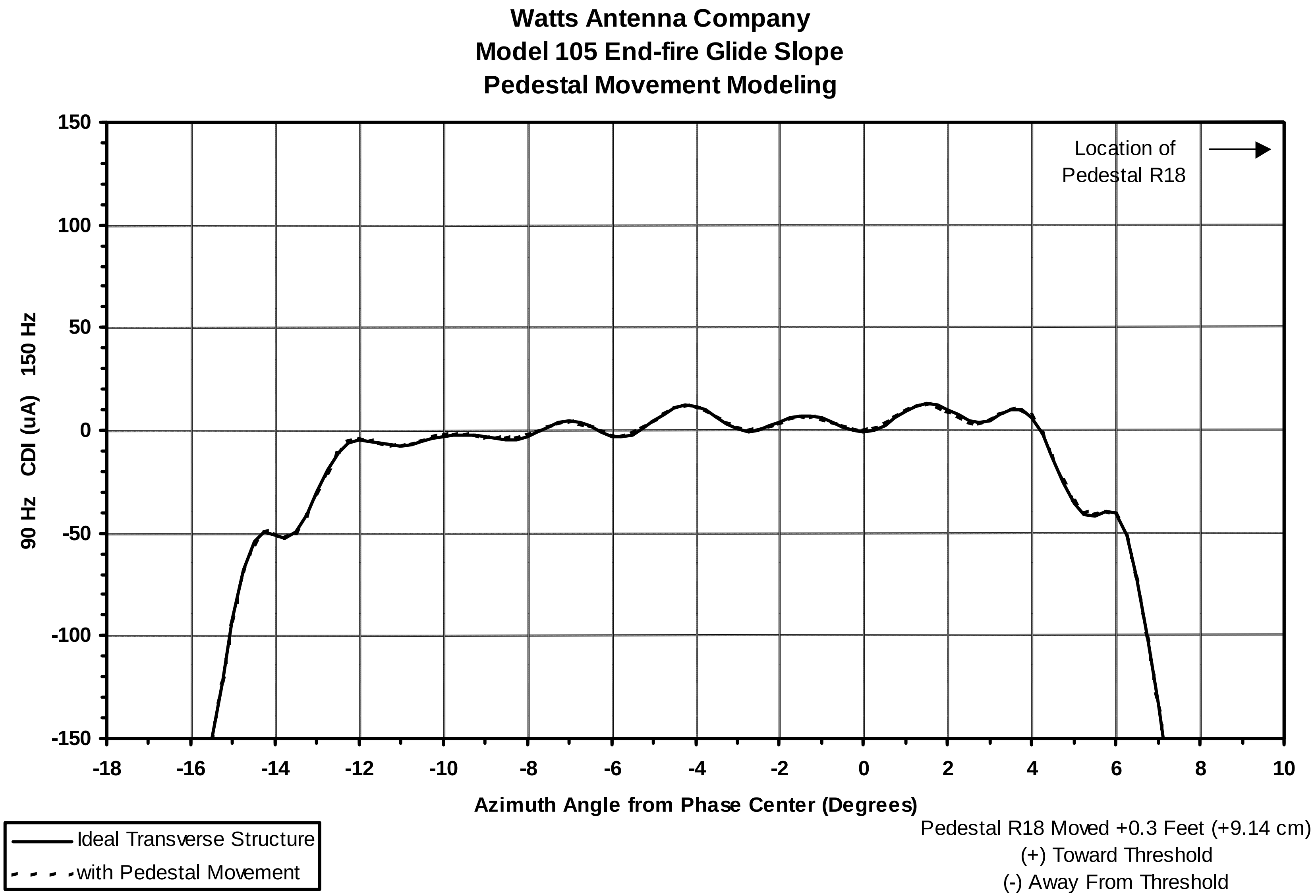

Figure A1-90. Pedestal R18 Moved 0.3 Feet Toward Threshold

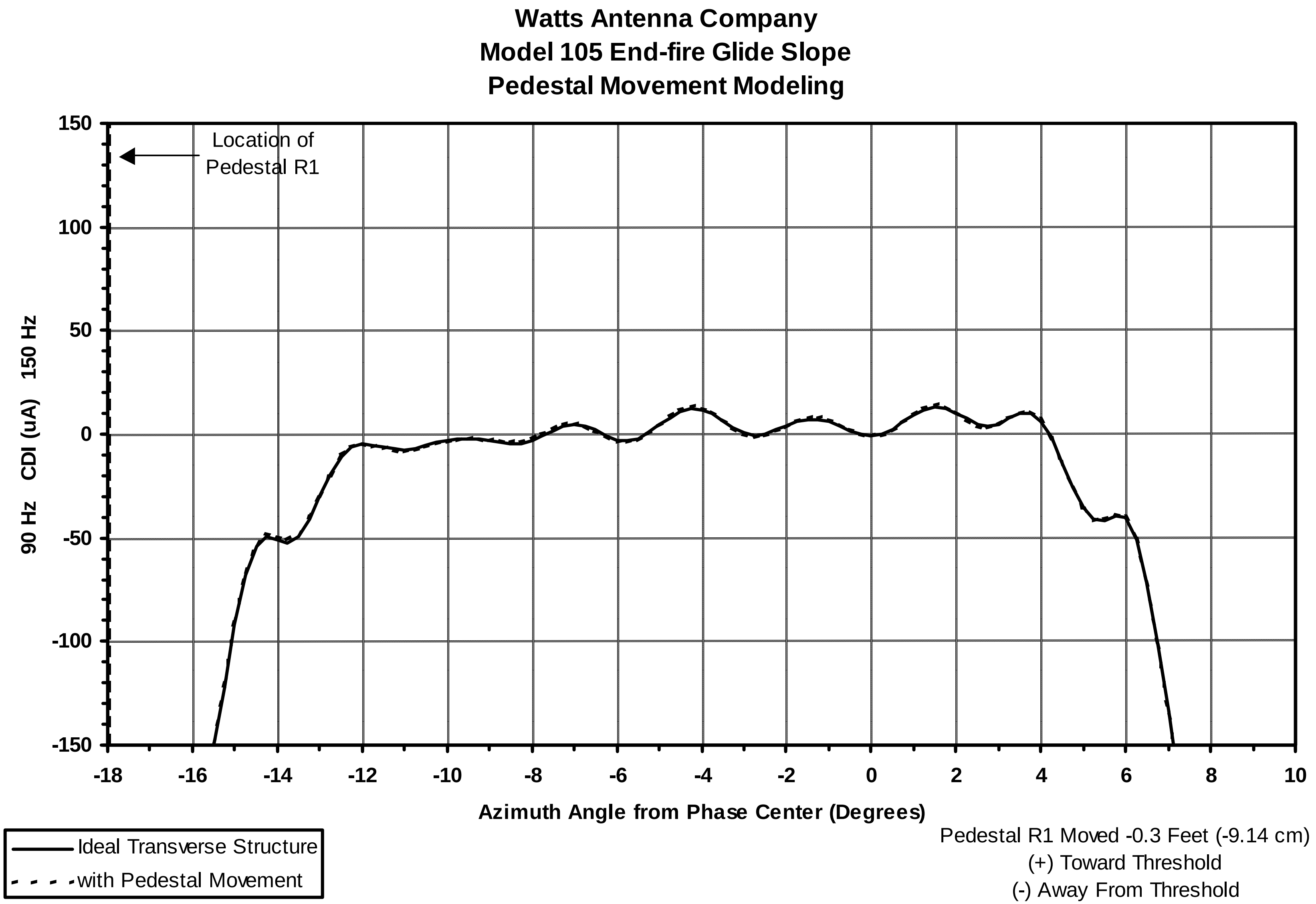

Figure A1-91. Pedestal R1 Moved 0.3 Feet Away From Threshold

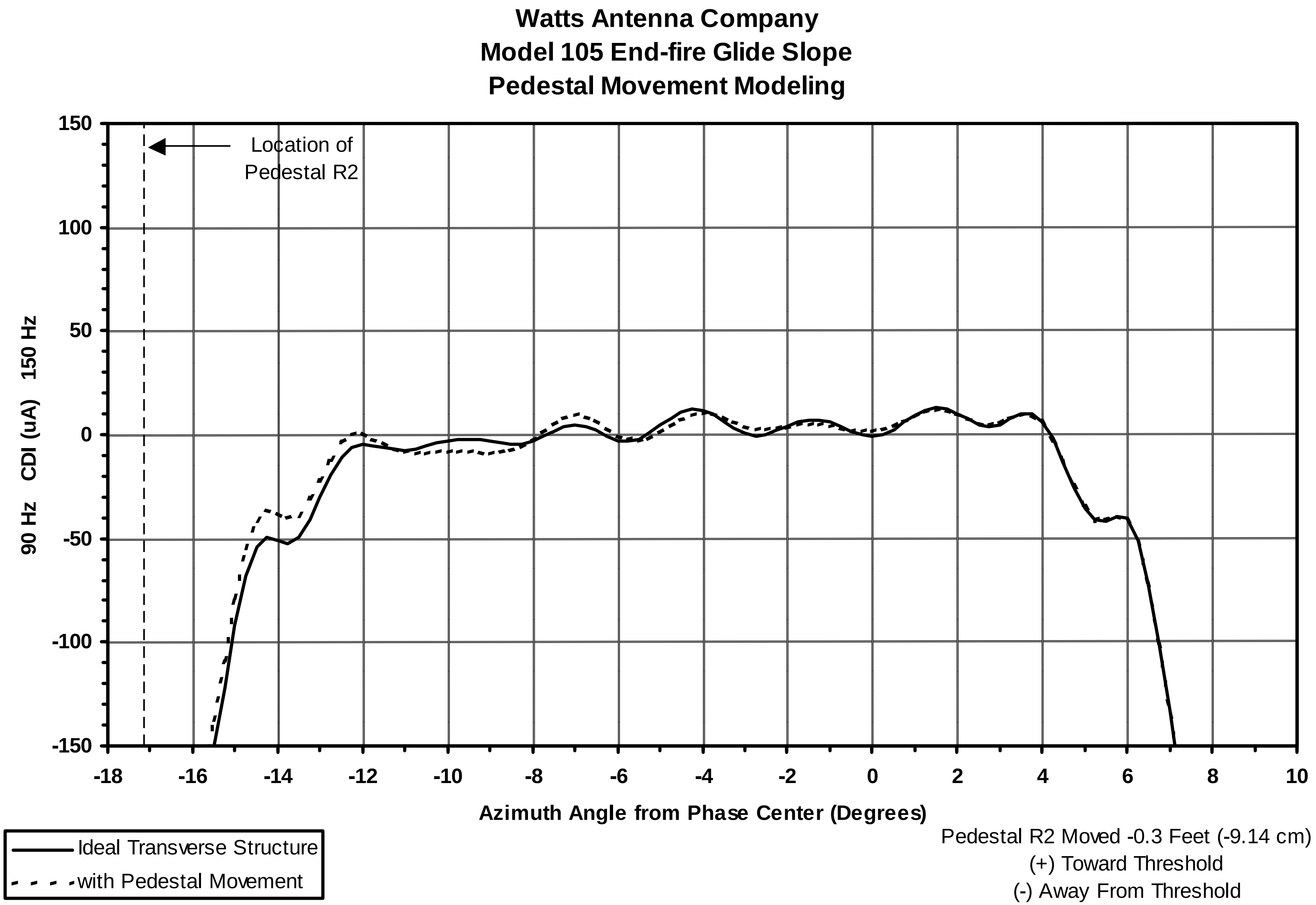

Figure A1-92. Pedestal R2 Moved 0.3 Feet Away From Threshold

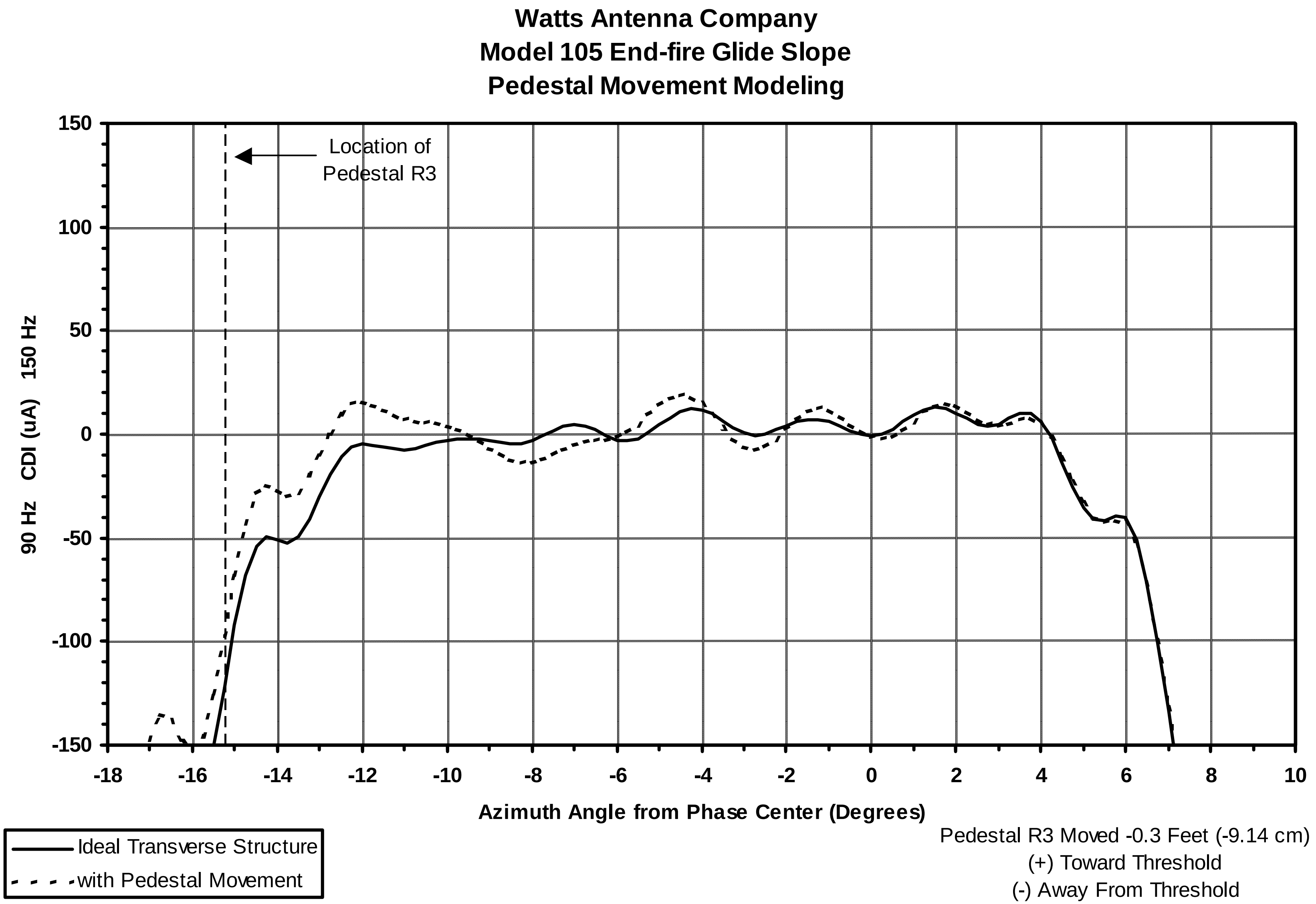

Figure A1-93. Pedestal R3 Moved 0.3 Feet Away From Threshold

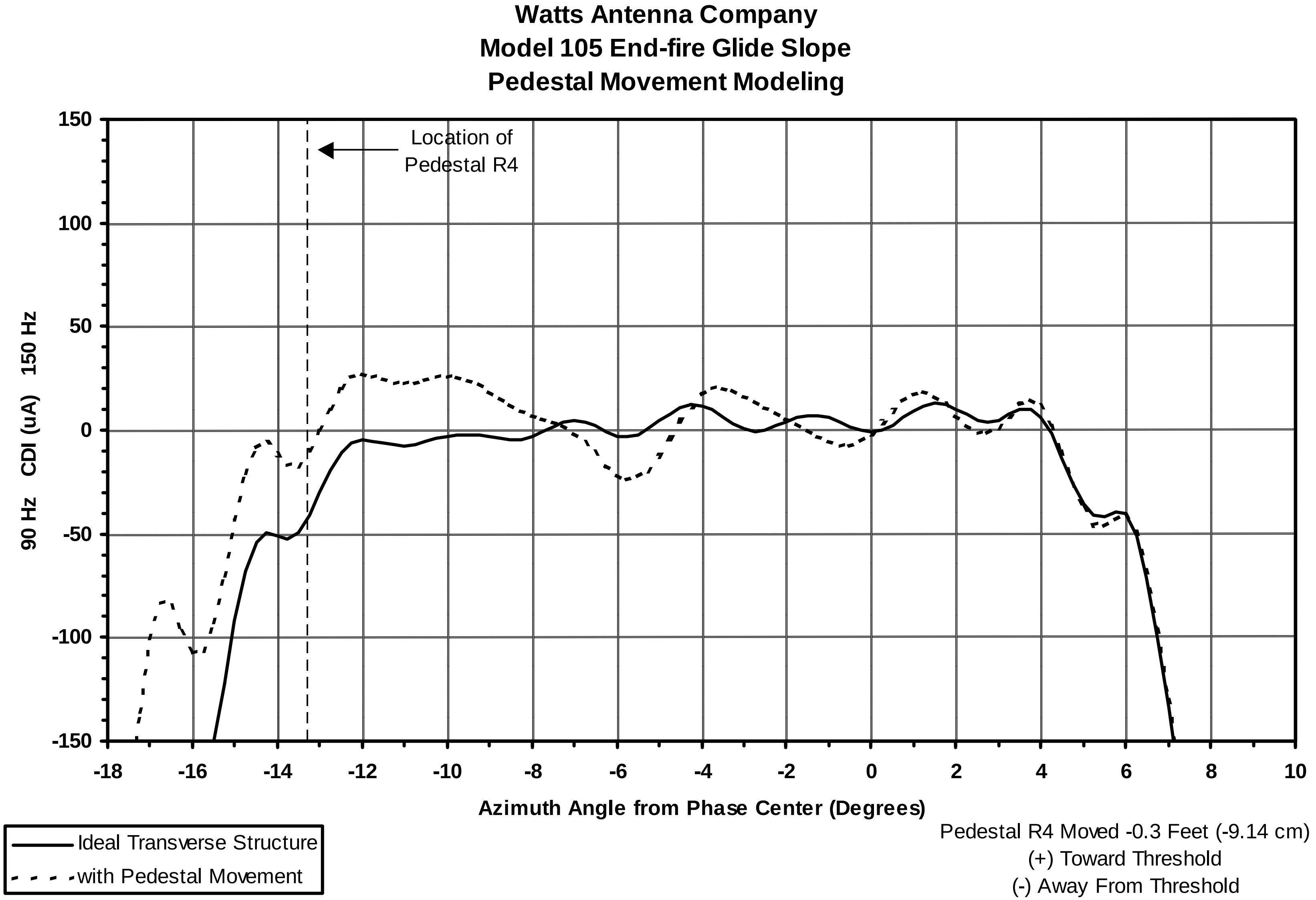

Figure A1-94. Pedestal R4 Moved 0.3 Feet Away From Threshold

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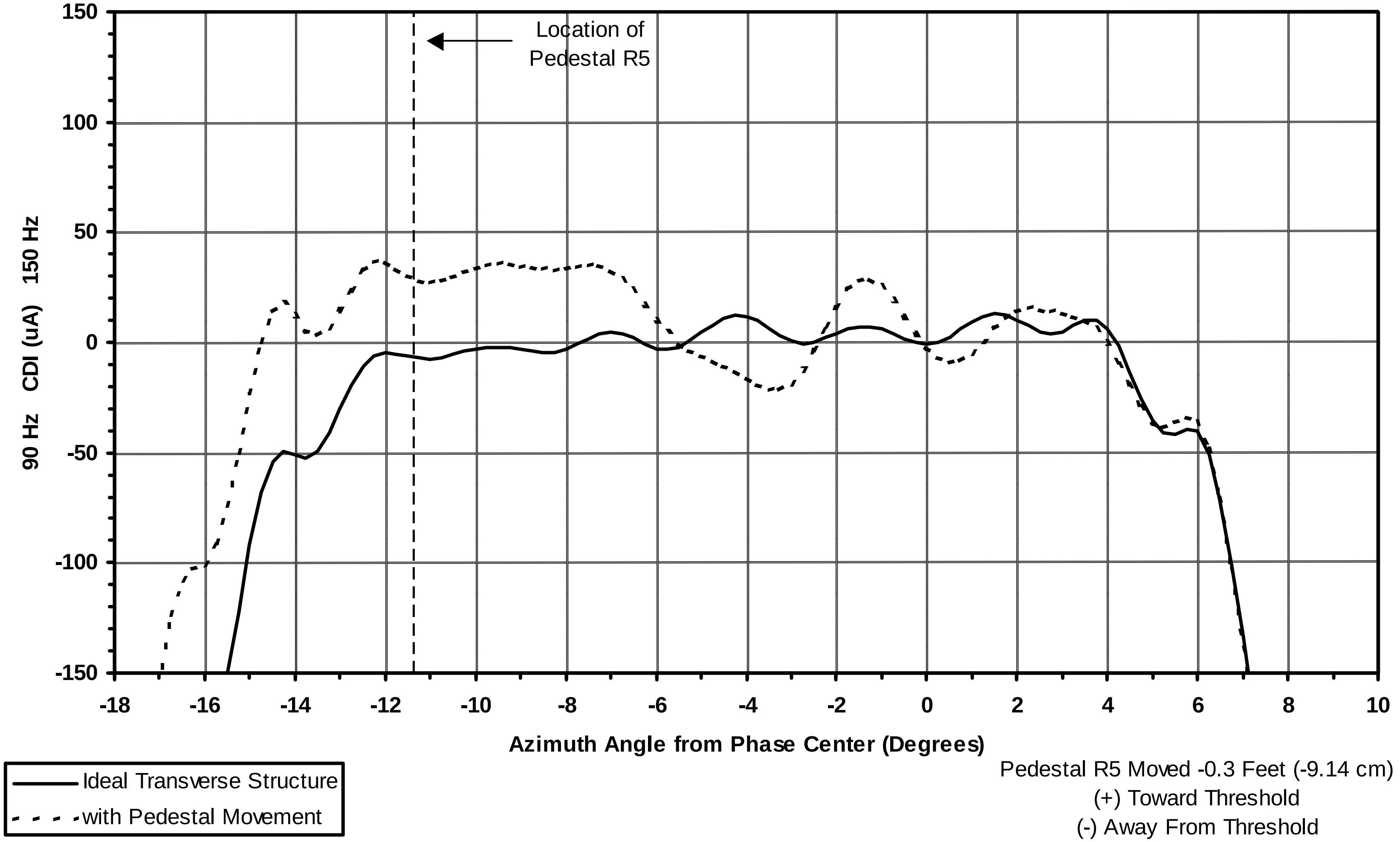

Figure A1-95. Pedestal R5 Moved 0.3 Feet Away From Threshold

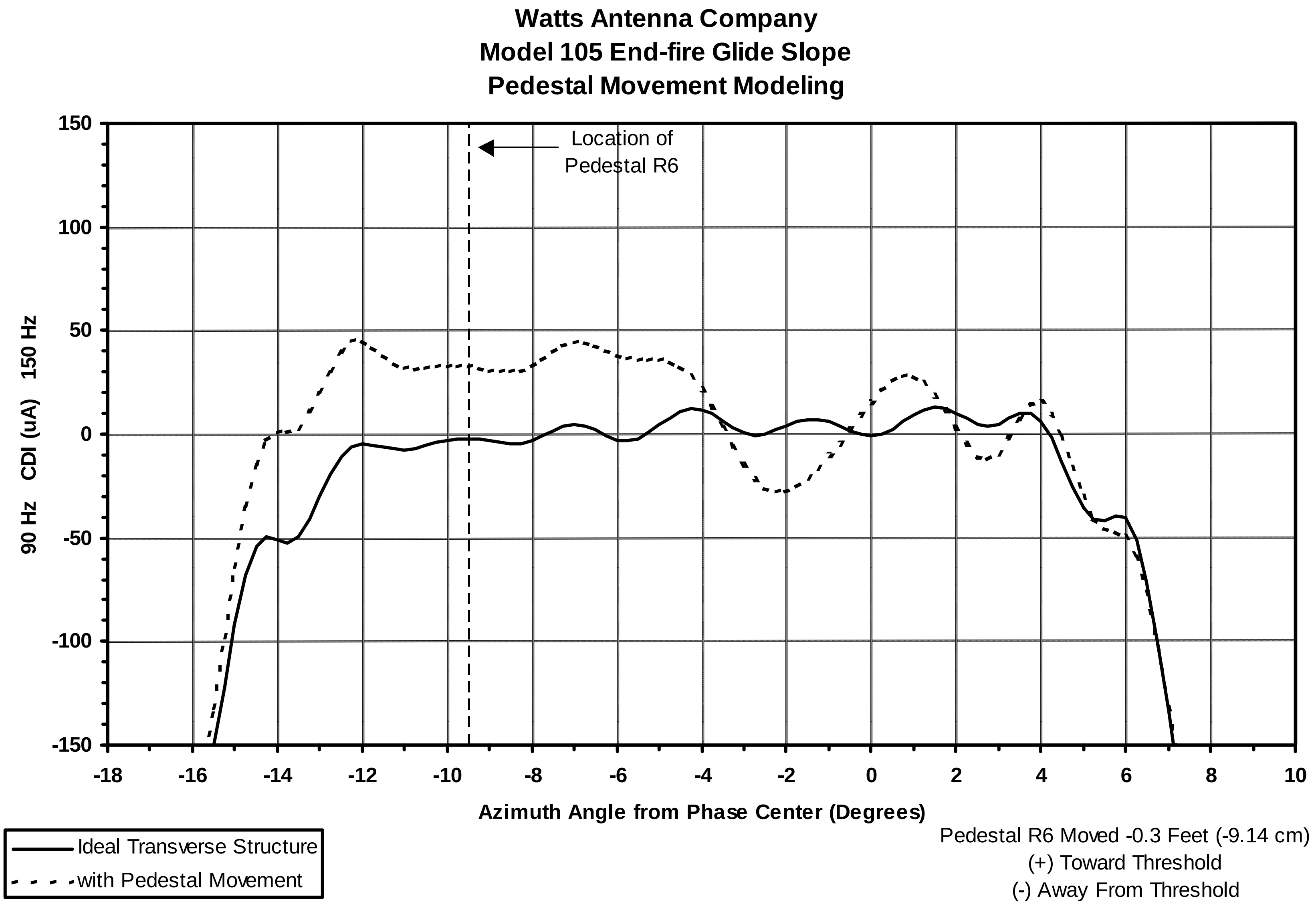

Figure A1-96. Pedestal R6 Moved 0.3 Feet Away From Threshold

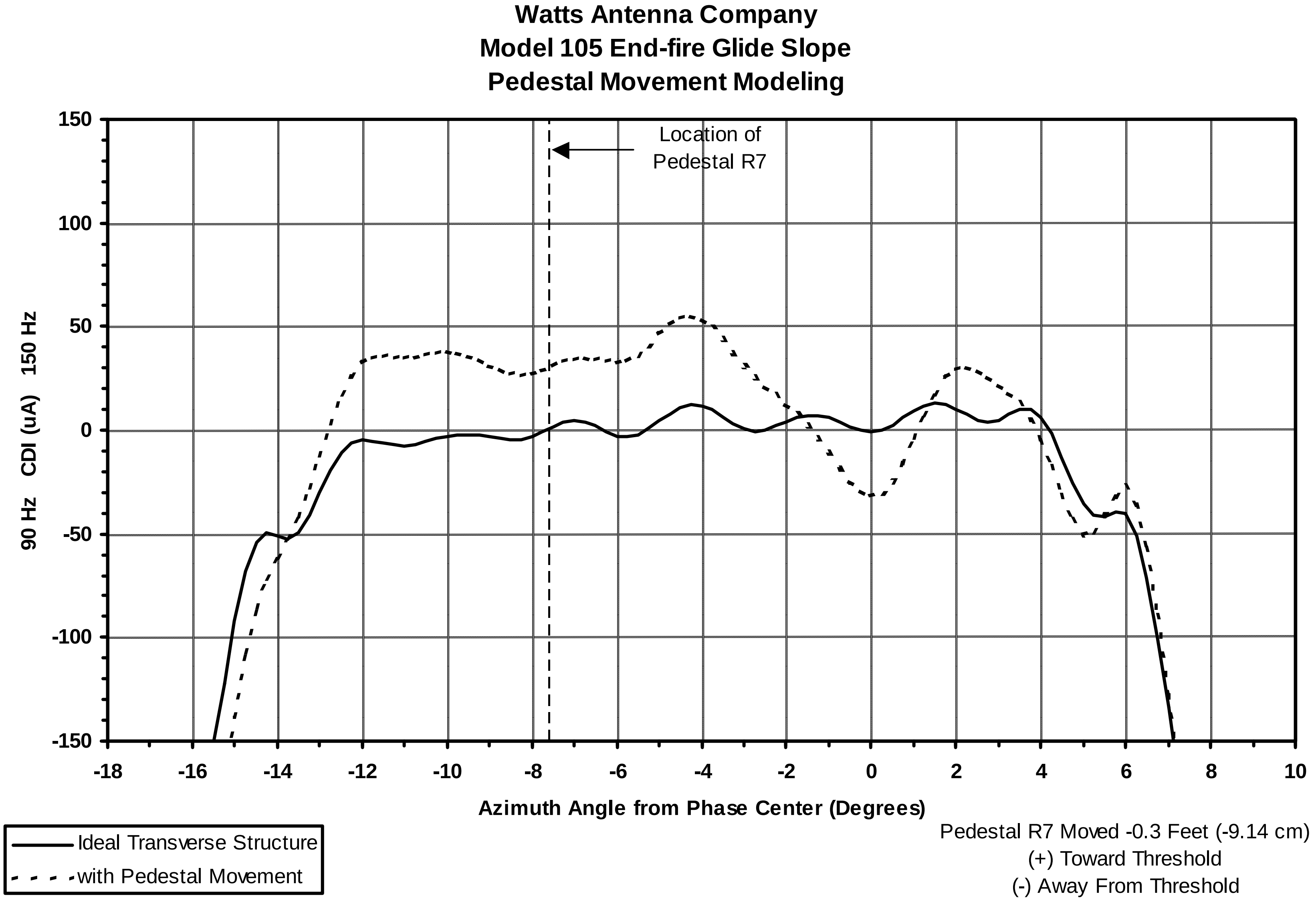

Figure A1-97. Pedestal R7 Moved 0.3 Feet Away From Threshold

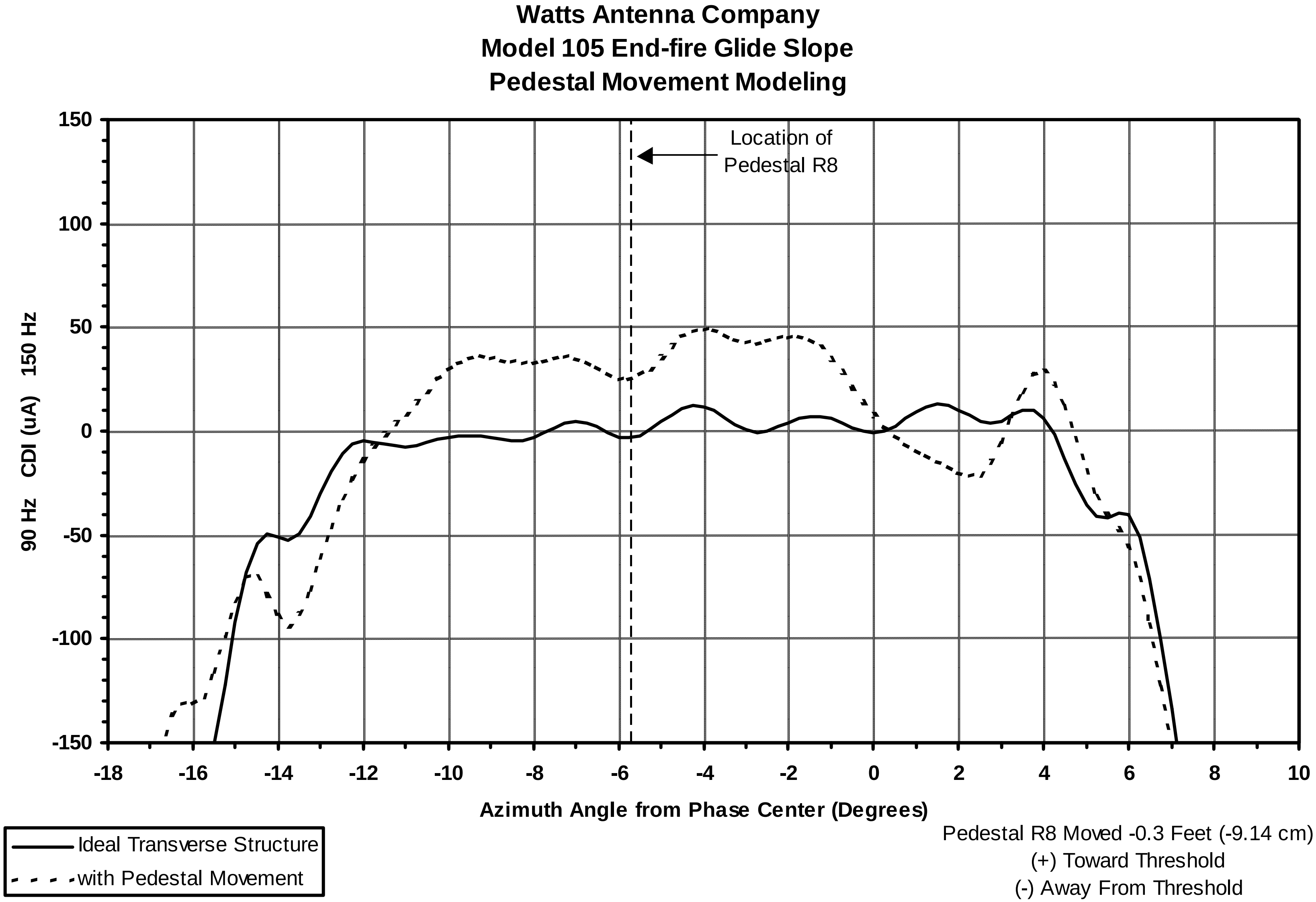

Figure A1-98. Pedestal R8 Moved 0.3 Feet Away From Threshold

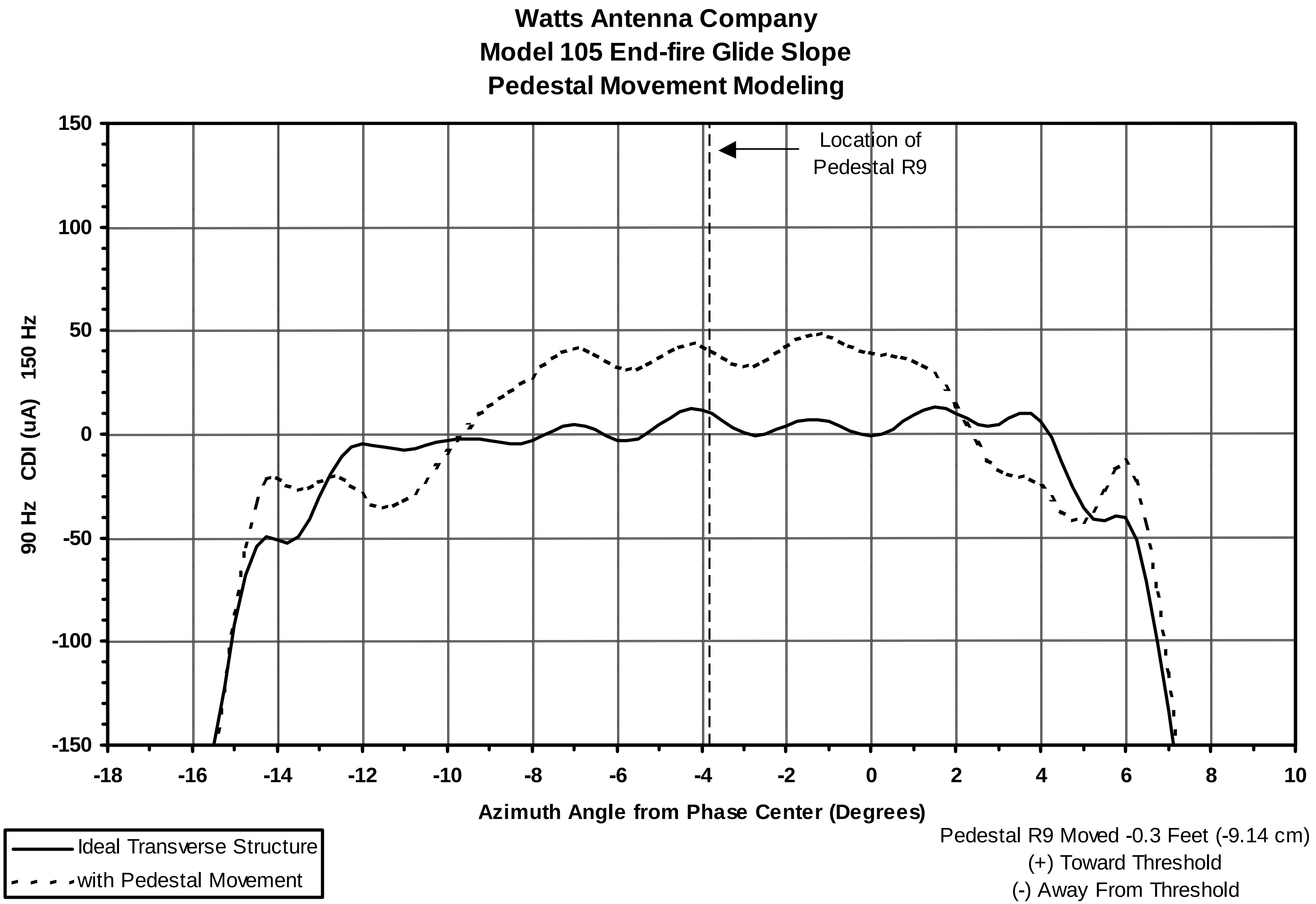

Figure A1-99. Pedestal R9 Moved 0.3 Feet Away From Threshold

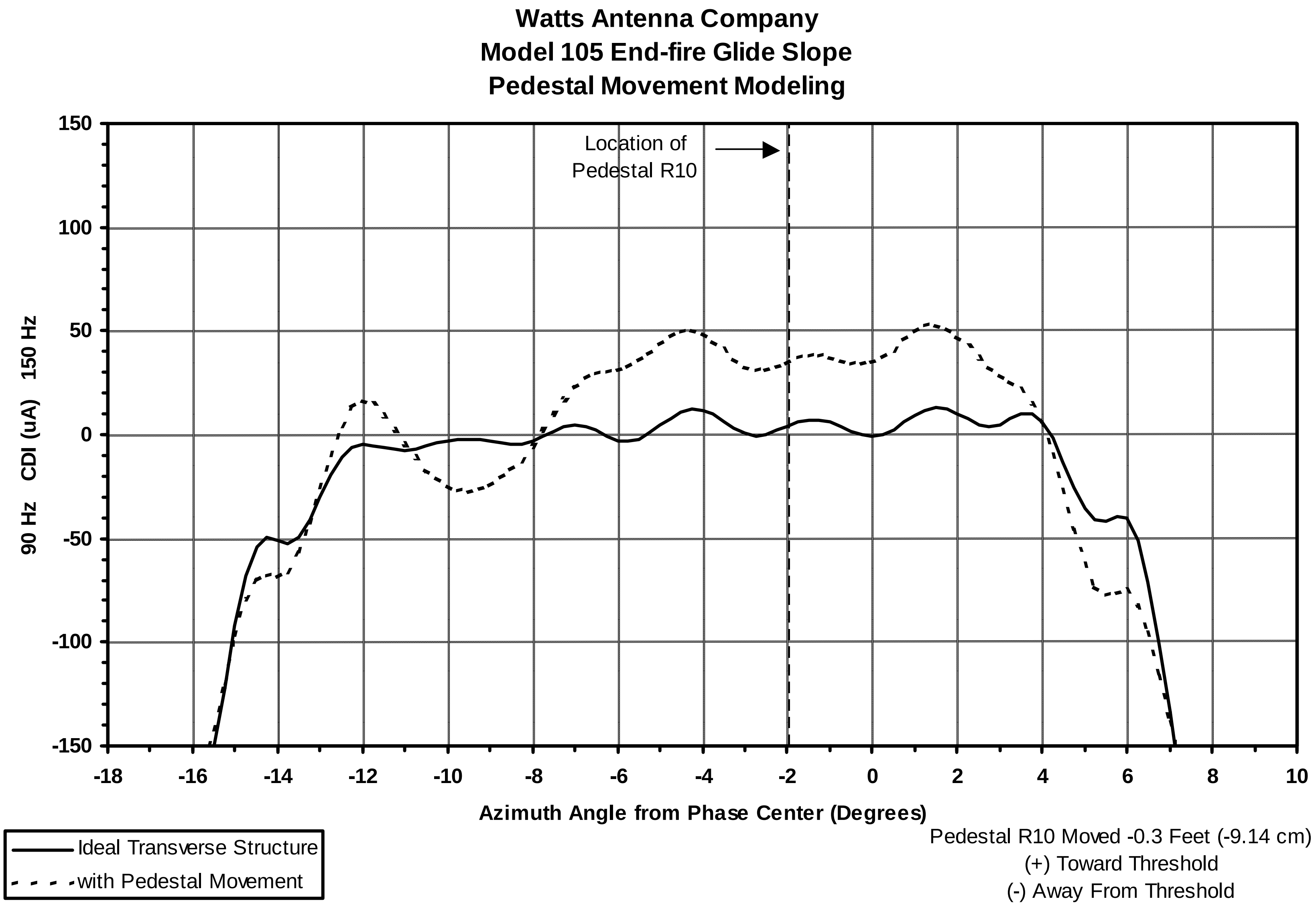

Figure A1-100. Pedestal R10 Moved 0.3 Feet Away From Threshold

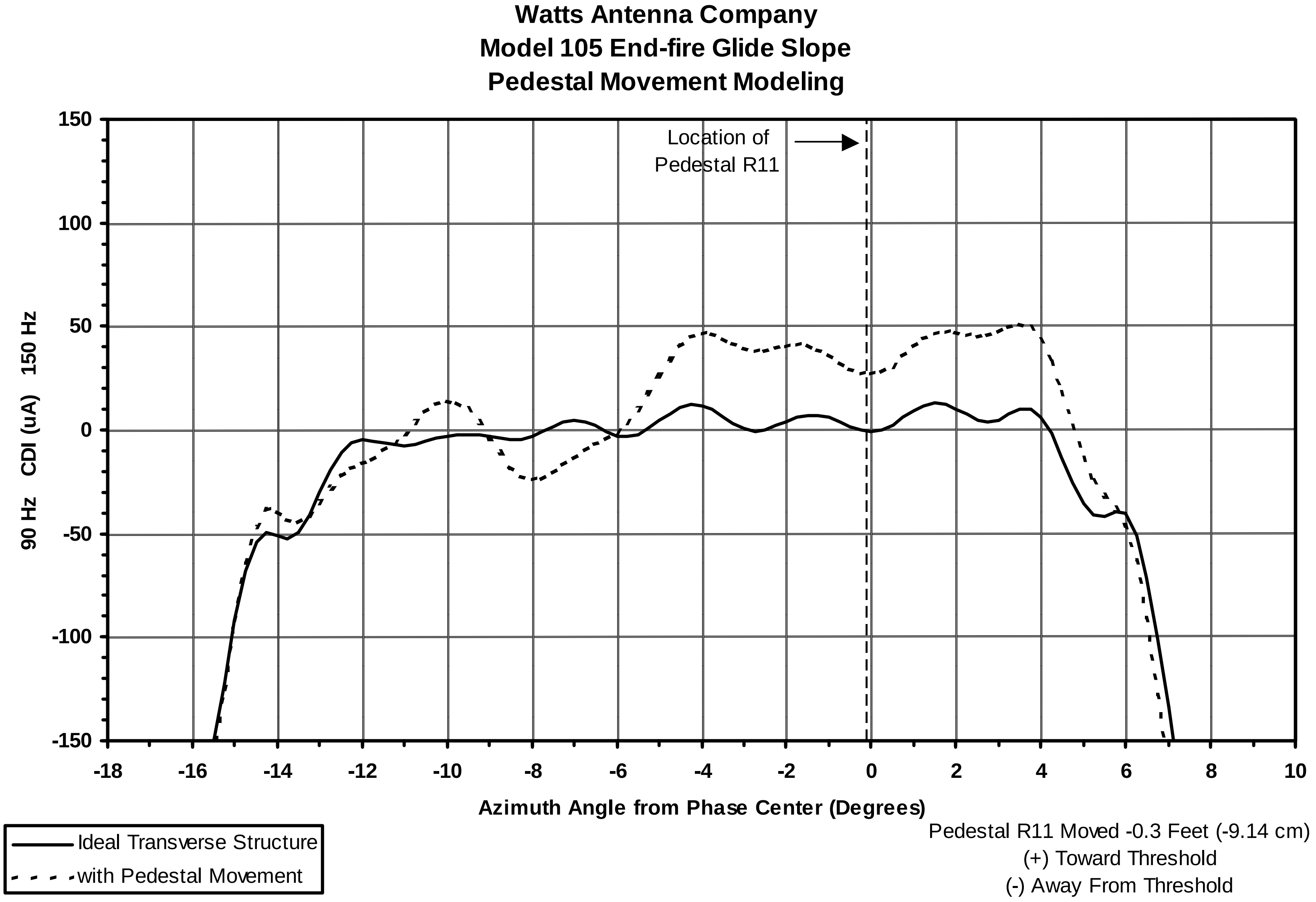

Figure A1-101. Pedestal R11 Moved 0.3 Feet Away From Threshold

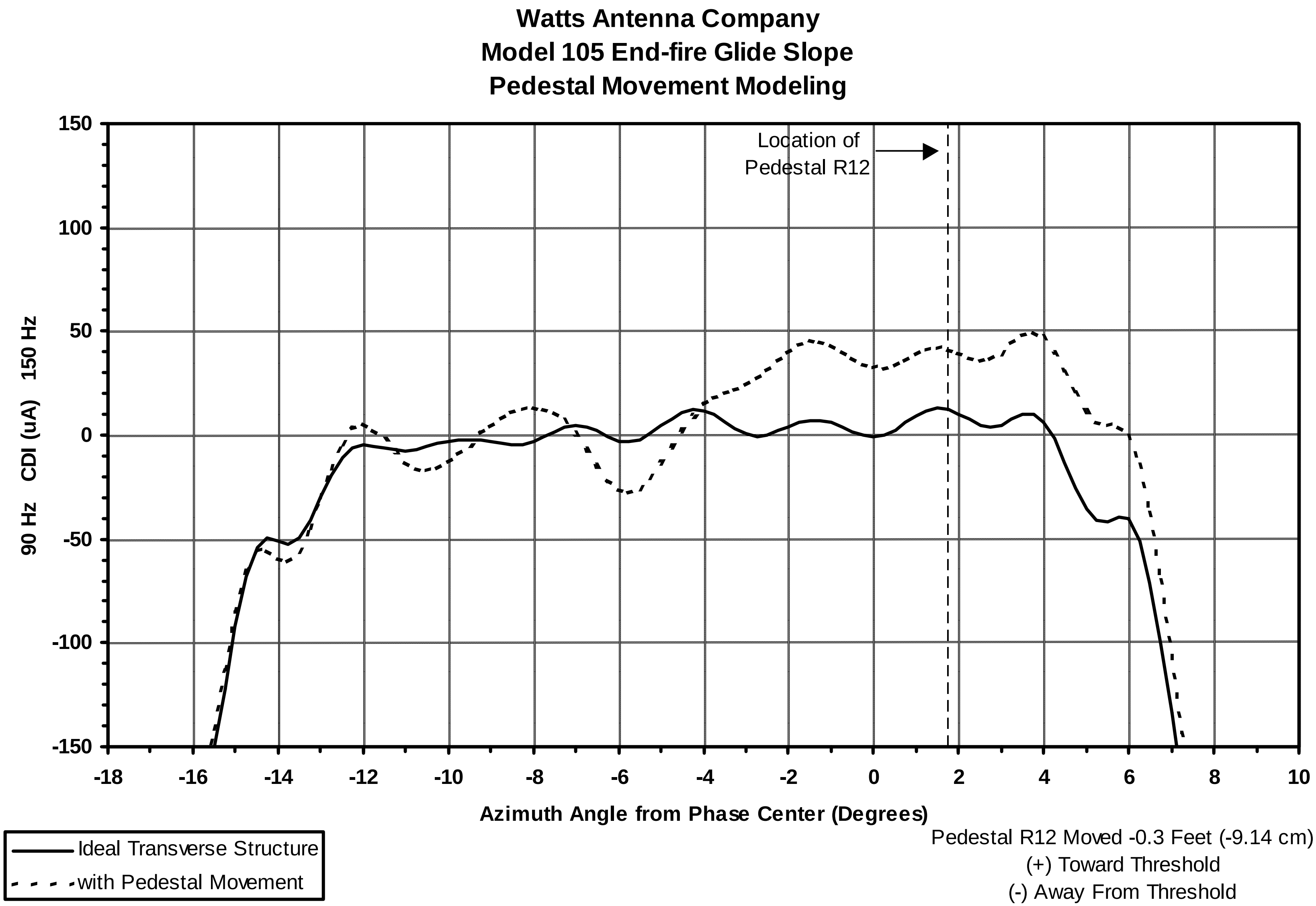

Figure A1-102. Pedestal R12 Moved 0.3 Feet Away From Threshold

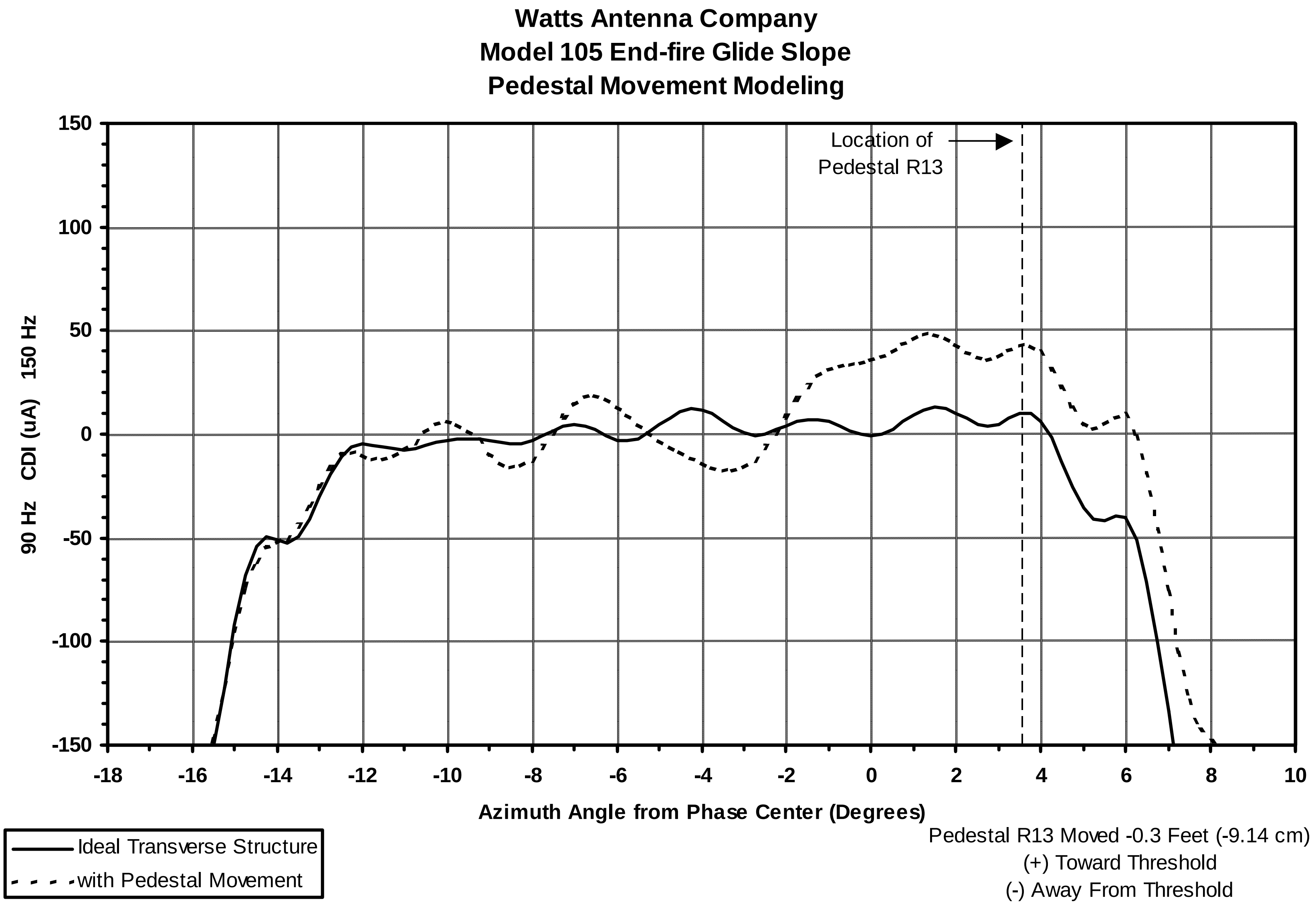

Figure A1-103. Pedestal R13 Moved 0.3 Feet Away From Threshold

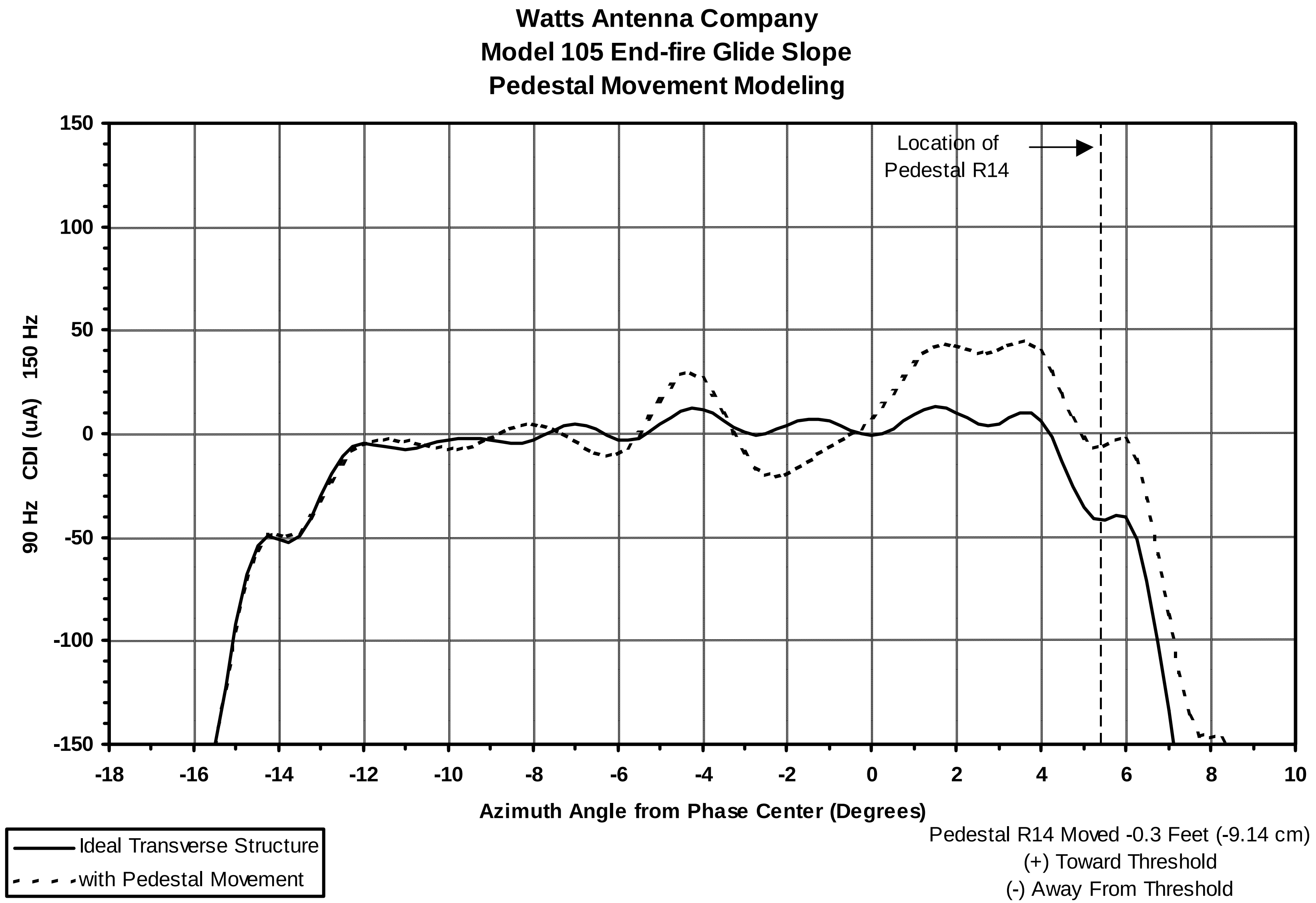

Figure A1-104. Pedestal R14 Moved 0.3 Feet Away From Threshold

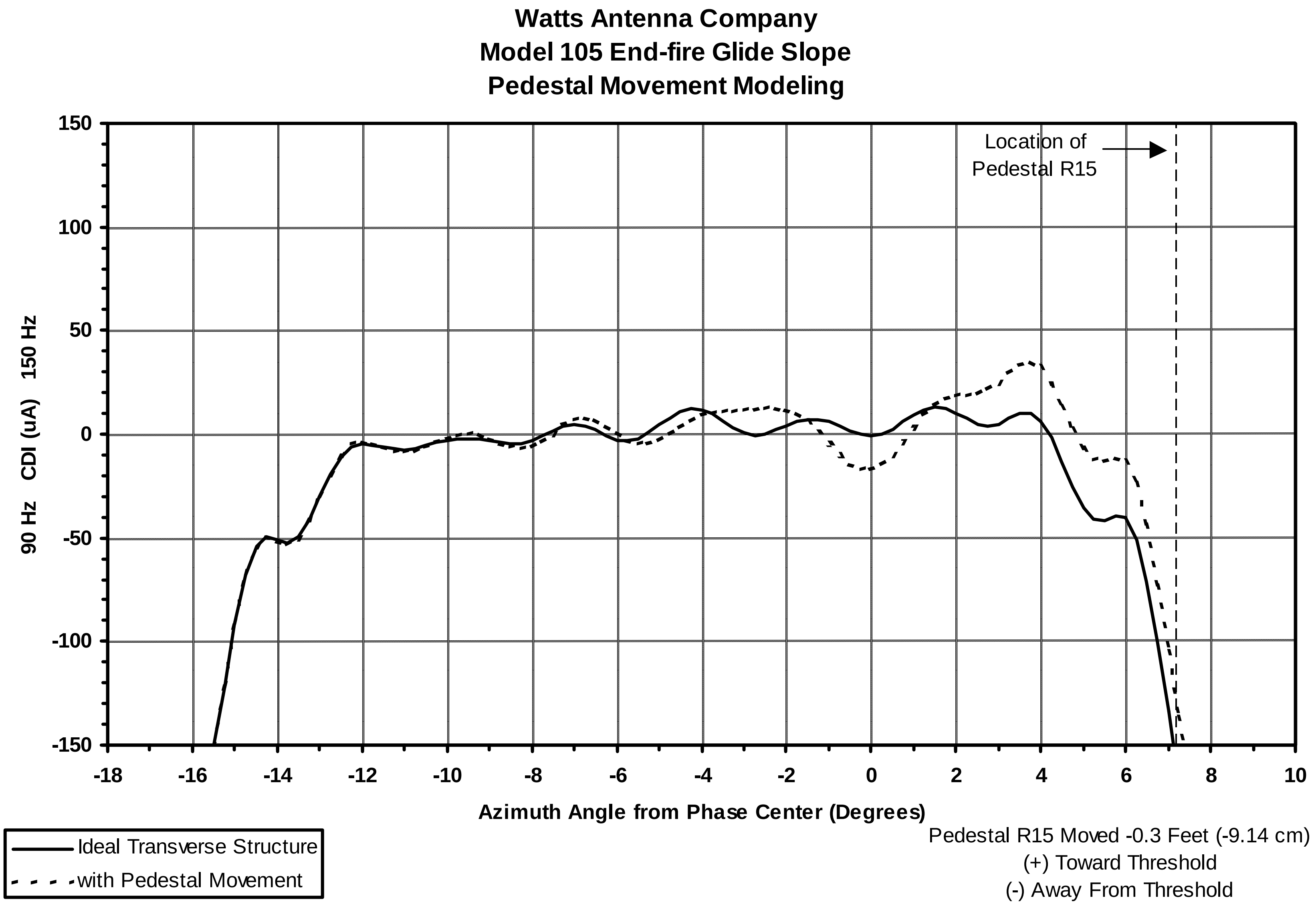

Figure A1-105. Pedestal R15 Moved 0.3 Feet Away From Threshold

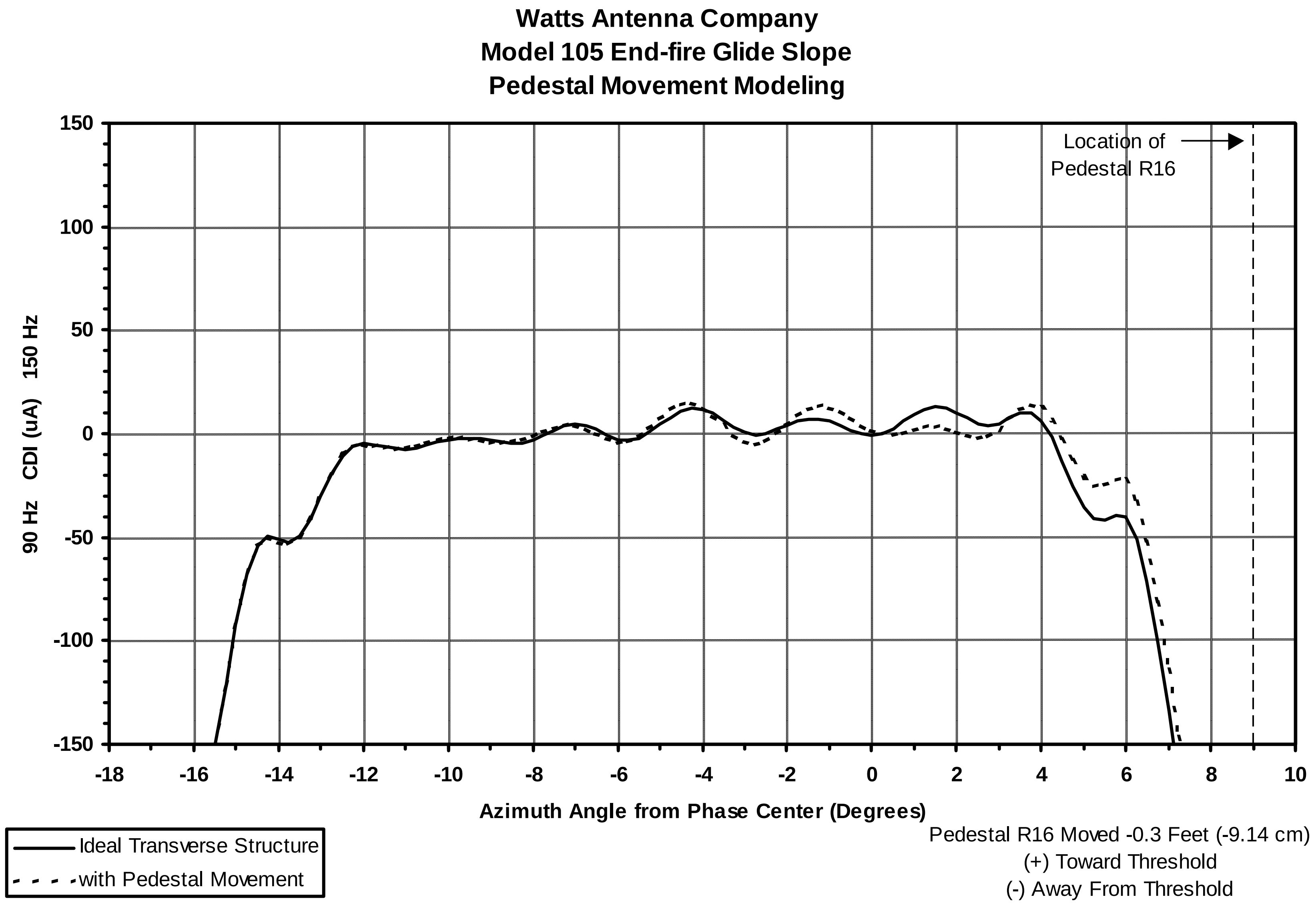

Figure A1-106. Pedestal R16 Moved 0.3 Feet Away From Threshold

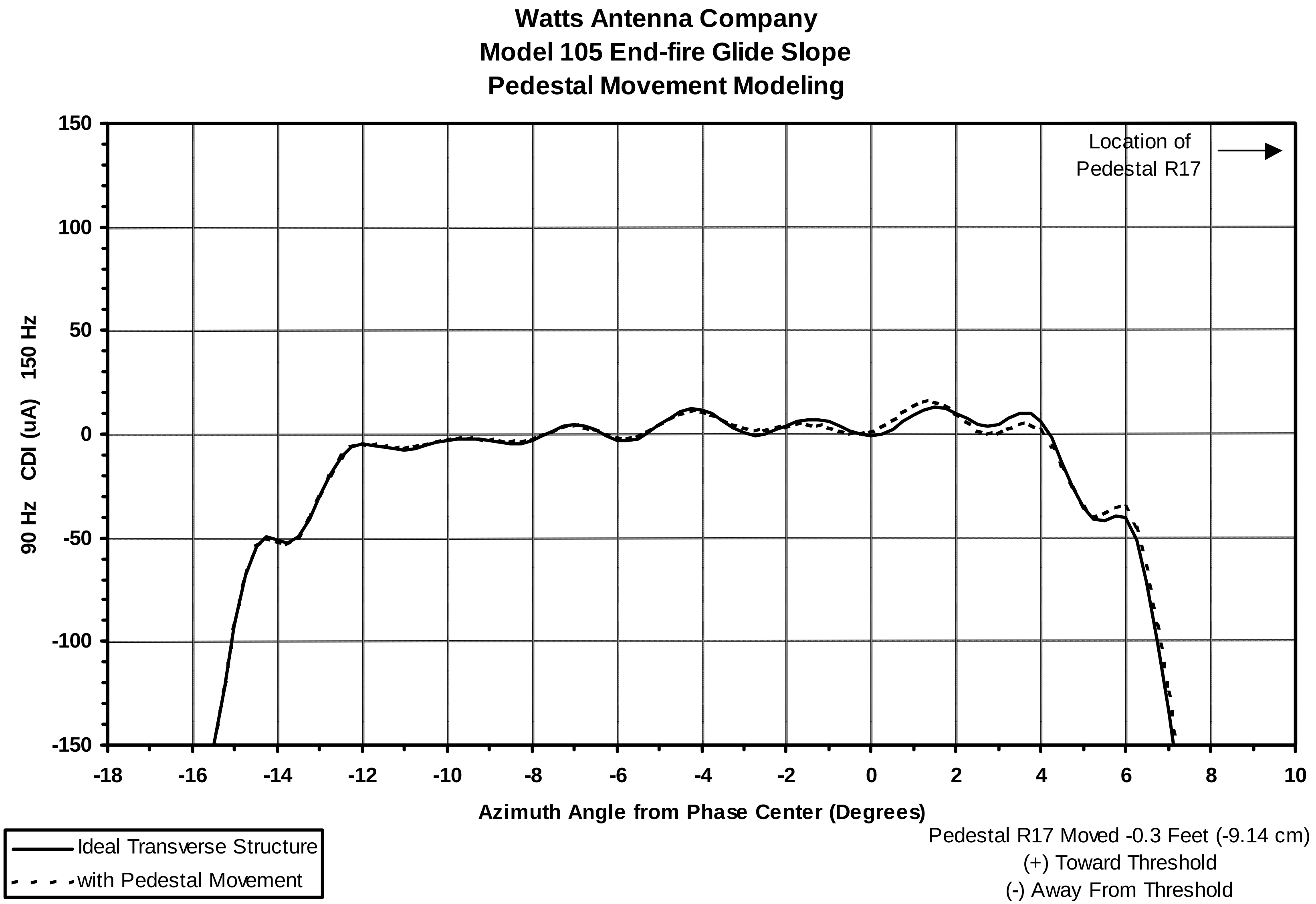

Figure A1-107. Pedestal R17 Moved 0.3 Feet Away From Threshold

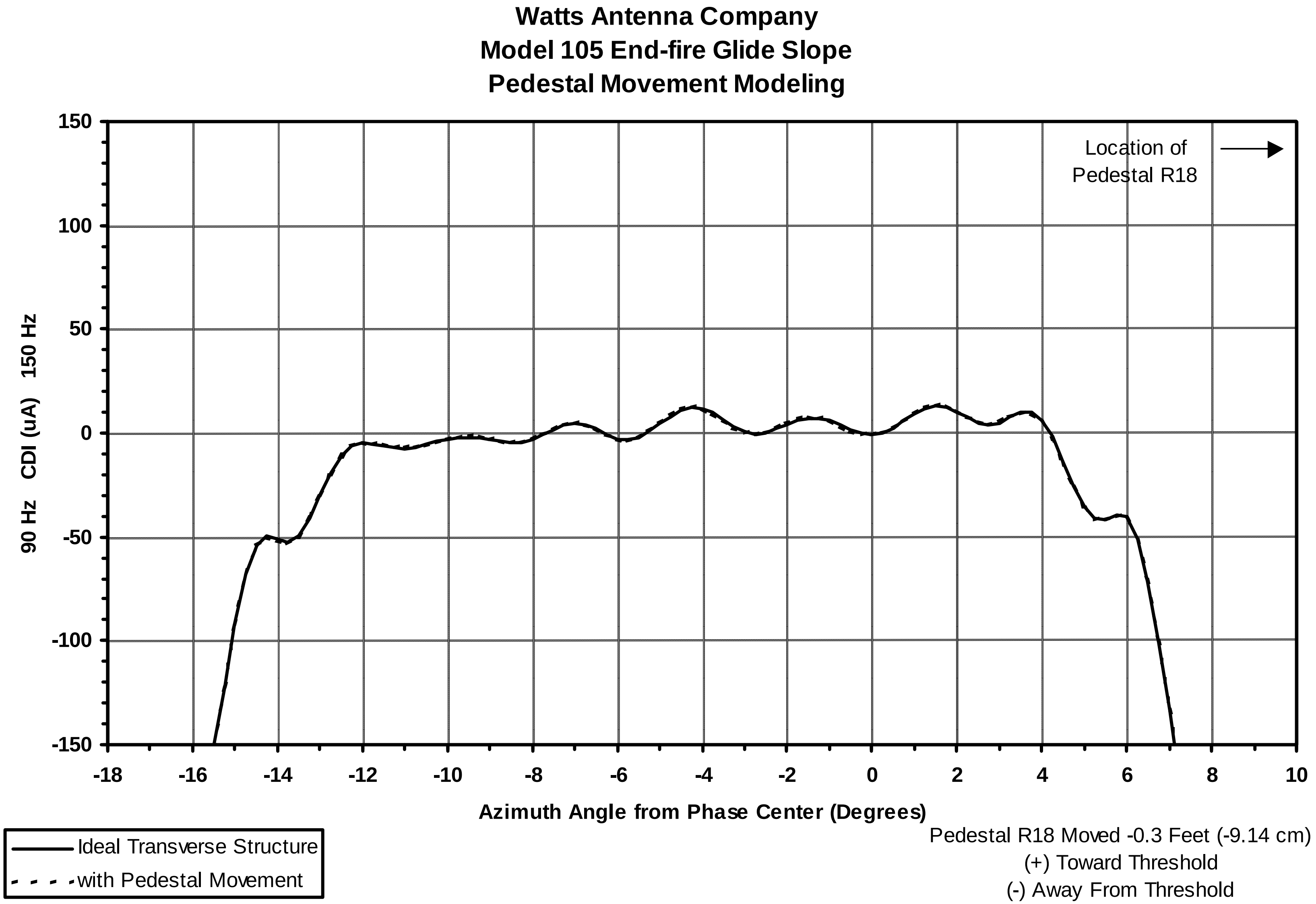

Figure A1-108. Pedestal R18 Moved 0.3 Feet Away From Threshold