Before The
FEDERAL COMMUNICATIONS COMMISSION
Washington, DC 20554

In the Matter of	)	
	)	
Petition for Rulemaking to Permit	)	RM – ________________
Directional FM Antenna Modeling	)	
Through Use of Computational Methods	)	

To: Office of the Secretary

Joint Petition for Rulemaking

DIELECTRIC, LLC

EDUCATIONAL MEDIA FOUNDATION

JAMPRO ANTENNAS, INC.

RADIO FREQUENCY SYSTEMS

SHIVELY LABS

CONTENTS

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The parties listed on the front and signature pages hereto (the "Petitioners") hereby respectfully request, pursuant to Section 1.401 of the Federal Communications Commission's Rules, that the Commission modify its rules to accept computational modeling of FM directional transmitting antennas as an alternative to the making of physical measurements of antenna characteristics and/or performance whenever measurements now are required by the rules. In the cases of FM directional antennas currently, measurements generally are required by the rules to provide data for filing with applications for licensing to prove the performance of the antennas to be licensed. As will be shown, with currently available computational modeling methods, such data can be obtained with adequate accuracy for the purpose, so that the public interest will be served by the Commission enabling use of such methods in lieu of measurements of actual antennas and their supporting and surrounding structures or scale models thereof.

To accomplish this objective, changes are proposed herein in the Commission's rules in Sections 73.316(c)(2), 73.1620(a)(3), and 73.1690(c)(2). In addition to language explicitly providing for acceptance of data derived through use of computational modeling for license and other applications involving FM directional antennas, language is proposed, comparable to requirements found elsewhere in rules related to FM directional antenna applications, requiring documentation of the qualifications of those conducting computational modeling and describing the methods used to derive the data required to be filed with each application involving an FM directional antenna for which the filing of such antenna performance characterization currently is specified.

The Petitioners are manufacturers and users of FM directional transmitting antennas and are impacted by the current requirement in the cited rules sections that only measured data characterizing the relative field patterns of FM directional antennas be submitted as part of license applications involving such antennas. Indeed, several of the Petitioners already use computational modeling in their design processes and then must duplicate that effort at greater expense to construct physical models on which to make measurements.

I. THERE ARE SIGNIFICANT COSTS IN TIME AND MONEY DUE TO THE REQUIRED PHYSICAL MEASUREMENT OF DIRECTIONAL FM ANTENNAS THAT CAN BE SAVED THROUGH USE OF COMPUTATIONAL MODELING WHILE SIMULTANEOUSLY MAINTAINING OR IMPROVING ACCURACY

The rules for licensing of FM directional antennas in §73.316(c)(2) and §73.316(c)(2)(iii) currently state, "(2) Applications for license upon completion of antenna construction must include the following:" …. "(iii) A tabulation of the measured relative field pattern required in paragraph (c)(1) of this section." Read literally, since it asks for a tabulation of the measured relative field pattern upon completion of antenna construction, this language would seem to imply that an FM antenna must be measured after installation, through field measurements of the installed antenna, which can be quite impractical to make. Such measurements would have been even more difficult to make when the rules first were promulgated in 1963. Consequently, we make the assumption that the rule was interpreted initially to require that FM directional antennas be measured on full-size test ranges since such ranges were available then for characterizing both the azimuth and elevation patterns of broadcast television antennas.[1] The antennas

[1] For example, the RCA Broadcast Antenna Engineering Center had three such ranges on a 135-acre site in Gibbsboro, NJ, at least as late as 1984, when the facility was described in the RCA Broadcast News publication, Volume No. 174, March 1984, pp. 12 – 17, available here: https://worldradiohistory.com/ARCHIVE-RCA/RCA-Broadcast-News/RCA-174.pdf. Last checked 28 May 2021.

would have been characterized prior to delivery for installation, and the provisions in the rule related to certifications of installation according to manufacturer instructions by a qualified engineer and at the correct orientation by a licensed surveyor would seem to support such an interpretation.[2] Judging by a review of a number of applications filed in the last couple decades, the use of full-size antenna components and large ranges continues, but it has become the practice of some manufacturers making such measurements to measure only portions of arrays having multiple layers or bays, with a sufficient number of bays included in the measurement, in the judgement of the manufacturer, to properly create the respective azimuth patterns in both the horizontally and vertically polarized components of the transmitted signals.[3] The elevation patterns in such cases generally are calculated rather than measured.[4] Producing measurements of the type described requires maintenance of large tracts of land on which to operate the full-size ranges, with the space amounting to tens of acres and distances involved in the hundreds of meters so as to make proper measurements in the far fields of the antennas, where their beams are fully formed. It also requires the ability to erect tower sections as part of the process, complete with any attachments in the regions of the antenna apertures that will be found on the real towers on which the antennas will be installed. This is necessary because the towers on which the antennas will be mounted, along with any nearby appurtenances or accessories, are considered to be part of the structural environments in which the transmitted signals can be reflected or reradiated, thereby affecting the patterns of the antennas. The implications are that manufacturers must maintain inventories of wide assortments of tower sections so that they do not have to fabricate too often a tower section matching what will be used to support a particular antenna. Nevertheless, when any towers not already in their inventories of sample sections are to be used to mount antennas, they either must obtain them from the tower manufacturers or fabricate equivalent tower sections themselves. Then, all the appurtenances within certain distances of the antennas must be obtained or fabricated and attached. If those appurtenances are

[2] See §73.316(c)(2)(vii) and §73.316(c)(2)(viii).
[3] See, for example, the license application in File Number: BMLED-20050207AAJ (KKJZ).
[4] See, for example, the license applications in File Numbers: BMLED-20050809ACP (WMFO); BLH-20060323ABU (KZLA-FM, now KLLI-FM); BMLH-20101221ACA (KPWR); and BLED-20140313ADT (KTCN).

Figure 1 – Full-scale test range (left) and anechoic chamber with scale-model antenna (right) for antenna characterization

not commonly used, they could go to waste after a single use, adding to the cost to the purchaser of that one antenna.

For some manufacturers, sometime in the intervening period between promulgation of the 1963 FM directional antenna rule[5] and now, it became routine practice to use scale models[6] of antennas on enclosed, indoor test ranges for characterizing the detailed performance of directional FM antennas. (See Figure 1 for a comparison of full-scale and scale-model antenna characterization facilities.) It is the data from measurements of the scale models on the indoor ranges that have been submitted with directional FM antenna licensing applications based on those manufacturers' antennas for at least several decades.[7] To a certain extent, the burdens and costs of physical measurements of antennas have been somewhat reduced historically by the Commission's acceptance of measurements made on the scale models of directional antennas,[8] but requirements to construct physical scale models, including models of the related towers and all their appurtenances still preclude the benefits of improved accuracy and cost savings that can be derived from the use of computational modeling of directional antennas and the towers or other structures on which they are mounted.

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[5] See discussion below on pp. 6 – 10.

[6] The scale models typically are built for operation at frequencies roughly 4½ times higher (the two commonly used ratios are 4.4:1 and 4.5:1) than the intended frequencies of operation of the actual antennas. Thus, the scale models are built for operation at frequencies ranging from around 396 MHz to around 486 MHz to correspond with full-size antennas operating from 88 to 108 MHz.

[7] See, for example, the license applications in File Numbers: BLED-20020905AAM (KCSN), scaling factor = 4.4; and BLED-20170802AEJ (WBUR-FM), scaling factor = 4.5.

[8] Use of scale models is described in Part 73 of the FCC rules (2019 edition) only in §73.1690(c)(2)(iii) and only with respect to replacement FM directional antennas. §73.1690 became effective in March 1982 (47 FR 8590) but did not describe use of scale models at that time.

II. The Commission Has a History of Accepting Computer Modeling of Directional Antennas in Other Broadcast Services, When Possible, Instead of Requiring Physical Measurements

The procedures required or allowed by the FCC for characterization of antenna azimuth patterns vary quite markedly between the several broadcast services – AM Radio, FM Radio, and Television. Azimuth patterns, of course, help determine in which directions broadcast stations distribute their emitted signal power, where they deliver service, and where they cause interference to one another. The techniques for controlling where signals are emitted in the azimuth plane and how their emissions are measured have improved over the century-long history of broadcasting via transmission of electromagnetic signals. They also have progressed with the addition of the new services that came along, operating mostly at higher frequencies in each case – from AM, to FM, to Television. Each of the services started out with intended non-directional (or "omnidirectional") antennas and azimuth patterns. In some early cases, azimuth patterns accidentally turned out to be directional, and much was learned about how to create directional patterns intentionally to permit reduction of interference between stations operating on the same or adjacent channels. While the first AM stations went on the air starting in 1920, the first intentionally directional antenna array took until 1931to start operation.[9] It wasn't until 1937 that the techniques for designing AM directional arrays were fully documented.[10] Methods eventually were developed to permit designing directional AM antenna arrays using a special-purpose analog simulator based on a pattern presented on a CRT,[11] but adjusting and proving the correct operation of the directional arrays themselves according to their designs required a large number of field strength measurements to be made following any adjustment of the array until its pattern finally was proved. This was necessary because of interaction

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[9] WFLA, Clearwater, FL. See George H. Brown, "and part of which I was," Angus Cupar Publishers, Princeton, NJ, copyright 1979 and 1982, p. 56. Also see, "The Development of the Directional AM Broadcast Antenna," RadioWorld, June 14, 2019, updated July 15, 2020, http://www.radioworld.com/columns-and-views/roots-of-radio/the-development-of-the-directional-am-broadcast-antenna, last visited 28 May, 2021.

[10] George H. Brown, "Directional Antennas," Proceedings of the Institute of Radio Engineers, Vol. 25, Issue 1, January 1937, pp. 78 – 145. See also George H. Brown, "and part of which I was," Angus Cupar Publishers, Princeton, NJ, copyright 1979 and 1982, pp. 55 – 69.

[11] G.H. Brown, W.C. Morrison, "The RCA antennalyzer – an instrument useful in the design of directional antenna systems," Proceedings of the Institute of Radio Engineers, Vol. 34, Issue 12, December, 1946, pp. 992 – 999.

between the environment in which an antenna was constructed (in particular, the local ground conductivity) and the behavior of the antenna azimuthal directivity and other characteristics. Given the relatively low, medium-wave frequencies at which AM radio operates, the long wavelengths involved, and the large structures they required for efficient emissions, such antenna systems, using a multiplicity of towers as antenna elements, had to be constructed on the ground, where they were susceptible to such interactions.

With the emergence of FM and then Television, broadcast signals moved to higher frequencies – VHF for FM and both VHF and UHF for Television. The shorter wavelengths they implied permitted antennas to be constructed as single, integrated structures instead of multiple, separate elements. Moreover, when only local service is considered (disregarding ionospheric "skip" conditions), unlike AM frequencies, which operate primarily with "ground wave" propagation, the VHF and UHF portions of the spectrum function primarily on a "line-of-sight" (LOS) basis, meaning that transmitting antennas work best when they are able to "see" the regions into which they will deliver their signals. Such LOS operation points to placement of VHF and UHF antennas at high locations so that they can be "seen" farther from their transmitting locations and they can deliver stronger signals throughout stations' service areas. Higher locations also help reduce multipath propagation, thus contributing to delivery of higher quality signals. Fortunately, the ability to build transmitting antennas for FM and TV as unitary structures, mounted high off the ground, means that their operation does not vary in such a way as to require periodic measurements and correction of their operation, as is the case with AM directional arrays.

As with AM, early FM and TV transmitting antennas were basically omnidirectional. Over time, directional antenna designs for VHF and UHF became available.[12] The current FCC rules permitting use of directional antennas for both FM and Television first were published in the Federal Register on the same day, December 14, 1963, when a major reorganization and revision of the broadcast rules, contained

[12] George H. Brown, "Directional Antennas for Television Broadcasting," IRE Transactions on Broadcasting," Vol. BC-6, Issue 2, August 1960.

in “Subchapter C – Broadcast Radio Services,” was published. The reorganization moved the contents of previous Parts 3 and 4 of the FCC rules and regulations to Parts 73 and 74, respectively. The rules related to FM directional antennas were and are contained in §73.316 [FM] “Antenna systems,” and the rules covering directional antennas for analog TV were and are contained in §73.685 [TV] “Transmitter location and antenna system.” Rules for directional antennas transmitting Digital Television (DTV) signals, which are relevant currently, mostly parallel the rules for analog TV and appear in §73.625, “DTV coverage of principal community and antenna system,” which was promulgated in 1997, at the time of adoption of the DTV rules. The following discussion applies to both §73.625 and §73.685 unless specifically described otherwise.

It is notable that, while the rules for directional antennas for FM and TV were very similar at their initial publication at their current section numbers, there were a few significant differences between them that have led to different procedures over the years. To help clarify the following discussion, the year of issuance of the referenced rule or its current applicability will be noted. In the 1963 FM case, it was stated that, “[d]irectional antennas may not be used for the purpose of reducing minimum mileage separation requirements but may be employed for the purpose of improving service or for the purpose of using a particular site ….,” while the 1963 TV rules stated simply that, “[d]irectional antennas may be employed for the purpose of improving service upon an appropriate showing of need.” Those restrictions have disappeared over the years since, and an FM rule (§73.215 Contour protection for short-spaced assignments) now exists specifically to describe how to address such situations. When the digital transition took place in the Television service in the late 1990s and the 2000s, specific advantage was taken of the potential for use of directional antennas to permit shorter spacing between stations, and such use has become an everyday part of the television channel assignment landscape ever since.

Turning back to the initial versions of the current rules on directional antennas, the 1963 FM rules provided, in part:

> §73.316(d) *Applications for directional antennas.* Applications proposing the use of directional antenna systems must be accompanied by the following:
>
> (1) Complete description of the proposed antenna system, including:
>
> (i) a description of the means whereby the directivity is proposed to be obtained, and
>
> (ii) the means (such as a rotatable reference antenna) whereby the operational antenna pattern will be determined prior to licensed operation and maintained within proper tolerances thereafter.
>
> (2) Horizontal and vertical plane radiation patterns showing the free space field strength in mv/m at 1 mile and effective radiated power in dbk for each direction. If directivity was computed, the showing shall include the method by which the radiation patterns were computed, including formulae used, sample calculations and tabulations of data. If the directivity was measured, the method employed shall be fully described, including the equipment used, and the resultant measured data shall be tabulated. …
>
> (3) Name, address, and qualifications of the engineer making the calculations.

The 1963 TV rules provided, in part:

> §73.685(f) Applications proposing the use of directional antenna systems must be accompanied by the following:
>
> (1) Complete description of the proposed antenna system.
>
> (2) Orientation of array with respect to true north; time phasing of fields from elements (degrees leading or lagging); space phasing of elements (in feet and degrees); and ratio of fields from elements.
>
> (3) Horizontal and vertical plane radiation patterns showing the free space field intensity in millivolts per meter at 1 mile and the effective radiated power, in dbk, for each direction. The method by which the radiation patterns were computed or measured shall be fully described, including formulas used, equipment employed, sample calculations and tabulations of data. …
>
> (4) Name, address, and qualifications of the engineer making the calculations.

There were many commonalities between the two sets of rules: In construction permit applications proposing directional antennas, they both sought complete descriptions of the proposed antenna systems, free space field intensities in mv/m and effective radiated power values in dBk in each direction from the respective antennas, and information on the methods used to calculate or measure the associated radiation patterns, plus sample calculations and tabulated data. They also required contact information for and qualifications of the engineer performing the calculations that were submitted. The most significant difference between the two 1963 approaches to directional antenna rules was that the FM rules required a "means (such as a rotatable reference antenna) whereby the operational antenna pattern will be determined prior to licensed operation and maintained within proper tolerances thereafter," while the TV rules had no such requirement. So, while the FM rules required a method for producing a "proof of performance" on the antenna prior to its use and for its maintenance over time thereafter, the TV rules did not. Indeed, the TV rules permitted either measurements or calculations of directional antenna patterns (by virtue of lack of prescribing or proscribing either one) to be submitted with construction permit applications, and no further demonstrations of performance of actual antennas were required thereafter.

Both the FM and TV rules related to directional antennas have been revised multiple times since 1963, and the DTV rules have been added (in 1997). Currently, as in the past, most of the requirements for such antennas being proposed and approved remain the same for both services. The last vestige of the difference between the two sets of 1963 rules is that the current FM rules require that measured pattern performance data for a directional antenna be submitted as part of the application for a license to cover the corresponding construction permit once the antenna has been installed; the current TV rules (including the DTV rules) only require pattern data for a construction permit and don't define whether that data must be derived through measurements or can be the product of calculations.

The real-world results of this rules difference are that directional TV antennas and their patterns are specified almost exclusively using calculations, which, over time, have migrated to computational modeling of the antennas, with no physical models of antennas, whether scale models or partial full-size arrays, being constructed in advance of manufacturing of the antennas themselves, while directional FM antennas still are built and documented in physical instantiations – some with full-size components on full-size test ranges and some scaled to higher frequencies, smaller sizes, and possibly smaller test ranges – with measured results from the pre-manufacturing test models submitted when it is time to license an antenna. In the case of directional TV antennas, quality control of antenna patterns is obtained by making near-field measurements directly on the radiating elements of the antennas to obtain relative field strength and phase values that permit synthesizing the far-field patterns of antennas without moving the antennas off their manufacturing stands. This approach provides considerable savings in both time and cost for antenna manufacturers and ultimately for the purchasers of their antennas. Full-size, far-field range testing remains available from at least some manufacturers to those willing to pay extra for it. In the cases of directional FM antennas, since it often is the data collected during the initial modeling exercise that is submitted at the time of licensure, the accuracy obtained can be less than it might be with more modern methods because of issues like the difficulties in obtaining high accuracy caused by ground reflections on full scale test ranges, the inaccuracies that occur in scaling up from reduced-size models to full-size antennas due to the dielectrics used on some components not scaling linearly, echoes inside small anechoic test chambers that are not truly anechoic, difficulties modeling details accurately, and so on.

When comparing the three fundamental broadcast services and the treatment of their directional antennas in the Commission's rules, the AM antenna rules were updated over a decade ago (in 2008, after an effort begun in 1991[13]) to permit use of the Method of Moments computer modeling system, based on the Numerical Electromagnetic Code (NEC) developed at the Lincoln Laboratories Federally-Funded Research and Development Center (FFRDC) at MIT. The rules enabling use of the Method of Moments apply to a large proportion of AM directional antennas in use in the U.S., but not all. Nevertheless, they permit many directional AM arrays to be (re-)constructed directly from computer models without the need for building test antennas to measure ground conductivity and without the need for repeatedly taking many field measurements over a large geographic area in order both to tune and to prove the performance of an antenna array. Also avoided are previously required periodic license parameter readings and periodic monitor point readings. Thus, the payoff can be much simpler pattern maintenance and need for much less frequent field testing. Over time, the Method of Moments has proved sufficiently accurate and reliable that the FCC updated the relevant rule further in 2017 to eliminate requirements for "new reference field strength measurements" upon filing of "subsequent license applications for the same directional antenna pattern and physical facilities" and to permit use of Method of Moments techniques on a wider range of AM antenna designs, among other relaxations.[14]

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[13] By the broadcast engineering consulting firms of Hatfield and Dawson; duTreil, Lundin, and Rackley; Lahm, Suffa & Cavell; Moffett, Larson & Johnson; and Silliman & Silliman.

[14] FCC MB Docket No. 13-249, FCC 17-119, In the Matter of Revitalization of the AM Radio Service, Published November 3, 2017, 82 FR 51161.

As has been discussed above, the TV/DTV rules already are flexible enough to permit use of computer modeling both for design of antenna patterns and for testing of resulting antenna performance without the need for physical models, either full size or scaled down, which add time and cost to the delivery of a directional transmitting antenna. That leaves only directional antennas for FM broadcasting with the requirements and burdens of having to go through the steps of first building models of antennas, measuring those models and collecting the related data, manufacturing and installing the antennas, and then submitting the data collected from the models, along with certifications by engineers and surveyors that the installations were performed correctly, in order to license the facilities.

It is worthy to note that, in the recent television spectrum repack, as some TV stations moved from UHF to Low-VHF, they needed new directional Low-VHF antennas. In several cases, the designs used were those of FM directional antennas scaled to be larger, to work at the lower frequencies of TV Channels 2 – 6. Because they were to be licensed for use by TV stations, the new Low-VHF antennas could be developed and proved with all the latest computer modeling techniques for design, manufacturing adjustment, and quality control. Had those very same antenna designs and patterns been constructed for the purpose of use a few MHz higher, in the FM band, only because of the differences in the FCC rules, it would have been necessary to physically model them prior to building them and to physically measure them to collect data for submission to the FCC during the licensing process. It also should be appreciated that, had computer modeling not been permissible for design of directional television antennas, it would have been essentially impossible for the industry to design, manufacture, test, and install the nearly 1000 antennas that had to be replaced to successfully complete the Post-Incentive Auction Spectrum Repack in the minimal time allowed for the process.

The FCC has, over a long period and a wide range of technologies, accepted computer modeling of systems or effects about which it sought input during its processing of applications of various kinds. One example of the Commission's acceptance of computer modeling is found in the FCC rules for RF radiation exposure evaluation, as applied to portable devices. In August 1996, it added language to its rules on the subject in §2.1093(d)(3), which said, "Compliance with SAR limits **can be demonstrated** by either laboratory measurement techniques or **by computational modeling**. [*Emphasis added*.] Methodologies and references for SAR evaluation are described in numerous technical publications including 'IEEE Recommended Practice for the Measurement of Potentially Hazardous Electromagnetic Fields – RF and Microwave,' IEEE C95.3-1991."[15] [Last sentence subsequently replaced.]

A description of the use of computational modeling for demonstrating SAR limit compliance of a portable device was published in 2015.[16] In an article in the in-house magazine of Ansys, Inc., the publisher of both Maxwell and HFSS modeling and analytical software packages, an engineer from Medtronic, one of the largest manufacturers of medical devices, described the use of computational modeling to predict the SAR levels produced by a wireless battery recharger to be used by those with subcutaneously implanted neurostimulators. The charging process involved passing RF energy in the 3 kHz to 300 kHz frequency range electromagnetically through skin and other tissues to a coil antenna under the skin. Both the Maxwell and HFSS programs were used – Maxwell to make the SAR predictions and HFSS to validate them. In addition, a physical instance of the power source was built, and its RF magnetic field energy was measured, with the results used to provide further validation of the SAR values predicted by the computational modeling. As shown in the paper, results of the finite element model (FEM) predictions matched the physical measurements and the alternative software validation tool to a high degree, with good accuracy. It should be noted that HFSS is one of the most widely used software modeling and design tools for development of both directional and non-directional broadcast antennas as well as high-power RF components of all types in the VHF and UHF spectrum regions.

[15] 61 FR 41017, Aug. 7, 1996

[16] V. Gaddam, "Charged Up," Ansys Advantage, Vol. IX, Issue 1, 2015, published by ANSYS, Inc., Canonsburg, PA, available at https://www.ansys.com/about-ansys/advantage-magazine/best-of-high-tech-2016/charged-up. Last checked 5 November 2020.

III. Issues with Physical Modeling and Example Showing that Computer Modeling Is At Least as Accurate as Physical Measurements, If Not More So

There currently are several software programs that can be used for modeling antennas as well as environmental objects in proximity to the antennas, plus filters, transmission lines, hybrids, lumped constant RF components, and so on. The modeling usually involves representation of the structures and shapes of objects in three dimensions. Analysis typically involves capacitance, inductance, impedance, phase, voltage standing wave ratio (VSWR), voltage breakdown, return loss, and other effects that exist between elements of an electromagnetic design. Importantly, such elements can include all the same structures that would be included, using current methods, in physically modeling an antenna in the environment in which it will be installed, but with greater precision. Moreover, since the modeling takes place in a computer, without the need for fabrication of structures and appurtenances and without the need to maintain large inventories of tower sections and other structures that exist in the environments in which such antennas are installed, it becomes practical to include more detailed and smaller elements that exist on the antenna supporting structure and in the surrounding environment, leading to more accurate results. Examples of the software programs available are several implementations and derivatives of the Numerical Electromagnetic Code (NEC) and the Method of Moments (MoM), both mentioned previously; High Frequency Structure Simulator (HFSS), based on 3D Finite Element Method (FEM) techniques; CST Microwave Studio; and others. Most of the software packages are based upon "solvers" that are useful for addressing specific design aspects. Consequently, modeling often may involve use of multiple programs, depending on particular design and environmental issues to be studied.

A. Range Measurement Inaccuracy

Important aspects of range-based antenna pattern measurements, whether full-scale or scale-modeled, far-field or conducted in anechoic chambers, are the alignment and reflectivity of the ranges used. Alignment typically relies on mechanical bore-sighting, with an assumption that an antenna used to transmit signals to an Antenna Under Test (AUT – regardless of whether it ultimately will be a transmitting or a receiving antenna) is perfectly electrically aligned, which electrical alignment perfection depends, in turn, on mechanical alignment accuracy. Accuracy of the testing process consequently is constrained by both mechanical and electrical deviations from the assumed perfect alignment, which deviations naturally will occur.

The principal reasons for deviation of patterns from those expected from idealized ranges are reflections from the range surface(s), unaccounted-for surrounding objects, positioner errors, and cables used to feed the antennas. Sometimes signals from external sources also pose problems. The total field at a point in space is the phasor sum of the test signal and any extraneous signals. The relative amplitudes and phases of the desired and extraneous signals will vary with position along the test aperture, causing constructive and destructive additions, thereby producing a measured pattern that will deviate from the pattern that would have been produced had it been measured in free space.[17]

B. Mechanical Tolerances and Human Error with Physical Modeling

Software eliminates lengthy set-up and take-down of models as well as the need for a technician to be physically present to adjust the model and take data points by hand. Accuracy is greatly improved using simulation, as it removes mechanical tolerances and human error affecting the data. In the case of FM pattern studies, information that traditionally has been recorded by hand, such as radiator locations and parasitic element sizes and locations in space are replaced by simply exporting parameters from a computer model. The full three-dimensional model can be sent directly to 3D Computer Aided Design (CAD) software to produce detailed component manufacturing and installation documentation, eliminating the likelihood of documentation error and physical measurement inaccuracies. Flow charts that show typical steps in the transfer of information for both physical-model and computer-simulation procedures are depicted in Figures 2 and 3, respectively.

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[17] Paraphrased from: Schadler, John L., "VHF and UHF Television Antenna Test Range Measurements," National Association of Broadcasters Engineering Handbook, 11th Edition, Copyright 2018, Garrison C. Cavell, Editor-In-Chief, Chapter 10.8, pp. 1883 – 1893.

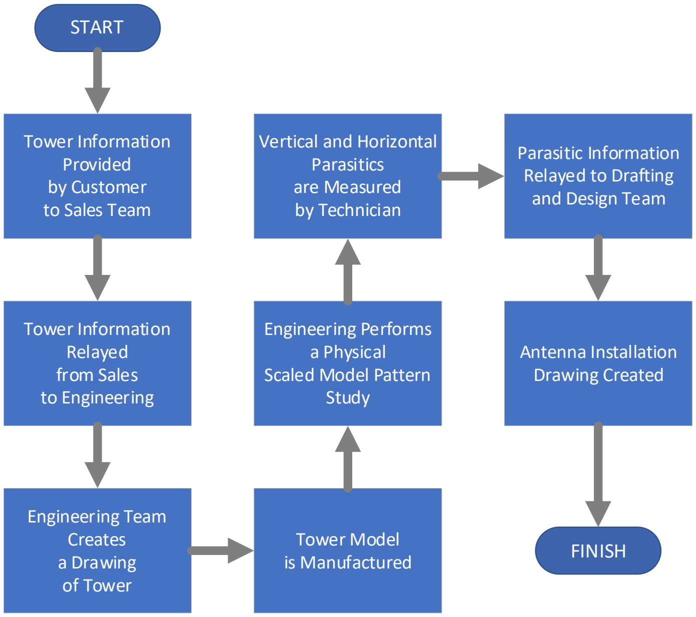


Figure 2 – Information Flow Chart for Physical Model Pattern Study

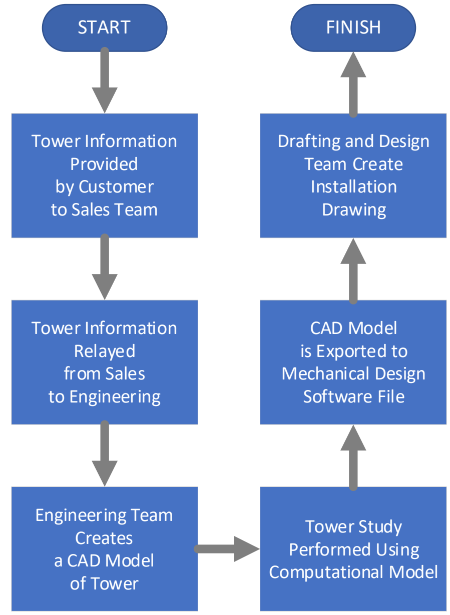


Figure 3 – Information Flow Chart for Computational Model Pattern Study

From the flow charts, it is evident that the transfer of information in the computer pattern study procedure is significantly more efficient and less likely to inherit errors during the transfer of information. Drafting and design personnel can work with the exact models that were used in pattern study simulations. These models can be dimensioned directly and transformed into working installation diagrams for customers. In addition to minimizing error possibility, this approach significantly reduces the time and resources needed to perform pattern analyses. For instance, only virtual tower models are necessary to complete simulation-based studies, as opposed to requirements for both drawn models and physical constructs for scaled or full-size physical-model pattern studies.

C. Automated Optimization

Another advantage of designing in a virtual environment is that component geometry can be completely optimized and not compromised by time, materials, and/or tolerances. Many variables can be adjusted automatically and systematically, with complete data tables exported for next steps in design processes. These results can be obtained through optimization algorithms that sequentially vary any number of parameters, simultaneously analyzing any combination of pattern shapers, parasitic elements, and radiator dimensions along with positions in space to find best-fit solutions. Trial and error techniques traditionally used to develop the geometry necessary to produce desired patterns are replaced by such artificial intelligence optimizing processes. Solution criteria are set based on desired azimuth pattern results and requirements of FCC rules, and multiple antenna design configurations can be studied in parallel to reduce overall analysis time.

D. Significance of Polarization Ratio Determination

The FCC rules in §73.316(a) state that supplemental vertically polarized effective radiated power (ERP) required to achieve circular or elliptical polarization cannot exceed the ERP authorized in the horizontal plane. Since, in most cases, broadcasters consider the vertically polarized components to be more important than the horizontally polarized components and therefore tend to maximize their vertical signals, accurate polarization measurements are important. Accurately range-measuring the power ratio of horizontally and vertically polarized components at any point in space is difficult, since no range is completely free of reflections. The facts that horizontally and vertically polarized waves reflect from surfaces differently and that there are inherent limitations in the pattern congruence of horizontally and vertically polarized radiation in test antennas compromise accuracy. If a test antenna is linearly polarized and is rotated from horizontal to vertical for polarization tests on an antenna, an assumption is made that the beam is perfectly straight and has no wobble. If separate radiation paths are used to measure the two polarizations, such as by switching between crossed dipoles, an assumption is made that the patterns and gains of the two paths are identical. In reality, each of these approaches includes sources of error due to failures of the attendant assumptions, which errors can be eliminated through use of 3D high frequency simulation. Since simulations are computed in true free-space environments, any undesired effects of surrounding environments, of anechoic chambers, or of asymmetric test antennas are eliminated, resulting in more accurate azimuth patterns and H/V ratio values.

E. Comparison of Physical and Computational Models

To show the validity of computer modeling in place of physical modeling of FM directional antennas, an example design developed using both methods, i.e., physical modeling and computational modeling of the same antenna for comparison with one another, has been provided by one of the signatories to this petition.

In the example design, a directional pattern study for Station WHEM, 91.3 MHz, Eau Clair, WI, was performed on a scale model FM test range on October 1, 2015, using a scaling factor of 4.4:1 for all elements involved in the study. The scaled elements included a model of an antenna bay and identically scaled models of parasitic elements and the mounting pipe to be used by the station. All the scaled-model components were rotated through 360 degrees while receiving a signal at the appropriately-scaled frequency from a linear cavity-backed source antenna. The horizontally and vertically polarized azimuth patterns were measured in an anechoic chamber test range. The signal source and scale-model antennas (the latter used as a receiving antenna) were mounted at identical elevations and at opposite ends of the test chamber. A network analyzer was used to supply the RF signal to the source antenna at 4.4 times the fundamental FM frequency (i.e., at 401.72 MHz) and to receive the signal intercepted by the antenna under test. Photographs of the scale-model pattern study configuration are shown in Figures 4 - 7.

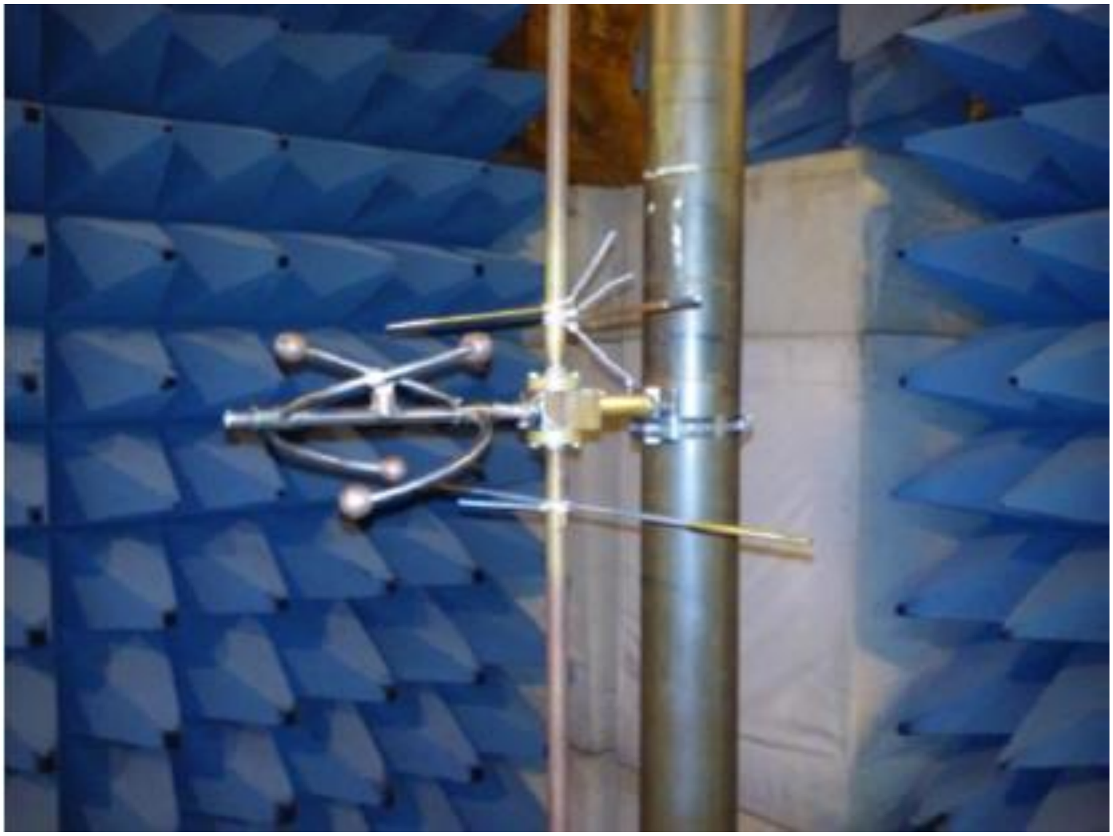


Figure 4 – Isometric View of Scaled Physical Model Used for Pattern Study in Anechoic Range

Figure 5 – Side View of Scaled Physical Model Used for Pattern Study in Anechoic Range

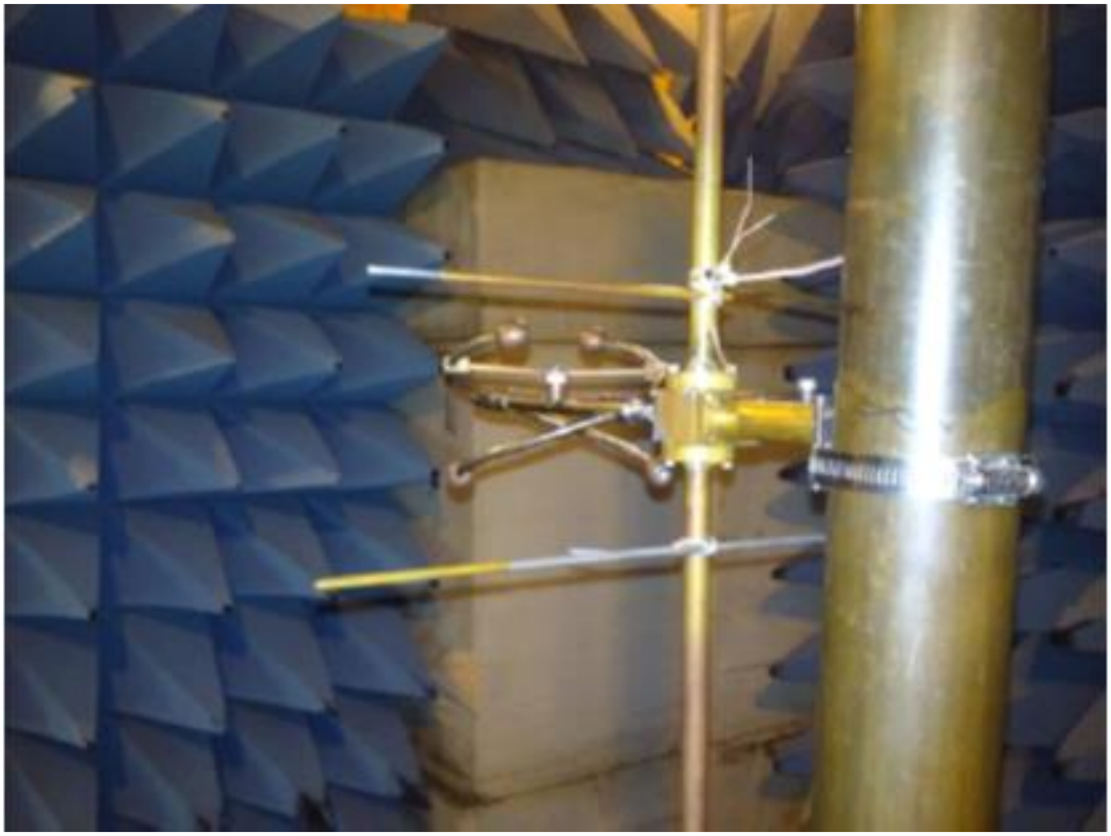


Figure 6 – Rear View of Scaled Physical Model Used for Pattern Study in Anechoic Range

Figure 7 – Overhead View of Scaled Physical Model Used for Pattern Study in Anechoic Range

The received signal strength was converted to a relative level, referenced to the source. The relative level was stored on a computer that also acted as the master controller for the test system. The computer controlled the measurement system via an IEEE-488 control bus. The final antenna installation drawing provided to the customer is attached in Appendix B. The pattern packet validating antenna proof of performance based on the scale model measurements is attached in Appendix C.

The physical, scale-model directional pattern study was replicated in an Ansys HFSS software environment on January 27, 2020. The computational model pattern study was performed in a simulated free-space environment using a full-scale CAD model of the antenna bay, the parasitic elements, and the mounting pipe at the fundamental frequency of 91.3 MHz. Screen captures of this pattern study configuration are provided in Figures 8 - 10.

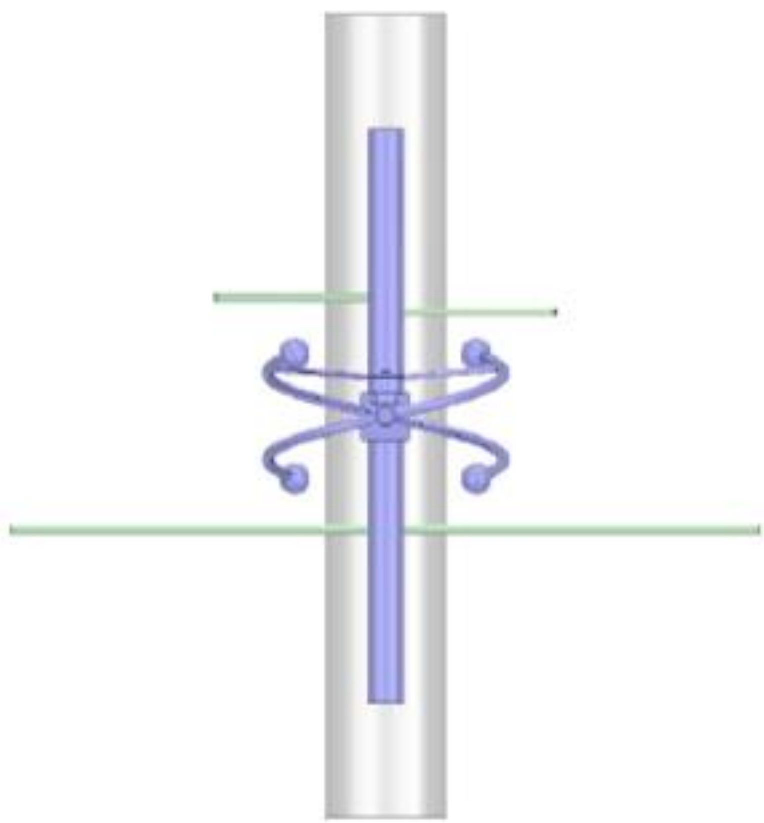


Figure 8 – Front View of Full-Size Computational Model Used for Pattern Study

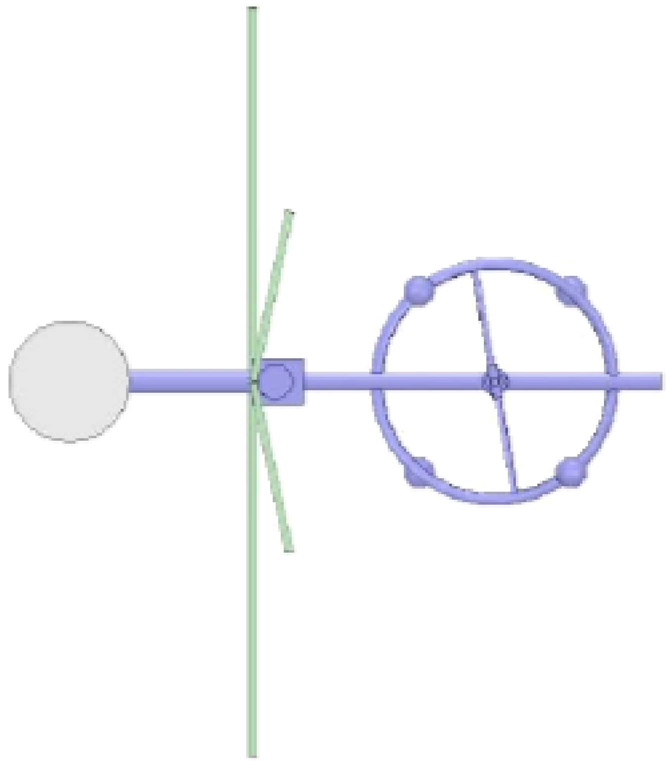


Figure 9 – Overhead View of Full-Size Computational Model Used for Pattern Study

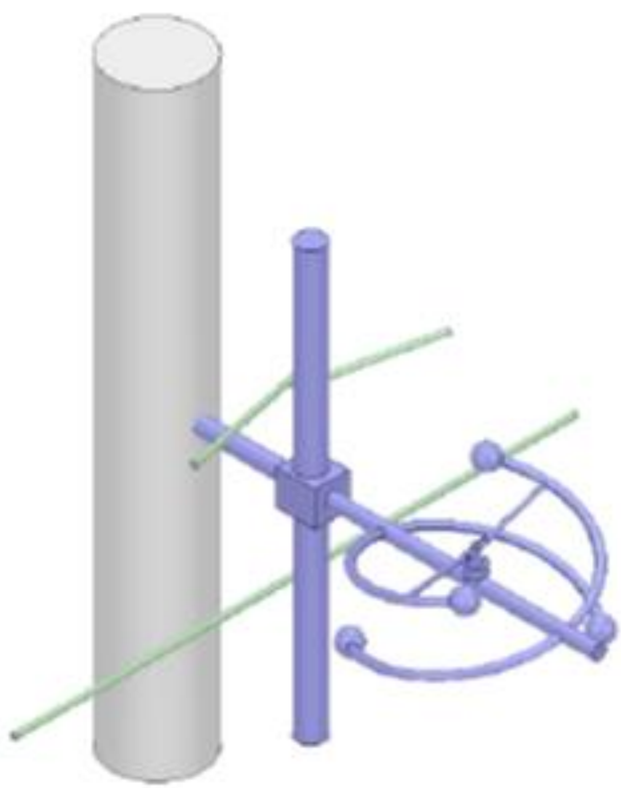


Figure 10 – Isometric View of Full-Size Computational Model Used for Pattern Study

Results of the physical, scale-model, directional pattern study were accepted by the broadcaster and demonstrate proof of performance and FCC pattern envelope compliance in the azimuth patterns of both the horizontally and vertically polarized signal components. Results of the computational model directional pattern study closely parallel those of the scale-model study. The horizontally polarized signal component azimuth pattern of the computationally simulated antenna shows a maximum positive deviation of 1.67 dB and a maximum negative deviation of 1.39 dB referenced to the horizontally polarized signal component azimuth pattern of the scaled physical model antenna. Figure 11 displays the overlaid horizontally polarized azimuth patterns and the FCC pattern mask. Azimuth pattern relative field data tabulations for the two horizontally polarized pattern studies are attached in Appendix D.

The vertically polarized signal component azimuth pattern of the computationally simulated antenna shows a maximum positive deviation of 1.00 dB and a maximum negative deviation of 0.59 dB referenced to the vertically polarized signal component azimuth pattern of the scaled physical model antenna. Figure 12 displays the overlaid vertically polarized patterns and the FCC pattern mask. The figure shows that the computationally simulated antenna exceeds the FCC pattern mask in the vertical polarization pattern by a minimal amount. Azimuth pattern relative field data tabulations for the two vertically polarized pattern studies are attached in Appendix E.

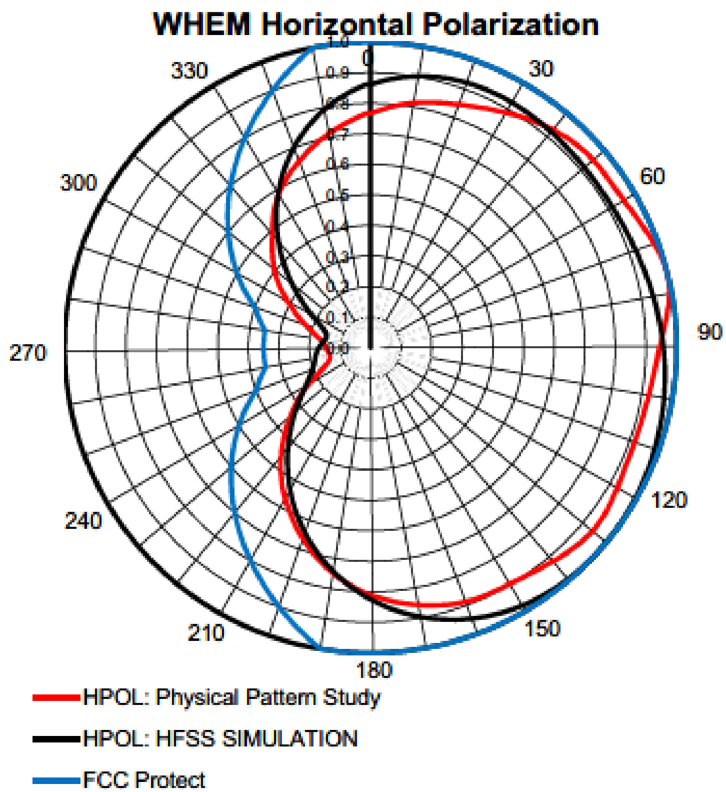


Figure 11 – Comparison of Horizontal Component Scale-Model Physical Pattern Measurement with Computational Model Results

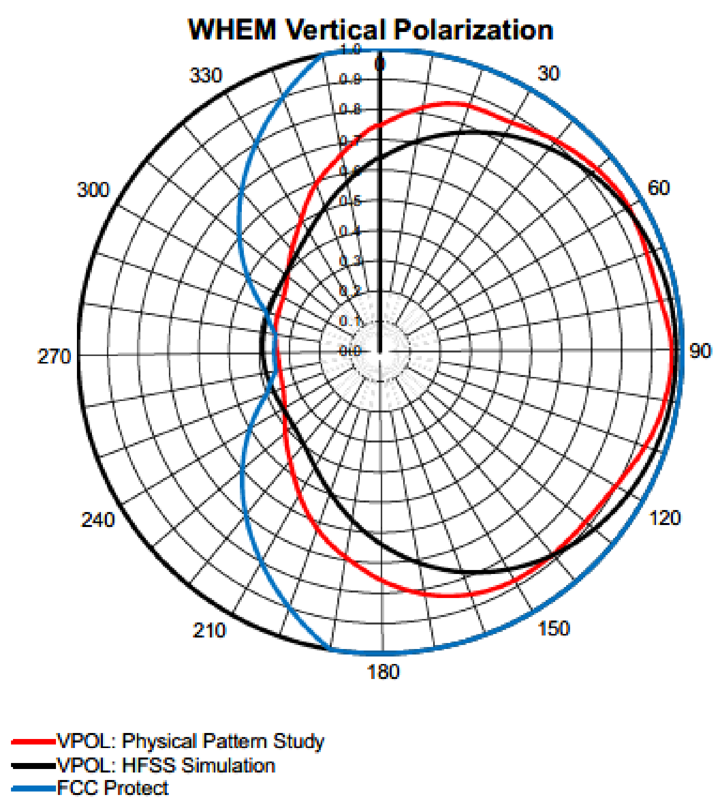


Figure 12 – Comparison of Vertical Component Scale-Model Physical Pattern Measurement with Computational Model Results

IV. THE COMMISSION SHOULD REVISE ITS RULES TO MAKE COMPUTATIONAL MODELING EQUIVALENT TO, AND ACCEPTABLE IN LIEU OF, PHYSICAL MEASUREMENTS FOR CHARACTERIZING DIRECTIONAL PROPERTIES OF FM RADIO TRANSMITTING ANTENNAS

Turning to the requirements currently in the Commission's rules with respect to the information necessary to be included in applications for FM directional antennas, requirements related to construction permit applications are specified in §73.316(c)(1), and requirements related to license applications are specified in §73.316(c)(2). For construction permits, only a tabulation of the proposed composite directional antenna (azimuthal) pattern is required. For licenses, a long list of items to be included in applications is specified in the rule. These items include a complete description of the antenna and its design, a plot of the composite pattern of the antenna in relative field values, a tabulation of measured relative field values at the bearings included in the pattern data submitted with the construction permit application, a statement about the mounting of the antenna on the tower, a statement about the structure of the tower on which the antenna is mounted, a statement that no other antenna shares the aperture with the antenna to be licensed, a statement of the qualifications of the engineer overseeing the antenna installation and certifying that it has been installed per its manufacturer's instructions, a statement from a licensed surveyor that the antenna is correctly oriented, and statements as to the RMS of the antenna and its coverage of its community of license.

It is noteworthy that a statement of the qualifications of the engineer overseeing the antenna installation is required, but no similar statement is required with respect to the qualifications of the engineer designing the antenna, even though the design has far more to do with the performance of the antenna than does the installation. It is the design engineer who will determine which elements of the tower, of its appurtenances, and of the surrounding environment to represent in the model of the tower and antenna, be it full size or scaled. It is the design engineer who will determine the antenna elements and components to be used and the materials of which they are constructed, their dimensions, and other parameters. When scale models are used, it is the design engineer who will determine how to scale such components as dielectrics, the characteristics of which may not be linearly related to just their physical sizes. It is the design engineer who will specify the installation procedures to be followed, as included in the manufacturer's instructions that the engineer overseeing the antenna installation will certify to having followed. Yet only the installation supervisor must be qualified and his/her qualifications provided. But it is the design engineer who can make a calculation or decision that could cause the intended antenna performance to appear in documentation and/or measurements but not in practice.

Effectively, the FCC has entrusted manufacturers with establishing criteria for knowledge and experience in their hiring of engineers who perform design tasks, while requiring those who follow a manufacturer's installation checklist to establish their qualifications directly with the Commission. Manufacturers effectively certify to their customers that the design engineers they employ have the knowhow to design the antennas that are needed for specific applications. Given the success of the antenna manufacturing industry over the last 60+ years in delivering directional FM antennas that produce expected results in terms of providing service where it is needed while avoiding interference to neighboring stations, it is clear that the Commission's choice to entrust manufacturers with qualifying design engineers was a good one.

In the past, manufacturers of FM directional antennas needed to hire or train design engineers who had experience building antennas at full or reduced scale and who knew which environmental elements that would be in proximity to an antenna, once installed, should be included in modeling of the antenna during the design process and during the taking of measurements required for filing with the Commission at the time of licensing. The tools available, when the initial version of the current rules for FM directional antennas first appeared in 1963, only included full-size or scaled modeling of antennas, combined with physical measurements, to approximate the characteristics that would be obtained when an antenna was installed. In the decades since then, computational methods have evolved to enable more accurate and precise predictions of the antenna performance that would be obtained with particular material characteristics, component shapes, dimensions, and other parameters used in the manufacturing of an antenna, in combination with the various materials and shapes of objects that would be in proximity to the antenna once it was installed.

To achieve the results of which the new computational methods are capable, it remains necessary for those using the newer modeling tools to have both the experience and expertise necessary to decide which elements in the environment near an antenna to include in modeling it and the accuracy required in modeling those elements, as well as all the skills needed for designing antennas. Thus, aside from the experience of physical construction of antenna models, the qualifications for antenna design engineers remain the same regardless of whether physical or computational models are used in the design and in predicting the performance of directional FM antennas. The computational models have the advantage, however, of permitting communication of numerical descriptions of components from computational modeling systems directly to computer numerical control (CNC) machinery that then can produce the components far more accurately and repeatably than can be obtained using manual methods, thereby obtaining the desired results more reliably.

The FCC has for decades entrusted manufacturers of FM directional antennas with engaging personnel who can apply the necessary skills to designing such antennas. The basic knowledge, experience, and expertise requirements with respect to antenna design and modeling remain the same when the newer computational modeling techniques are applied as was the case prior to their availability. The obligation on the part of the antenna manufacturers to deliver the antennas that they specify remains to the stations that acquire their products, while only the installation of the antennas currently requires certification to the FCC by engineers who provide their qualifications. It therefore stands to reason that the manufacturers of FM directional antennas should be permitted to apply the new tools at their discretion and that the FCC should accept the results of computational modeling as being just as valid as the results from physical construction and measurement of either full-size or scaled models of such antennas.

Nevertheless, to establish confidence in the results of designs created using computational modeling and to avoid having the permissive use of such tools abused by those without the necessary skills, it is proposed that a provision be added to the rules to directly address the latter possibility. The new provision is proposed to be inserted in new $73.316(c)(2)(iv) (with other provisions of §73.316(c)(2) starting at the current (iv) be incremented by one to higher numbers, i.e., (v) through (x)). The proposed new provision is largely based on terms in §73.1690(c)(2)(iii) and would apply to both new and replacement designs of FM directional antennas. It would require that identification of the software tools used, the processes applied, the elements included in the models, the qualifications of the designers, and similar information be provided for each antenna for which computational modeling is applied in lieu of the making of measurements. All other proposed changes but one comprise additions of the words "or computationally modeled," or equivalent, adjacent to each relevant occurrence of "measured," to provide for the permissive use of computational modeling whenever measurements are required currently. The one exception is a new reference in §73.1690(c)(2)(iii) to the addition proposed for (new) §73.316(c)(2)(iv). All the proposed changes in rules text are presented in Appendix A hereto.

Wherefore, for the foregoing reasons, the Petitioners respectfully request the Federal Communications Commission to issue a Notice of Proposed Rulemaking proposing to adopt the language offered in Appendix A to authorize the use of computational modeling of FM directional antennas to derive pattern data in place of the making of physical measurements to acquire such data.

Respectfully submitted,

By: __/s/____________________
S. Merrill Weiss
Consultant to the Petitioners
Merrill Weiss Group LLC
227 Central Avenue
Metuchen, NJ 08840-1242

The Petitioners:

By: __/s/____________________
Keith L. Pelletier,
Vice President, General Manager
Dielectric, LLC
22 Tower Road
Raymond, ME 04071

By: __/s/____________________
Brandon J. George,
BDS Manager NA / Principal RF Engineer
Radio Frequency Systems
200 Pond View Drive
Meriden, CT 06450

By __/s/____________________
Sam Wallington,
Vice President of Operations and Engineering
Educational Media Foundation
5700 West Oaks Boulevard
Rocklin, CA 95765

By: __/s/____________________
Angela Gillespie
Vice President
Shively Labs
188 Harrison Road
Bridgton, ME 04009

By: __/s/____________________
Alex M. Perchevitch
President
Jampro Antennas, Inc.
6340 Sky Creek Drive
Sacramento, CA 95828

cc.: Albert Shuldiner, Chief, Audio Division, FCC Media Bureau
James Bradshaw, Senior Deputy Chief, Audio Division, FCC Media Bureau

Appendix A – Proposed FCC Rules Modifications to Permit Computational Modeling of Directional FM Antennas

In the proposed text that follows, additions are shown underlined. There are no deletions. Changes in paragraph numbering are shown with arrows pointing from current numbers to new numbers.

§73.316 FM Antenna Systems

(c) *Applications for directional antennas.*

(2) Applications for license upon completion of antenna construction must include the following:

(iii) A tabulation of the measured or computationally modeled relative field pattern required in paragraph (c)(1) of this section. The tabulation must use the same zero-degree reference as the plotted pattern and must contain values for at least every 10 degrees. Sufficient vertical patterns to indicate clearly the radiation characteristics of the antenna above and below the horizontal plane. Complete information and patterns must be provided for angles of –10 deg. from the horizontal plane and sufficient additional information must be included on that portion of the pattern lying between + 10 deg. and the zenith and –10 deg. and the nadir, to conclusively demonstrate the absence of undesirable lobes in these areas. The vertical plane pattern must be plotted on rectangular coordinate paper with reference to the horizontal plane. In the case of a composite antenna composed of two or more individual antennas, the composite antenna pattern should be used, and not the pattern for each of the individual antennas.

(new iv) When a directional antenna is computationally modeled, as permitted in paragraphs (c)(2)(iii) and (c)(2)(x) of this section and in §73.1690(c)(2), a statement from the engineer(s) responsible for designing the antenna, performing the modeling, and preparing the manufacturer's instructions for installation of the antenna, identifying the software tool(s) used in the modeling, the procedures applied with the software, and listing such engineers' respective qualifications. Such computational modeling shall include modeling of the antenna mounted on a tower or tower section, and the tower or tower section model must include transmission lines, ladders, conduits, other antennas, and any other installations that may affect the computationally modeled directional pattern.

Renumber iv → v

Renumber v → vi

Renumber vi → vii

Renumber vii → viii

Renumber viii → ix

(ix → x)(A) For a station authorized pursuant to § 73.215 or Sec. § 73.509, a showing that the root mean square (RMS) of the measured <u>or computationally modeled</u> composite antenna pattern (encompassing both the horizontally and vertically polarized radiation components (in relative field)) is at least 85 percent of the RMS of the authorized composite directional antenna pattern (in relative field). The RMS value, for a composite antenna pattern specified in relative field values, may be determined from the following formula:

RMS = the square root of:
[(relative field value 1)^2 + (relative field value 2)^2 + ... + (last relative field value)^2]
total number of relative field values

(B) where the relative field values are taken from at least 36 evenly spaced radials for the entire 360 degrees of azimuth. The application for license must also demonstrate that coverage of the community of license by the 70 dBu contour is maintained for stations authorized pursuant to § 73.215 on Channels 221 through 300, as required by § 73.315(a), while noncommercial educational stations operating on Channels 201 through 220 must show that the 60 dBu contour covers at least a portion of the community of license.

§**73.1620 Program Tests**

(a) Upon completion of construction of an AM, FM, TV or Class A TV station in accordance with the terms of the construction permit, the technical provisions of the application, the rules and regulations and the applicable engineering standards, program tests may be conducted in accordance with the following:
(3) FM licensees replacing a directional antenna pursuant to § 73.1690(c)(2) without changes which require a construction permit (see § 73.1690(b)) may immediately commence program test operations with the new antenna at one half (50%) of the authorized ERP upon installation. If the directional antenna replacement is an EXACT duplicate of the antenna being replaced (i.e., same manufacturer, antenna model number, and measured <u>or computationally modeled</u> composite pattern), program tests may commence with the new antenna at the full authorized power upon installation. The licensee must file a modification of license application on FCC Form 302–FM within 10 days of commencing operations with the newly installed antenna, and the license application must contain all of the exhibits required by § 73.1690(c)(2). After review of the modification-of-license application to cover the antenna change, the Commission will issue a letter notifying the applicant whether program test operation at the full authorized power has been approved for the replacement directional antenna.

§73.1690 Modification of Transmission Systems

(c) The following FM, TV and Class A TV station modifications may be made without prior authorization from the Commission. A modification of license application must be submitted to the Commission within 10 days of commencing program test operations pursuant to § 73.1620. With the exception of applications filed solely pursuant to paragraphs (c)(6), (c)(9), or (c)(10) of this section, the modification of license application must contain an exhibit demonstrating compliance with the Commission's radio frequency radiation guidelines. In addition, except for applications solely filed pursuant to paragraphs (c)(6) or (c)(9) of this section, where the installation is located on or near an AM tower, as defined in § 1.30002, an exhibit demonstrating compliance with § 1.30003 or § 1.30002, as applicable, is also required.

(2) Replacement of a directional FM antenna, where the measured or computationally modeled composite directional antenna pattern does not exceed the licensed composite directional pattern at any azimuth, where no change in effective radiated power will result, and where compliance with the principal coverage requirements of § 73.315(a) will be maintained by the measured or computationally modeled directional pattern. The antenna must be mounted not more than 2 meters above or 4 meters below the authorized values. The modification of license application on Form 302-FM to cover the antenna replacement must contain all of the data in the following sections (i) through (v). Program test operations at one half (50%) power may commence immediately upon installation pursuant to § 73.1620(a)(3). However, if the replacement directional antenna is an exact replacement (i.e., no change in manufacturer, antenna model number, AND measured or computationally modeled composite antenna pattern), program test operations may commence immediately upon installation at the full authorized power.

(i) A measured or computationally modeled directional antenna pattern and tabulation on the antenna manufacturer's letterhead showing both the horizontally and vertically polarized radiation components and demonstrating that neither of the components exceeds the authorized composite antenna pattern along any azimuth.

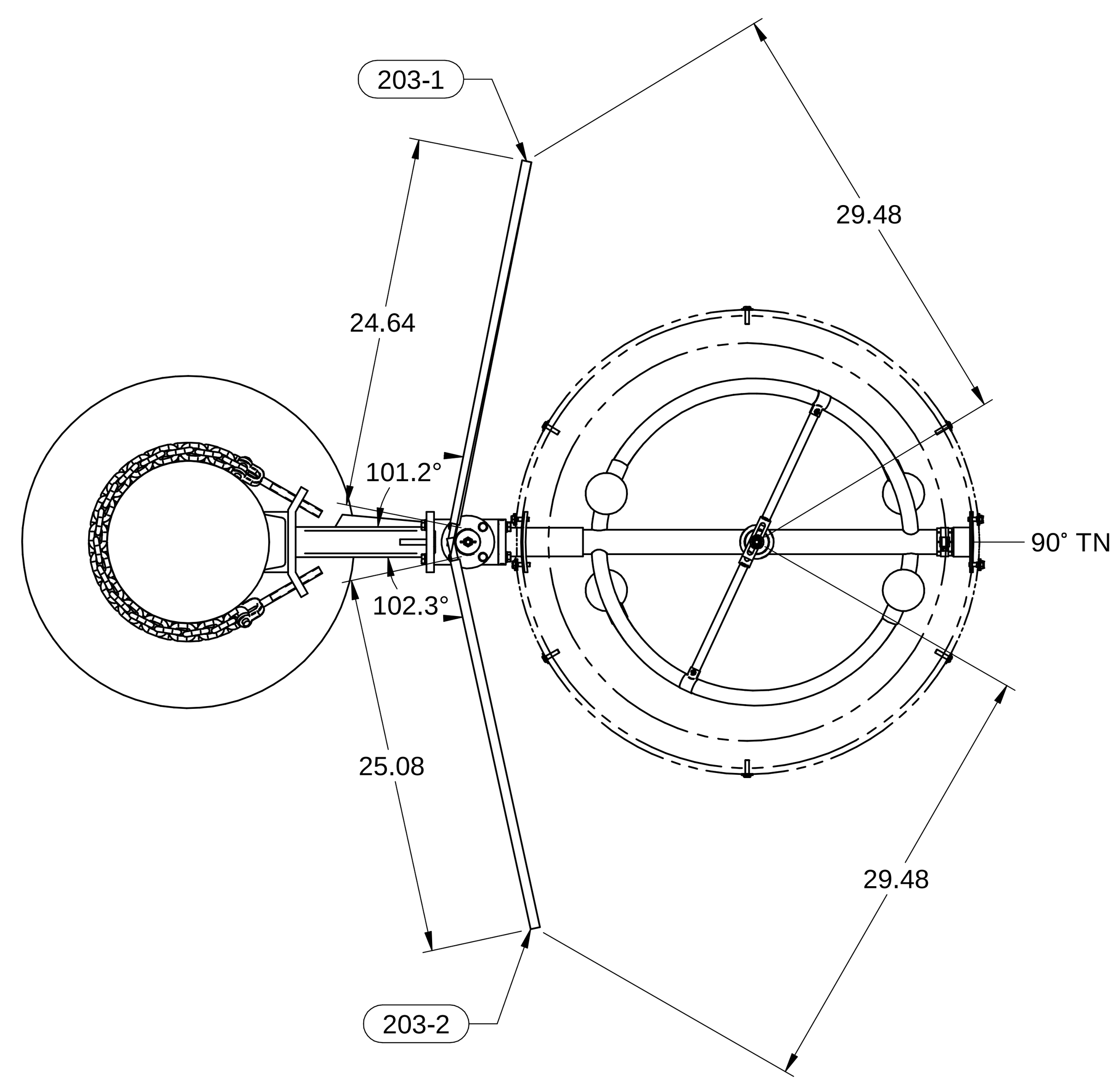
(ii) Contour protection stations authorized pursuant to § 73.215 or § 73.509 must attach a showing that the RMS (root mean square) of the composite measured or computationally modeled directional antenna pattern is 85% or more of the RMS of the authorized composite antenna pattern. See § 73.316(c)(9). If this requirement cannot be met, the licensee may include new relative field values with the license application to reduce the authorized composite antenna pattern so as to bring the measured or computationally modeled composite antenna pattern into compliance with the 85 percent requirement.

(iii) A description from the manufacturer as to the procedures used to measure or computationally model the directional antenna pattern. The antenna measurements or computational modeling must be performed with the antenna mounted on a tower, tower section, or scale model equivalent to that on which the antenna will be permanently mounted, and the tower or tower section must include transmission lines, ladders, conduits, other antennas, and any other installations which may affect the measured or computationally modeled directional pattern. See §73.316(c)(2)(iv) for details of the showings required in connection with applications filed related to FM directional antennas with data.

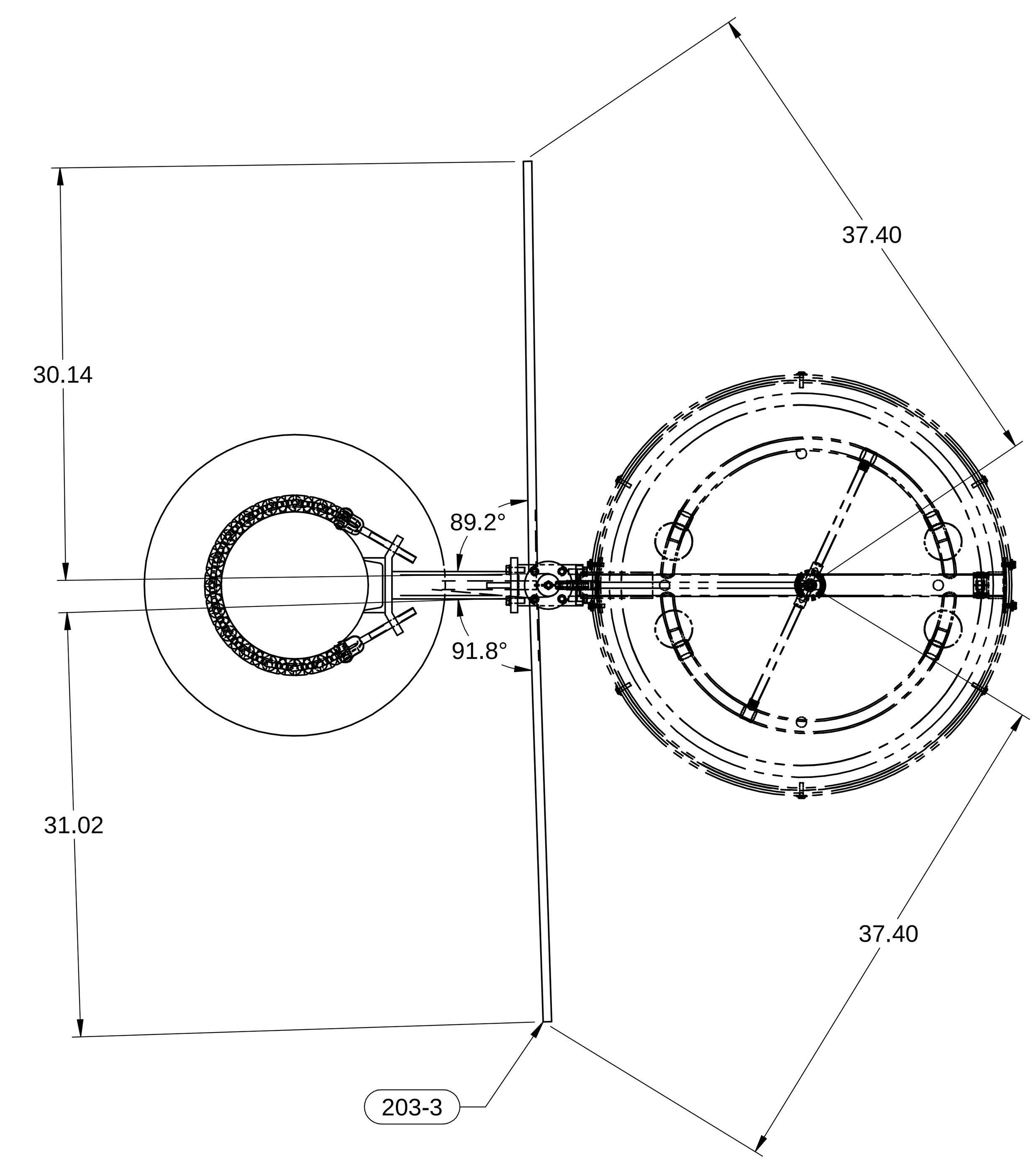
Appendix B – Antenna Installation Drawing

Appears on following page.

REV:	SHEET	ZONE	REVISION NOTE CAD MAINTAINED. CHANGES SHALL BE INCORPORATED BY THE DESIGN ACTIVITY.	ECO	DATE APPR
A			PRODUCTION RELEASE		10/23/15

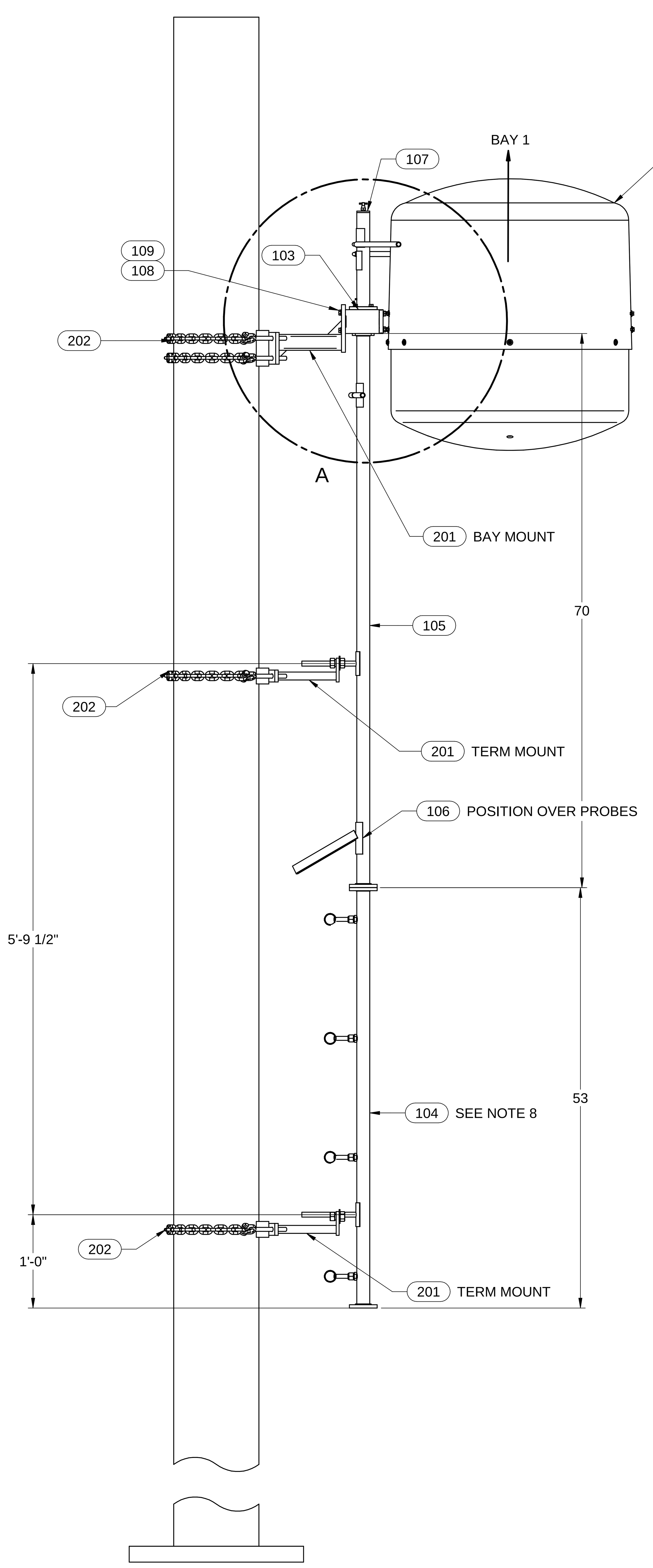


ITEMS 203-1 AND 203-2 SHOWN
ITEM 203-3 HIDDEN FOR CLAIRITY



ITEM 203-3 SHOWN
ITEMS 203-1 AND 203-2
HIDDEN FOR CLAIRITY

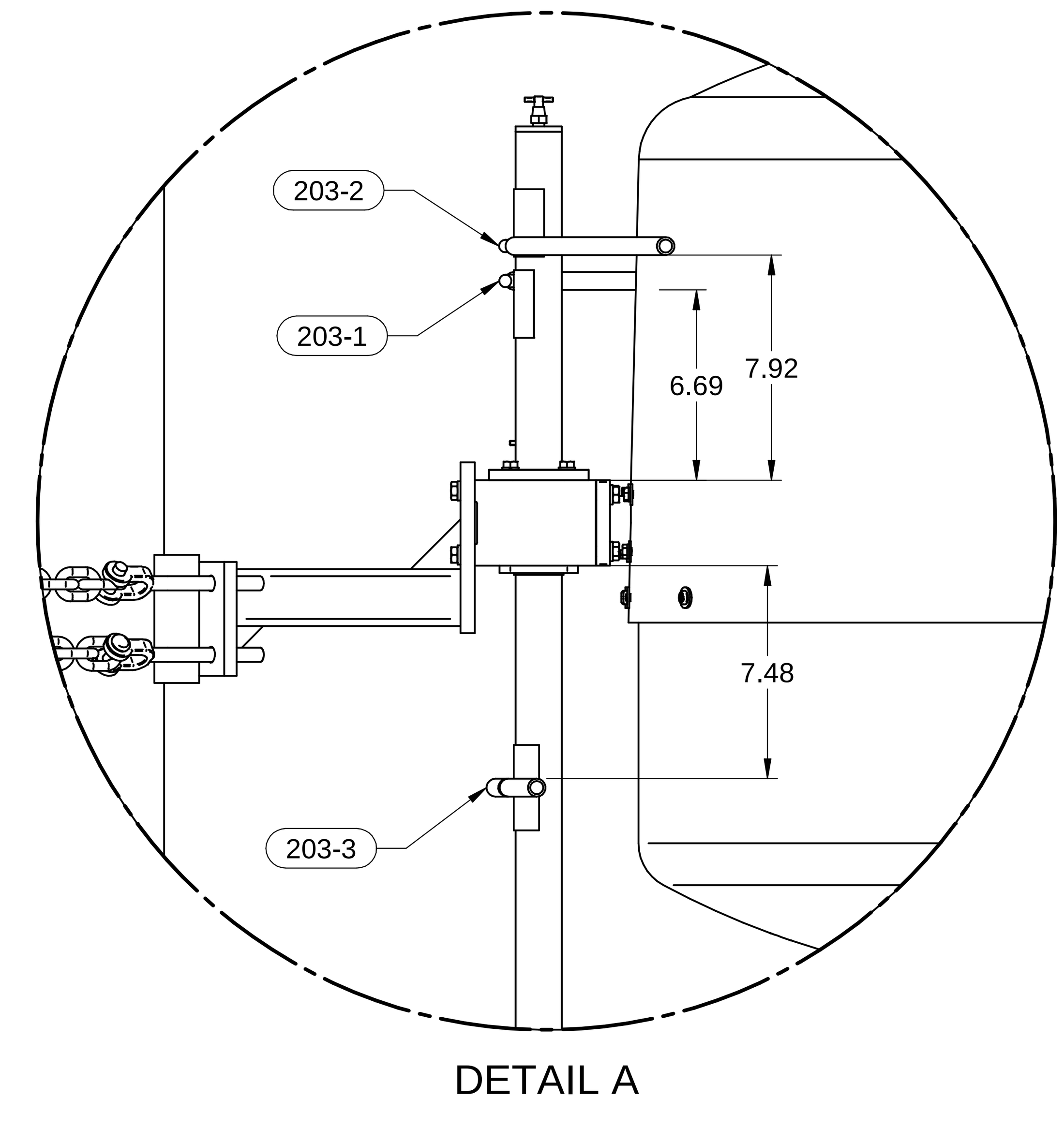
		ANTENNA BOM P/N 300003299		
ITEM NO	MATERIAL	MATERIAL DESCRIPTION	REQ'D QTY	UNIT
101	R86501	DCRH PLAIN BAY WITH RADOME	1	EA
103	R68429	JCT BLK END ASSY DCRH	1	EA
104	R75886	AFM 1-50 FM SHORT-STUB 53" LONG	1	EA
105	R80174	F/L INPUT SECT 1-50 x 70"	1	EA
106	R0046348501	ICE SHIELD KIT T/L 1-50 FM ANT	1	EA
107	R103326	EXTENSION TOP BLOCK 1-50 T/L	1	EA
108	R0023816125	HHCS SS 3/8-16X1.25	4	EA
109	R0163800000	LOCK WASHER SPLIT 3/8 SS	4	EA
		MOUNT BOM P/N 300003300		
ITEM NO	MATERIAL	MATERIAL DESCRIPTION	REQ'D QTY	UNIT
201	300003502	CUSTOM CHAIN MOUNT FOR 10. PIPE (Ø10.75)	1	EA
202	R15566	ANT MOUNT RETAINER 10.75 DIA	4	EA
203-1	300003503-1	PARASITIC KIT HORZONAL WHEM DCRH1ERD 91.3 MHz	1	EA
203-2	300003503-2	PARASITIC KIT HORZONAL WHEM DCRH1ERD 91.3 MHz	1	EA
203-3	300003503-3	PARASITIC KIT HORZONAL WHEM DCRH1ERD 91.3 MHz	1	EA
204	R0002187008	HOSE CLAMP 1.19-2.25 DIA	6	EA



INSTALLATION NOTES:

1. ANTENNA SHALL BE INSTALLED PER THIS INSTALLATION DRAWING. ANY DEVIATIONS WILL VOID WARRANTY UNLESS APPROVED BY DIELECTRIC.
2. TO ACHIEVE ANY GIVEN PATTERN STUDY PERFORMED BY DIELECTRIC, THE PROVIDED ANTENNA MUST BE INSTALLED AND ORIENTED AS DEPICTED IN THIS DRAWING. IF ANY SUCH PATTERN WAS NOT PROVIDED, THE ANTENNA ORIENTATION AND POSITION IS AT THE DISCRETION OF THE BUYER TO WHICH THE ANTENNA WAS SOLD. SHOULD ANY QUESTIONS ARISE DURING THE INSTALLATION PROCESS, CONTACT DIELECTRIC AT, 1-800-341-9678, TO ASSIST IN THIS PROCESS; BE PREPARED TO PROVIDE THE PART NUMBER OR DRAWING NUMBER SHOWN BELOW.
3. COMPONENTS ARE MATCH MARKED FOR EASE IN ASSEMBLY.
4. ITEM NUMBERS DEPICTED ON THIS DRAWING CORRESPOND TO ITEM NUMBERS LISTED ON ENCLOSED BILL OF MATERIAL.
5. APPLY THIN LAYER OF DC4 DOW CORNING COMPOUND TO ALL "O"-RING SEALS PRIOR TO ASSEMBLY.
6. UNLESS OTHERWISE SPECIFIED, THE TOP BAY MUST NOT BE LOCATED ANY CLOSER THAN 5 ft. BELOW THE TOWER TOP.
7. BAY TAP POINT DIRECTION INDICATED BY ARROWS LOCATED IN THE BAY IN ELEVATION VIEW.
8. THE VARIABLE TRANSFORMER IS SHIPPED WITH ALL PROBES FULLY INSERTED. AT INSTALLATION, BE CERTAIN TO LOOSEN LOCKNUTS AND PULL ALL PROBES TO FULL OUTWARD POSITION. ALL PROBES MUST BE IN FULL OUTWARD POSITION BEFORE POWERING UP ANTENNA. REFER TO INSTRUCTION MANUAL FOR TUNING INSTRUCTIONS.
9. SUGGESTED LOCATION FOR TERMINATION MOUNT. LOCATION MAY VARY PER TOWER DESIGN.
10. FOR HEATED ANTENNAS ONLY: HEATER HARNESS TO BE DRESSED AND SECURED TO TOWER PER INSTALLERS DISCRETION. LOOSE OR DANGLING WIRE IN RF FIELD WILL SHORT AND RESULT IN ANTENNA FAILURE.
11. REFER TO DRAWING A88212 FOR ALL HARDWARE TORQUE SPECIFICATIONS.
    * FOR FIBERGLASS APPLICATIONS, TORQUE MOUNTING HARDWARE TO 180 in-lbs (15 ft-lbs)
12. IT IS IMPORTANT TO MAINTAIN DOCUMENT FOR HISTORICAL PURPOSES. THE MOST CRITICAL PORTION OF INFORMATION TO BE MAINTAINED IS THE PART NUMBER AS SPECIFIED.
13. AFTER ANTENNA HAS BEEN INSTALLED AND TUNED ON THE TOWER, IT IS REQUESTED THAT A COPY OF THE TEST DATA BE FORWARDED TO:

    DIELECTRIC
    C/O FM ENGINEERING MANAGER
    22 TOWER RD. RAYMOND, ME. O4O71
    PHONE 1 – 800 – 341 - 9678



DETAIL A

UNLESS OTHERWISE SPECIFIED
MANUFACTURING TOLERANCE AND PROCEDURES MUST BE IN ACCORDANCE WITH D78691. ALL ALUMINUM, COPPER, AND BRASS WELDING MUST COMPLY WITH A-62700, SECT. XIV "PRODUCTION WELDING PROCEDURES". STRUCTURAL STEEL WELDING MUST COMPLY WITH "AWS 1.1 CURRENT REVISION".

STATUS: **RELEASED**

PART NO: / MATERIAL NO:
300003299 ANT
300003300 MNTS

SAP DOCUMENT NO:

MATERIAL:

FINISH:
N/A

REFER TO D8110 FOR PLATING
REFER TO D17800 FOR PAINT

DIMENSIONAL TOLERANCES
(UNLESS OTHERWISE NOTED)
DECIMAL DIMENSIONS
3 PLACE DIMENSIONS ±.005
2 PLACE DIMENSIONS ±.02
FRACTIONAL DIMENSIONS
0"-6" ±1/32"
ABOVE 6" UP TO 12" ±1/16"
ABOVE 12" UP TO 48" ±1/8"
ABOVE 48" ±1/4"
ANGULAR DIMENSIONS ±1/2°
REFERENCE DIMENSIONS ARE NOT FOR MANUFACTURING OR INSPECTION

ANGLE PROJECTION

	NAME	DATE
DESIGNED BY	rcmason	1/29/2019
DETAIL BY	rcmason	1/29/2019
CHKD. BY	dfolsom	10/15/15
ENG. 1 APPR.	rsmart	10/16/15
ENG. 2 APPR.	NJCB	10/22/15
MANUFACT.	jmayhan	10/22/15

Dielectric Raymond, ME

TITLE:
INSTALLATION
WHEM DCRH1ERD 91.3 FM
S0 42428

D	GAGE CODE 08441	DRAWING NO: 017A57000

3:17:15 PM SHEET: 1 OF 1

Appendix C – Antenna Proof of Performance Based on Scale Model Measurements

Dielectric

Proposal Number	**42428**
Date	**10/1/2015**
Call Letters	**WHEM**
Location	**Eau Claire, WI**
Customer	**WHEM**
Antenna Type	**DCRH1ERD**
Frequency	**91.3MHz**
Drawing #	**P17**

PATTERN CERTIFICATION

TABLE OF CONTENTS

Dielectric

Proposal Number	**42428**
Date	**10/1/2015**
Call Letters	**WHEM**
Location	**Eau Claire, WI**
Customer	**WHEM**
Antenna Type	**DCRH1ERD**
Frequency	**91.3MHz**
Drawing #	**P17**

PATTERN CERTIFICATION

Method of Measurement

The azimuth pattern for WHEM, Dielectric Document Sketch #P17, was measured in the following manner.

A single 4.4 to 1 scale model "DCRH1ERD" bay radiator was mounted on a similarly scaled model of the tower according to information provided to Dielectric by the customer; refer to Dielectric Document Sketch #P17. The antenna under test, all parasitics, all known tower appurtenances, and the tower section were rotated through 360 degrees while receiving a signal at the appropriate frequency from a linear cavity-backed source antenna. Both the horizontal and vertical polarization azimuth patterns were measured in an anechoic test range.

The transmit and scale model antennas are mounted at identical elevations and at opposite ends of the chamber. A Hewlett Packard model 8753ET network analyzer was used to supply the RF signal to the source antenna at 4.4 times the fundamental FM frequency and to receive the signal intercepted by the antenna under test. The received signal was converted to a relative level, referenced to the source. This level was stored on a computer acting as the master controller. The computer controls the measurement system via IEEE-488 control bus through a GPIB card.

Derek Small is a Sr. RF Engineer here at Dielectric. Derek received a BS in Electrical Engineering from the University of Maine in 1986. He has 29 years experience in RF engineering and has been employed by Dielectric since 2015.

Signed by: Derek J Small ______________________________

Date: 9/30/2015

Dielectric

Proposal Number	**42428**
Date	**10/1/2015**
Call Letters	**WHEM**
Location	**Eau Claire, WI**
Customer	**WHEM**
Antenna Type	**DCRH1ERD**
Frequency	**91.3MHz**
Drawing #	**P17**

FM AZIMUTH PATTERN APPROVAL

The azimuth pattern of the horizontal polarization and vertical polarization as supplied by Dielectric in the document labeled "Pattern P17", is acknowledged as acceptable. We understand that Dielectric does not guarantee or predict signal strength in any particular location.

____
(Customer's name)

By: ______________________________
(Name typed or printed)

Title: ______________________________

____
(Signature)

Dielectric

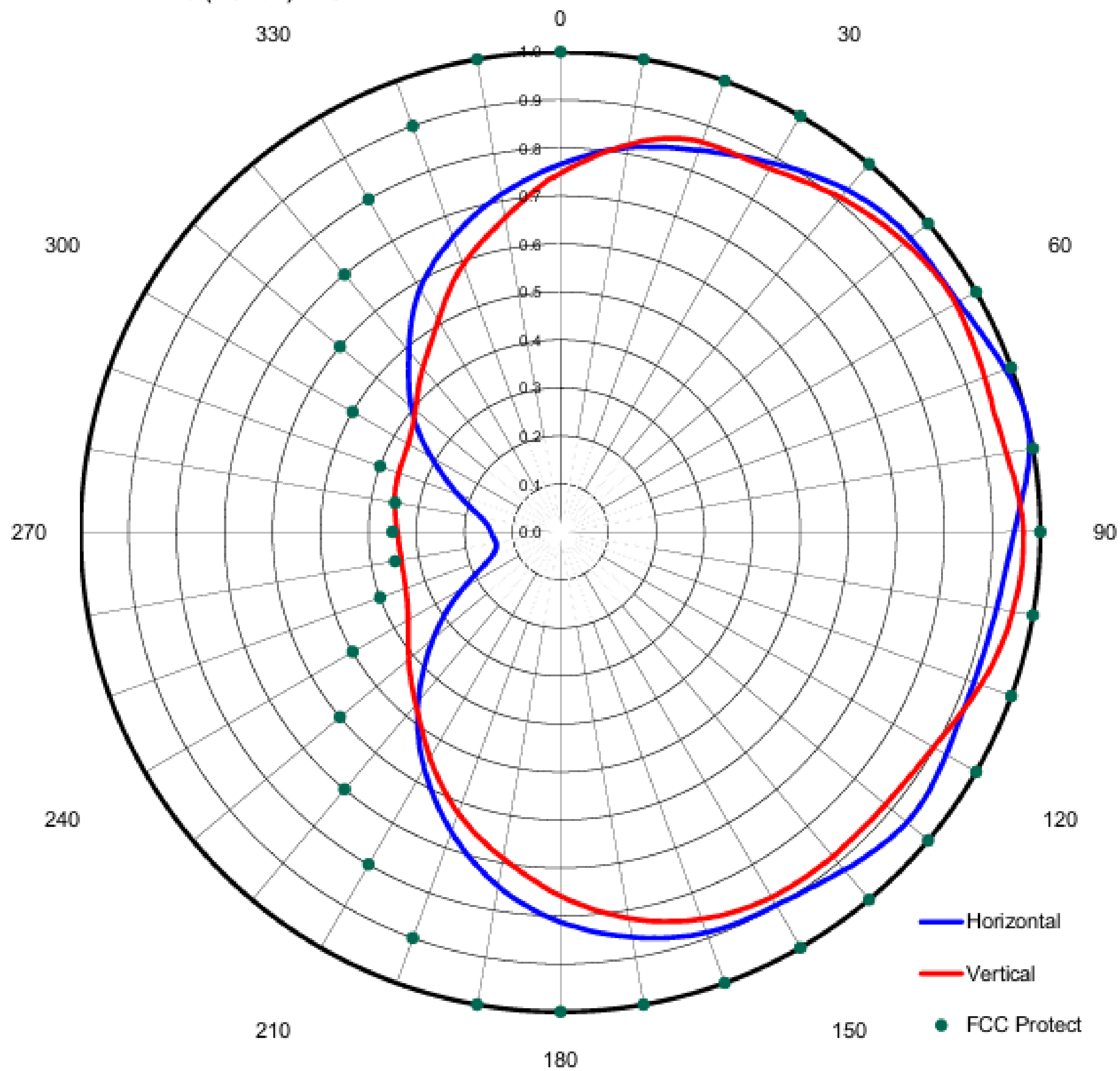
Proposal Number	**42428**
Date	**10/1/2015**
Call Letters	**WHEM**
Location	**Eau Claire, WI**
Customer	**WHEM**
Antenna Type	**DCRH1ERD**
Frequency	**91.3MHz**
Drawing #	**P17**

AZIMUTH PATTERN

86.42% Ccov 50.3% Hrms - 49.7% Vrms

Gain **1.87 (2.73 dB) HPOL** Calculated / Measured **Measured**

1.79 (2.52 dB) VPOL



Dielectric

Proposal Number	**42428**
Date	**10/1/2015**
Call Letters	**WHEM**
Location	**Eau Claire, WI**
Customer	**WHEM**
Antenna Type	**DCRH1ERD**
Frequency	**91.3MHz**
Drawing #	**P17**

TABULATION OF HORIZONTAL AZIMUTH PATTERN

	Angle	Field	dBk	ERP kW
		0.766	0.695	1.174
	10	0.813	1.212	1.322
	20	0.846	1.558	1.431
	30	0.887	1.969	1.574
	40	0.930	2.380	1.730
	50	0.952	2.583	1.813
	60	0.958	2.638	1.836
	70	0.987	2.897	1.948
	80	0.993	2.949	1.972
	90	0.946	2.528	1.790
	100	0.923	2.314	1.704
	110	0.917	2.258	1.682
	120	0.928	2.361	1.722
	130	0.942	2.491	1.775
	140	0.919	2.277	1.689
	150	0.898	2.076	1.613
	160	0.888	1.979	1.577
	170	0.857	1.670	1.469
	180	0.813	1.212	1.322
	190	0.749	0.500	1.122
	200	0.665	-0.533	0.884
	210	0.568	-1.903	0.645
	220	0.461	-3.716	0.425
	230	0.346	-6.208	0.239
	240	0.234	-9.605	0.110
	250	0.154	-13.239	0.047
	260	0.136	-14.319	0.037
	270	0.145	-13.762	0.042
	280	0.167	-12.535	0.056
	290	0.226	-9.908	0.102
	300	0.310	-7.162	0.192
	310	0.406	-4.819	0.330
	320	0.491	-3.168	0.482
	330	0.585	-1.647	0.684
	340	0.654	-0.678	0.855
	350	0.714	0.084	1.020
Additional Point	76	1.000	3.010	2.000

Dielectric

Proposal Number	**42428**
Date	**10/1/2015**
Call Letters	**WHEM**
Location	**Eau Claire, WI**
Customer	**WHEM**
Antenna Type	**DCRH1ERD**
Frequency	**91.3MHz**
Drawing #	**P17**

TABULATION OF VERTICAL AZIMUTH PATTERN

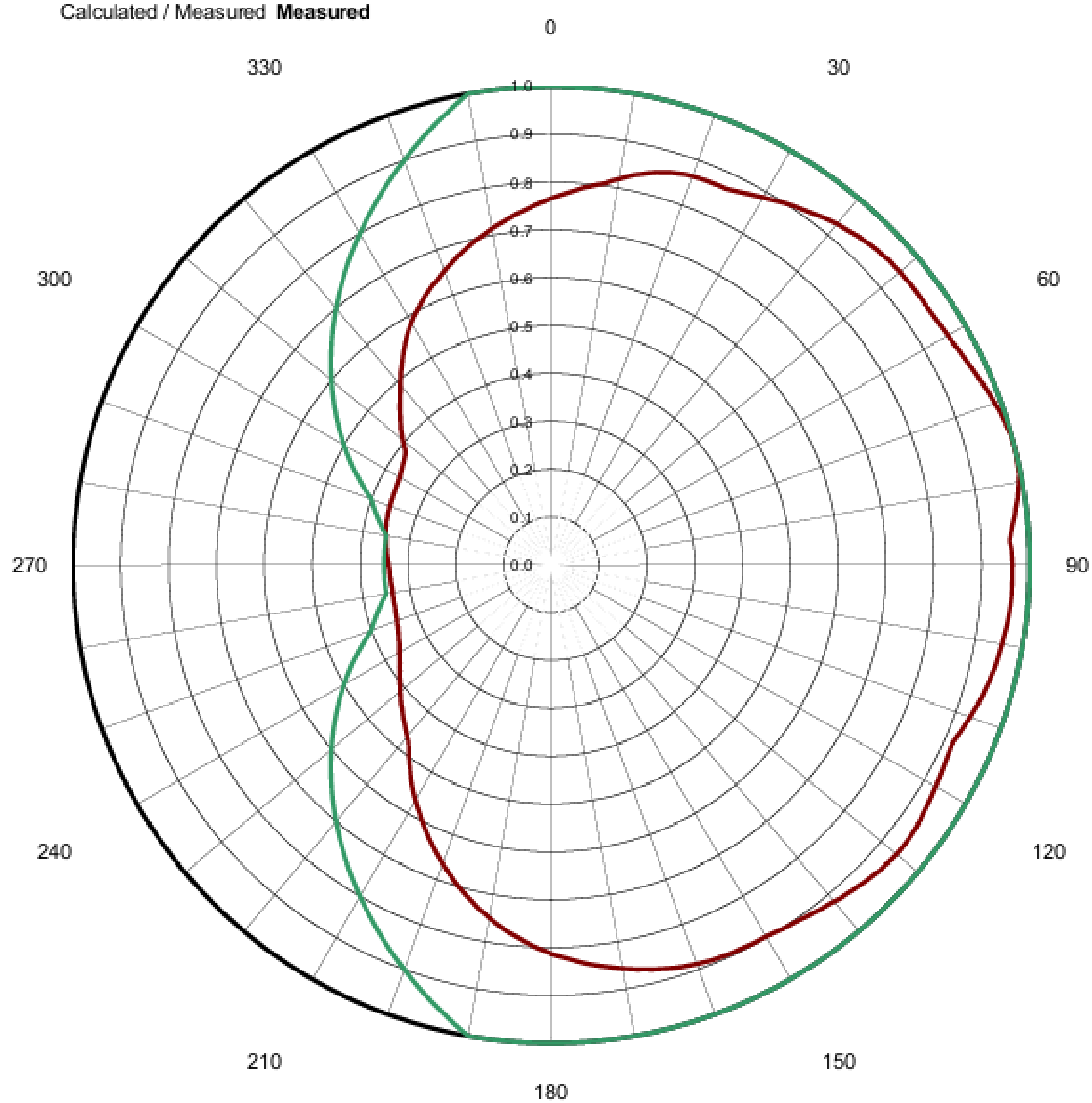
Angle	Field	dBk	ERP kW
	0.747	0.477	1.116
10	0.819	1.276	1.342
20	0.864	1.741	1.493
30	0.874	1.841	1.528
40	0.909	2.182	1.653
50	0.937	2.445	1.756
60	0.951	2.574	1.809
70	0.941	2.482	1.771
80	0.944	2.510	1.782
90	0.965	2.701	1.862
100	0.957	2.629	1.832
110	0.932	2.399	1.737
120	0.898	2.076	1.613
130	0.884	1.939	1.563
140	0.883	1.930	1.559
150	0.879	1.890	1.545
160	0.858	1.680	1.472
170	0.817	1.255	1.335
180	0.758	0.604	1.149
190	0.690	-0.213	0.952
200	0.623	-1.100	0.776
210	0.544	-2.278	0.592
220	0.469	-3.566	0.440
230	0.413	-4.671	0.341
240	0.367	-5.696	0.269
250	0.343	-6.284	0.235
260	0.337	-6.437	0.227
270	0.340	-6.360	0.231
280	0.350	-6.108	0.245
290	0.359	-5.888	0.258
300	0.366	-5.720	0.268
310	0.395	-5.058	0.312
320	0.446	-4.003	0.398
330	0.509	-2.855	0.518
340	0.592	-1.543	0.701
350	0.665	-0.533	0.884

Dielectric

Proposal Number	**42428**
Date	**10/1/2015**
Call Letters	**WHEM**
Location	**Eau Claire, WI**
Customer	**WHEM**
Antenna Type	**DCRH1ERD**
Frequency	**91.3MHz**
Drawing #	**P17**

COMPOSITE AZIMUTH PATTERN

Calculated / Measured **Measured**



Dielectric

Proposal Number	**42428**
Date	**10/1/2015**
Call Letters	**WHEM**
Location	**Eau Claire, WI**
Customer	**WHEM**
Antenna Type	**DCRH1ERD**
Frequency	**91.3MHz**
Drawing #	**P17**

TABULATION OF COMPOSITE AZIMUTH PATTERN

	Angle	Field	dBk	Power kW	Input Power
		0.766	0.695	1.174	2.000
	10	0.819	1.276	1.342	2.000
	20	0.864	1.741	1.493	2.000
	30	0.887	1.969	1.574	2.000
	40	0.930	2.380	1.730	2.000
	50	0.952	2.583	1.813	2.000
	60	0.958	2.638	1.836	2.000
	70	0.987	2.897	1.948	2.000
	80	0.993	2.949	1.972	2.000
	90	0.965	2.701	1.862	2.000
	100	0.957	2.629	1.832	2.000
	110	0.932	2.399	1.737	2.000
	120	0.928	2.361	1.722	2.000
	130	0.942	2.491	1.775	2.000
	140	0.919	2.277	1.689	2.000
	150	0.898	2.076	1.613	2.000
	160	0.888	1.979	1.577	2.000
	170	0.857	1.670	1.469	2.000
	180	0.813	1.212	1.322	2.000
	190	0.749	0.500	1.122	2.000
	200	0.665	-0.533	0.884	2.000
	210	0.568	-1.903	0.645	2.000
	220	0.469	-3.566	0.440	2.000
	230	0.413	-4.671	0.341	2.000
	240	0.367	-5.696	0.269	2.000
	250	0.343	-6.284	0.235	2.000
	260	0.337	-6.437	0.227	2.000
	270	0.340	-6.360	0.231	2.000
	280	0.350	-6.108	0.245	2.000
	290	0.359	-5.888	0.258	2.000
	300	0.366	-5.720	0.268	2.000
	310	0.406	-4.819	0.330	2.000
	320	0.491	-3.168	0.482	2.000
	330	0.585	-1.647	0.684	2.000
	340	0.654	-0.678	0.855	2.000
	350	0.714	0.084	1.020	2.000
Additional Point	76	1.000	3.010	2.000	2.000

Dielectric

Proposal Number	**42428**
Date	**10/1/2015**
Call Letters	**WHEM**
Location	**Eau Claire, WI**
Customer	**WHEM**
Antenna Type	**DCRH1ERD**
Frequency	**91.3MHz**
Drawing #	**P17**

CUSTOMER GAIN SUMMARY

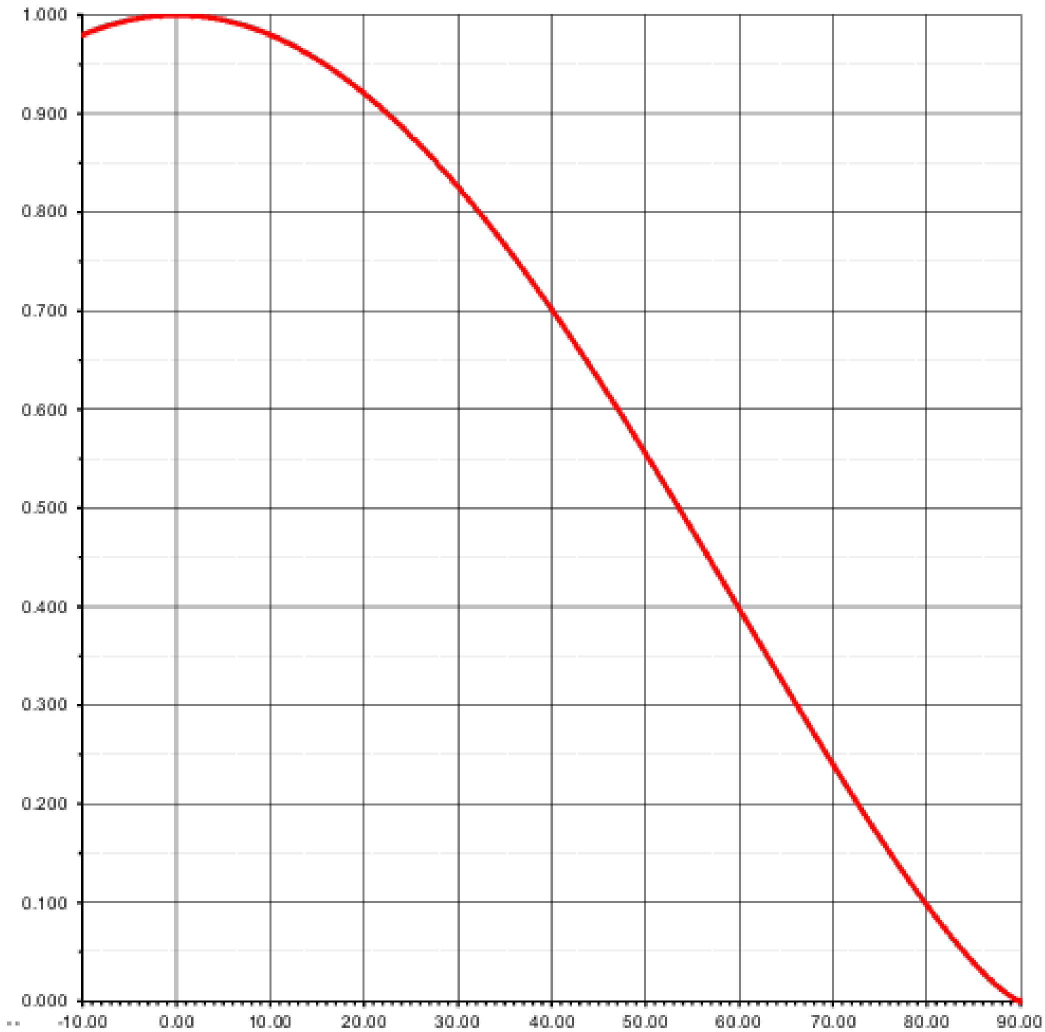
Azimuth Pattern Gain of Horizontal Polarization	1.87 (2.73 dB)
Elevation Pattern Gain Per Polarization	0.46 (-3.37 dB)
Peak Gain of Horizontal Polarization	0.86 (-0.64 dB)

Dielectric

Proposal Number	**42428**
Date	**10/1/2015**
Call Letters	**WHEM**
Location	**Eau Claire, WI**
Customer	**WHEM**
Antenna Type	**DCRH1ERD**
Frequency	**91.3MHz**
Drawing #	**P17**

ELEVATION PATTERN

RMS Gain at Main Lobe	**0.46**	**-(3.37 dB)**	Beam Tilt	
Per Polarization			Frequency	**91.3MHz**
Calculated / Measured	**Calculated**			



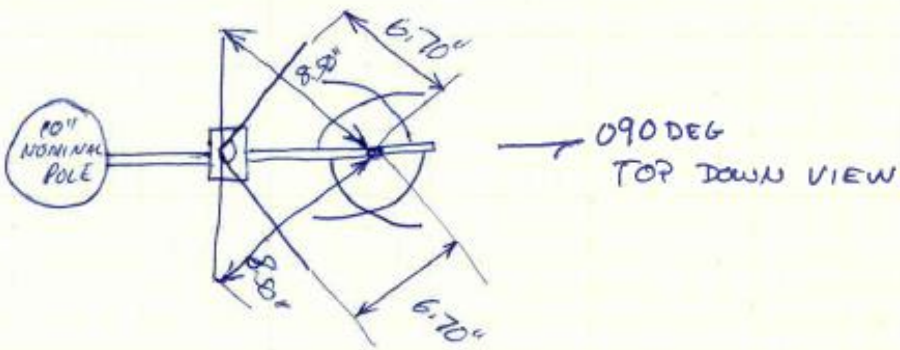
Dielectric

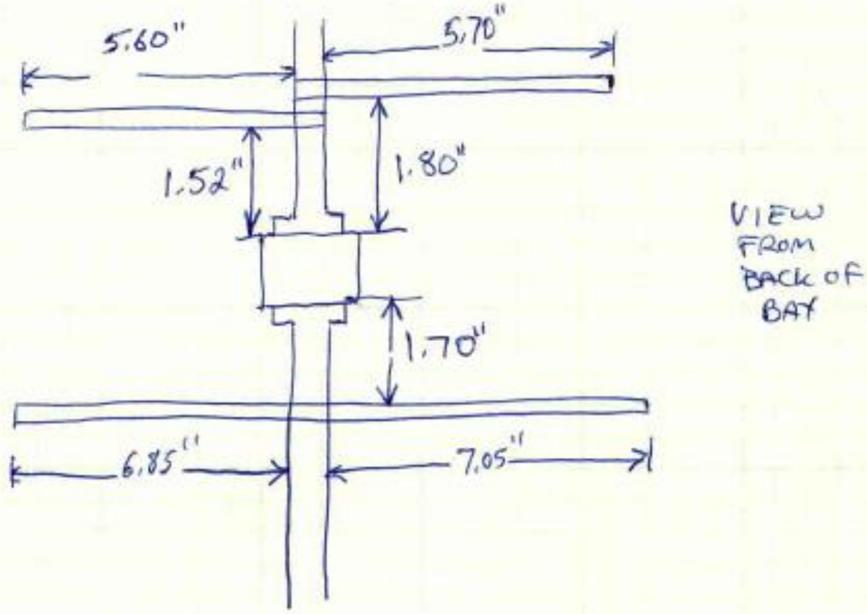
*Input power used will be either Hpol or Vpol depending on composite pattern

Horizontal	Vertical	Input Power H or V max
0.766	0.747	2.000
0.813	0.819	2.000
0.846	0.864	2.000
0.887	0.874	2.000
0.930	0.909	2.000
0.952	0.937	2.000
0.958	0.951	2.000
0.987	0.941	2.000
0.993	0.944	2.000
0.946	0.965	2.000
0.923	0.957	2.000
0.917	0.932	2.000
0.928	0.898	2.000
0.942	0.884	2.000
0.919	0.883	2.000
0.898	0.879	2.000
0.888	0.858	2.000
0.857	0.817	2.000
0.813	0.758	2.000
0.749	0.690	2.000
0.665	0.623	2.000
0.568	0.544	2.000
0.461	0.469	2.000
0.346	0.413	2.000
0.234	0.367	2.000
0.154	0.343	2.000
0.136	0.337	2.000
0.145	0.340	2.000
0.167	0.350	2.000
0.226	0.359	2.000
0.310	0.366	2.000
0.406	0.395	2.000
0.491	0.446	2.000
0.585	0.509	2.000
0.654	0.592	2.000
0.714	0.665	2.000

WHEM DCRHIERD P17
91.3 MHZ
D. SCHLEGEL SR RF TECH
10/1/2015

* STANDARD MOUNT
* 3 HORIZONTAL PARASITICS (ALL ON BACK OF TL)
  1 HORIZONTAL BELOW BLOCK
  2 HORIZONTAL ABOVE BLOCK ANGLED TO BAY





Appendix D – Horizontally Polarized Component Pattern Studies – Relative Field Data

TABULATION OF AZIMUTH PATTERN

Scaled Model Horizontal Azimuth Pattern

Angle	Field	Angle	Field	Angle	Field	Angle	Field	Angle	Field	Angle	Field	Angle	Field	Angle	Field
0	0.766	45	0.945	90	0.946	135	0.933	180	0.813	225	0.403	270	0.145	315	0.447
1	0.771	46	0.947	91	0.942	136	0.930	181	0.807	226	0.391	271	0.146	316	0.456
2	0.776	47	0.948	92	0.939	137	0.928	182	0.802	227	0.380	272	0.147	317	0.464
3	0.781	48	0.951	93	0.936	138	0.925	183	0.796	228	0.369	273	0.149	318	0.473
4	0.786	49	0.951	94	0.933	139	0.923	184	0.790	229	0.357	274	0.150	319	0.481
5	0.792	50	0.952	95	0.931	140	0.919	185	0.783	230	0.346	275	0.152	320	0.491
6	0.796	51	0.952	96	0.929	141	0.916	186	0.777	231	0.335	276	0.155	321	0.501
7	0.801	52	0.953	97	0.927	142	0.914	187	0.771	232	0.324	277	0.157	322	0.511
8	0.805	53	0.953	98	0.926	143	0.911	188	0.764	233	0.313	278	0.160	323	0.520
9	0.809	54	0.953	99	0.924	144	0.909	189	0.757	234	0.302	279	0.163	324	0.530
10	0.813	55	0.953	100	0.923	145	0.906	190	0.749	235	0.291	280	0.167	325	0.540
11	0.817	56	0.953	101	0.922	146	0.904	191	0.741	236	0.280	281	0.172	326	0.550
12	0.820	57	0.954	102	0.920	147	0.903	192	0.734	237	0.268	282	0.176	327	0.559
13	0.823	58	0.955	103	0.919	148	0.901	193	0.725	238	0.257	283	0.181	328	0.568
14	0.826	59	0.956	104	0.919	149	0.899	194	0.717	239	0.246	284	0.187	329	0.577
15	0.830	60	0.958	105	0.918	150	0.898	195	0.709	240	0.234	285	0.193	330	0.585
16	0.833	61	0.959	106	0.918	151	0.897	196	0.701	241	0.224	286	0.199	331	0.593
17	0.836	62	0.963	107	0.917	152	0.897	197	0.692	242	0.213	287	0.206	332	0.600
18	0.839	63	0.965	108	0.917	153	0.896	198	0.682	243	0.203	288	0.212	333	0.607
19	0.842	64	0.968	109	0.917	154	0.895	199	0.674	244	0.194	289	0.219	334	0.614
20	0.846	65	0.971	110	0.917	155	0.895	200	0.665	245	0.185	290	0.226	335	0.622
21	0.850	66	0.974	111	0.917	156	0.894	201	0.655	246	0.177	291	0.234	336	0.628
22	0.853	67	0.977	112	0.917	157	0.893	202	0.646	247	0.170	292	0.241	337	0.635
23	0.857	68	0.981	113	0.918	158	0.892	203	0.636	248	0.164	293	0.249	338	0.640
24	0.861	69	0.984	114	0.918	159	0.890	204	0.627	249	0.159	294	0.257	339	0.647
25	0.865	70	0.987	115	0.919	160	0.888	205	0.617	250	0.154	295	0.265	340	0.654
26	0.870	71	0.991	116	0.920	161	0.886	206	0.607	251	0.150	296	0.274	341	0.660
27	0.874	72	0.993	117	0.922	162	0.884	207	0.598	252	0.147	297	0.282	342	0.666
28	0.878	73	0.995	118	0.924	163	0.881	208	0.587	253	0.144	298	0.291	343	0.673
29	0.882	74	0.998	119	0.926	164	0.878	209	0.578	254	0.141	299	0.301	344	0.679
30	0.887	75	0.999	120	0.928	165	0.875	210	0.568	255	0.140	300	0.310	345	0.685
31	0.891	76	1.000	121	0.930	166	0.872	211	0.558	256	0.138	301	0.320	346	0.691
32	0.896	77	0.999	122	0.932	167	0.868	212	0.548	257	0.137	302	0.330	347	0.697
33	0.901	78	0.998	123	0.934	168	0.865	213	0.538	258	0.136	303	0.340	348	0.702
34	0.905	79	0.997	124	0.936	169	0.861	214	0.527	259	0.136	304	0.350	349	0.708
35	0.909	80	0.993	125	0.939	170	0.857	215	0.516	260	0.136	305	0.359	350	0.714
36	0.913	81	0.989	126	0.940	171	0.853	216	0.506	261	0.136	306	0.369	351	0.719
37	0.917	82	0.985	127	0.941	172	0.849	217	0.495	262	0.137	307	0.379	352	0.724
38	0.922	83	0.979	128	0.942	173	0.845	218	0.484	263	0.138	308	0.388	353	0.729
39	0.926	84	0.975	129	0.942	174	0.841	219	0.473	264	0.139	309	0.397	354	0.735
40	0.930	85	0.969	130	0.942	175	0.837	220	0.461	265	0.139	310	0.406	355	0.740
41	0.933	86	0.964	131	0.941	176	0.832	221	0.449	266	0.141	311	0.414	356	0.745
42	0.936	87	0.959	132	0.939	177	0.827	222	0.438	267	0.142	312	0.423	357	0.751
43	0.940	88	0.954	133	0.938	178	0.822	223	0.426	268	0.143	313	0.431	358	0.756
44	0.942	89	0.950	134	0.935	179	0.818	224	0.414	269	0.144	314	0.439	359	0.761

TABULATION OF AZIMUTH PATTERN

HFSS Simulated Horizontal Azimuth Pattern

Angle	Field	Angle	Field	Angle	Field	Angle	Field	Angle	Field	Angle	Field	Angle	Field	Angle	Field
0	0.860	45	0.917	90	0.957	135	0.999	180	0.828	225	0.373	270	0.170	315	0.395
1	0.866	46	0.916	91	0.959	136	0.999	181	0.820	226	0.363	271	0.168	316	0.408
2	0.871	47	0.916	92	0.960	137	0.998	182	0.812	227	0.353	272	0.166	317	0.421
3	0.876	48	0.915	93	0.962	138	0.998	183	0.804	228	0.344	273	0.165	318	0.434
4	0.880	49	0.915	94	0.964	139	0.997	184	0.796	229	0.334	274	0.163	319	0.447
5	0.884	50	0.914	95	0.965	140	0.996	185	0.788	230	0.325	275	0.161	320	0.460
6	0.888	51	0.914	96	0.967	141	0.995	186	0.779	231	0.316	276	0.159	321	0.473
7	0.892	52	0.914	97	0.969	142	0.994	187	0.770	232	0.307	277	0.157	322	0.486
8	0.896	53	0.913	98	0.970	143	0.992	188	0.761	233	0.298	278	0.155	323	0.499
9	0.899	54	0.913	99	0.972	144	0.991	189	0.752	234	0.290	279	0.153	324	0.512
10	0.902	55	0.913	100	0.973	145	0.989	190	0.743	235	0.282	280	0.152	325	0.525
11	0.905	56	0.913	101	0.975	146	0.988	191	0.734	236	0.274	281	0.151	326	0.538
12	0.908	57	0.913	102	0.976	147	0.986	192	0.724	237	0.267	282	0.149	327	0.551
13	0.910	58	0.914	103	0.978	148	0.984	193	0.714	238	0.260	283	0.149	328	0.563
14	0.913	59	0.914	104	0.979	149	0.982	194	0.705	239	0.253	284	0.148	329	0.576
15	0.915	60	0.914	105	0.980	150	0.979	195	0.695	240	0.247	285	0.148	330	0.588
16	0.917	61	0.915	106	0.982	151	0.977	196	0.685	241	0.241	286	0.149	331	0.600
17	0.918	62	0.916	107	0.983	152	0.974	197	0.675	242	0.235	287	0.150	332	0.612
18	0.920	63	0.916	108	0.984	153	0.972	198	0.664	243	0.230	288	0.152	333	0.624
19	0.921	64	0.917	109	0.985	154	0.969	199	0.654	244	0.225	289	0.154	334	0.635
20	0.922	65	0.918	110	0.986	155	0.965	200	0.644	245	0.221	290	0.157	335	0.647
21	0.923	66	0.919	111	0.988	156	0.962	201	0.633	246	0.217	291	0.160	336	0.658
22	0.924	67	0.920	112	0.989	157	0.959	202	0.623	247	0.213	292	0.165	337	0.669
23	0.925	68	0.921	113	0.990	158	0.955	203	0.612	248	0.209	293	0.170	338	0.680
24	0.925	69	0.922	114	0.991	159	0.951	204	0.601	249	0.206	294	0.175	339	0.691
25	0.925	70	0.923	115	0.992	160	0.947	205	0.590	250	0.203	295	0.181	340	0.702
26	0.926	71	0.925	116	0.993	161	0.943	206	0.579	251	0.200	296	0.188	341	0.712
27	0.926	72	0.926	117	0.993	162	0.939	207	0.569	252	0.198	297	0.196	342	0.722
28	0.926	73	0.927	118	0.994	163	0.934	208	0.558	253	0.196	298	0.204	343	0.732
29	0.926	74	0.929	119	0.995	164	0.929	209	0.547	254	0.194	299	0.212	344	0.741
30	0.926	75	0.931	120	0.996	165	0.924	210	0.535	255	0.192	300	0.221	345	0.751
31	0.925	76	0.932	121	0.997	166	0.919	211	0.524	256	0.190	301	0.231	346	0.760
32	0.925	77	0.934	122	0.997	167	0.914	212	0.513	257	0.189	302	0.241	347	0.768
33	0.924	78	0.935	123	0.998	168	0.908	213	0.502	258	0.187	303	0.251	348	0.777
34	0.924	79	0.937	124	0.998	169	0.903	214	0.491	259	0.186	304	0.262	349	0.785
35	0.923	80	0.939	125	0.999	170	0.897	215	0.480	260	0.185	305	0.273	350	0.794
36	0.923	81	0.941	126	0.999	171	0.891	216	0.469	261	0.183	306	0.284	351	0.801
37	0.922	82	0.942	127	0.999	172	0.885	217	0.458	262	0.182	307	0.296	352	0.809
38	0.922	83	0.944	128	1.000	173	0.878	218	0.447	263	0.181	308	0.307	353	0.816
39	0.921	84	0.946	129	1.000	174	0.872	219	0.436	264	0.179	309	0.319	354	0.823
40	0.920	85	0.948	130	1.000	175	0.865	220	0.426	265	0.178	310	0.332	355	0.830
41	0.919	86	0.950	131	1.000	176	0.858	221	0.415	266	0.177	311	0.344	356	0.837
42	0.919	87	0.951	132	1.000	177	0.851	222	0.404	267	0.175	312	0.357	357	0.843
43	0.918	88	0.953	133	1.000	178	0.843	223	0.394	268	0.173	313	0.369	358	0.849
44	0.917	89	0.955	134	1.000	179	0.836	224	0.383	269	0.172	314	0.382	359	0.855

Appendix E – Vertically Polarized Component Pattern Studies – Relative Field Data

TABULATION OF AZIMUTH PATTERN

Scaled Model Vertical Azimuth Pattern

Angle	Field	Angle	Field	Angle	Field	Angle	Field	Angle	Field	Angle	Field	Angle	Field	Angle	Field
0	0.747	45	0.924	90	0.965	135	0.882	180	0.758	225	0.440	270	0.340	315	0.419
1	0.755	46	0.927	91	0.965	136	0.882	181	0.752	226	0.435	271	0.341	316	0.425
2	0.762	47	0.930	92	0.965	137	0.882	182	0.745	227	0.429	272	0.342	317	0.430
3	0.769	48	0.932	93	0.965	138	0.882	183	0.738	228	0.424	273	0.343	318	0.436
4	0.776	49	0.935	94	0.965	139	0.883	184	0.730	229	0.418	274	0.344	319	0.441
5	0.784	50	0.938	95	0.964	140	0.883	185	0.724	230	0.413	275	0.345	320	0.446
6	0.792	51	0.940	96	0.963	141	0.883	186	0.717	231	0.407	276	0.346	321	0.451
7	0.799	52	0.942	97	0.962	142	0.882	187	0.710	232	0.402	277	0.347	322	0.457
8	0.805	53	0.944	98	0.961	143	0.882	188	0.703	233	0.397	278	0.348	323	0.462
9	0.813	54	0.946	99	0.958	144	0.882	189	0.697	234	0.392	279	0.349	324	0.468
10	0.819	55	0.948	100	0.957	145	0.882	190	0.690	235	0.387	280	0.350	325	0.474
11	0.826	56	0.950	101	0.955	146	0.881	191	0.684	236	0.383	281	0.352	326	0.480
12	0.833	57	0.951	102	0.954	147	0.881	192	0.678	237	0.378	282	0.353	327	0.487
13	0.838	58	0.951	103	0.952	148	0.880	193	0.671	238	0.374	283	0.354	328	0.494
14	0.844	59	0.952	104	0.950	149	0.880	194	0.665	239	0.370	284	0.355	329	0.501
15	0.849	60	0.951	105	0.947	150	0.879	195	0.658	240	0.367	285	0.356	330	0.509
16	0.853	61	0.951	106	0.944	151	0.878	196	0.652	241	0.363	286	0.356	331	0.517
17	0.857	62	0.950	107	0.942	152	0.876	197	0.644	242	0.360	287	0.357	332	0.525
18	0.860	63	0.948	108	0.939	153	0.875	198	0.638	243	0.357	288	0.358	333	0.534
19	0.863	64	0.947	109	0.935	154	0.873	199	0.630	244	0.355	289	0.359	334	0.543
20	0.864	65	0.946	110	0.932	155	0.871	200	0.623	245	0.352	290	0.359	335	0.551
21	0.865	66	0.945	111	0.928	156	0.869	201	0.616	246	0.350	291	0.359	336	0.560
22	0.866	67	0.944	112	0.925	157	0.867	202	0.608	247	0.348	292	0.360	337	0.569
23	0.866	68	0.943	113	0.922	158	0.864	203	0.600	248	0.346	293	0.360	338	0.577
24	0.867	69	0.942	114	0.917	159	0.861	204	0.592	249	0.345	294	0.361	339	0.585
25	0.867	70	0.941	115	0.914	160	0.858	205	0.584	250	0.343	295	0.361	340	0.592
26	0.868	71	0.940	116	0.910	161	0.855	206	0.576	251	0.342	296	0.362	341	0.600
27	0.868	72	0.939	117	0.907	162	0.852	207	0.568	252	0.341	297	0.363	342	0.607
28	0.870	73	0.939	118	0.904	163	0.848	208	0.560	253	0.340	298	0.364	343	0.614
29	0.871	74	0.938	119	0.901	164	0.844	209	0.552	254	0.339	299	0.365	344	0.621
30	0.874	75	0.938	120	0.898	165	0.840	210	0.544	255	0.338	300	0.366	345	0.628
31	0.876	76	0.939	121	0.895	166	0.836	211	0.535	256	0.338	301	0.368	346	0.635
32	0.880	77	0.940	122	0.893	167	0.832	212	0.527	257	0.338	302	0.370	347	0.642
33	0.883	78	0.941	123	0.891	168	0.827	213	0.519	258	0.337	303	0.372	348	0.649
34	0.886	79	0.942	124	0.890	169	0.822	214	0.511	259	0.337	304	0.375	349	0.657
35	0.890	80	0.944	125	0.888	170	0.817	215	0.504	260	0.337	305	0.377	350	0.665
36	0.894	81	0.946	126	0.887	171	0.812	216	0.496	261	0.337	306	0.380	351	0.673
37	0.897	82	0.948	127	0.886	172	0.806	217	0.489	262	0.337	307	0.383	352	0.682
38	0.902	83	0.952	128	0.885	173	0.801	218	0.482	263	0.337	308	0.387	353	0.689
39	0.906	84	0.954	129	0.884	174	0.795	219	0.475	264	0.337	309	0.391	354	0.698
40	0.909	85	0.956	130	0.884	175	0.790	220	0.469	265	0.337	310	0.395	355	0.707
41	0.912	86	0.959	131	0.883	176	0.783	221	0.463	266	0.338	311	0.399	356	0.716
42	0.915	87	0.961	132	0.883	177	0.777	222	0.457	267	0.338	312	0.404	357	0.724
43	0.918	88	0.963	133	0.883	178	0.771	223	0.451	268	0.338	313	0.409	358	0.734
44	0.922	89	0.964	134	0.882	179	0.765	224	0.446	269	0.339	314	0.414	359	0.740

TABULATION OF AZIMUTH PATTERN

HFSS Simulated Vertical Azimuth Pattern

Angle	Field	Angle	Field	Angle	Field	Angle	Field	Angle	Field	Angle	Field	Angle	Field	Angle	Field
0	0.638	45	0.896	90	0.980	135	0.904	180	0.639	225	0.386	270	0.388	315	0.411
1	0.645	46	0.900	91	0.980	136	0.900	181	0.632	226	0.384	271	0.388	316	0.413
2	0.652	47	0.903	92	0.980	137	0.896	182	0.624	227	0.382	272	0.389	317	0.416
3	0.659	48	0.907	93	0.980	138	0.892	183	0.617	228	0.380	273	0.389	318	0.418
4	0.665	49	0.911	94	0.979	139	0.888	184	0.609	229	0.379	274	0.389	319	0.421
5	0.672	50	0.914	95	0.979	140	0.884	185	0.602	230	0.377	275	0.390	320	0.424
6	0.679	51	0.917	96	0.979	141	0.880	186	0.594	231	0.376	276	0.390	321	0.427
7	0.686	52	0.921	97	0.978	142	0.876	187	0.587	232	0.375	277	0.390	322	0.430
8	0.692	53	0.924	98	0.978	143	0.871	188	0.580	233	0.374	278	0.390	323	0.433
9	0.699	54	0.927	99	0.977	144	0.867	189	0.572	234	0.374	279	0.390	324	0.436
10	0.706	55	0.930	100	0.977	145	0.862	190	0.565	235	0.373	280	0.390	325	0.440
11	0.712	56	0.933	101	0.976	146	0.857	191	0.558	236	0.373	281	0.390	326	0.443
12	0.719	57	0.935	102	0.975	147	0.852	192	0.550	237	0.372	282	0.391	327	0.447
13	0.725	58	0.938	103	0.975	148	0.847	193	0.543	238	0.372	283	0.391	328	0.451
14	0.732	59	0.941	104	0.974	149	0.842	194	0.536	239	0.372	284	0.391	329	0.455
15	0.738	60	0.943	105	0.973	150	0.837	195	0.529	240	0.372	285	0.391	330	0.460
16	0.745	61	0.946	106	0.972	151	0.832	196	0.522	241	0.372	286	0.391	331	0.464
17	0.751	62	0.948	107	0.970	152	0.826	197	0.515	242	0.372	287	0.391	332	0.469
18	0.757	63	0.950	108	0.969	153	0.821	198	0.509	243	0.373	288	0.391	333	0.473
19	0.764	64	0.952	109	0.968	154	0.815	199	0.502	244	0.373	289	0.391	334	0.478
20	0.770	65	0.954	110	0.967	155	0.809	200	0.496	245	0.373	290	0.391	335	0.483
21	0.776	66	0.956	111	0.965	156	0.803	201	0.489	246	0.374	291	0.391	336	0.488
22	0.782	67	0.958	112	0.964	157	0.797	202	0.483	247	0.374	292	0.391	337	0.493
23	0.788	68	0.960	113	0.962	158	0.791	203	0.477	248	0.375	293	0.391	338	0.499
24	0.793	69	0.962	114	0.960	159	0.785	204	0.471	249	0.376	294	0.391	339	0.504
25	0.799	70	0.963	115	0.958	160	0.779	205	0.465	250	0.376	295	0.392	340	0.510
26	0.805	71	0.965	116	0.957	161	0.773	206	0.459	251	0.377	296	0.392	341	0.516
27	0.811	72	0.966	117	0.955	162	0.766	207	0.454	252	0.377	297	0.392	342	0.521
28	0.816	73	0.968	118	0.953	163	0.760	208	0.448	253	0.378	298	0.392	343	0.527
29	0.821	74	0.969	119	0.950	164	0.753	209	0.443	254	0.379	299	0.393	344	0.533
30	0.827	75	0.970	120	0.948	165	0.747	210	0.438	255	0.380	300	0.393	345	0.539
31	0.832	76	0.972	121	0.946	166	0.740	211	0.433	256	0.380	301	0.394	346	0.546
32	0.837	77	0.973	122	0.944	167	0.733	212	0.429	257	0.381	302	0.394	347	0.552
33	0.842	78	0.974	123	0.941	168	0.726	213	0.424	258	0.382	303	0.395	348	0.558
34	0.847	79	0.975	124	0.939	169	0.719	214	0.420	259	0.382	304	0.396	349	0.565
35	0.852	80	0.975	125	0.936	170	0.712	215	0.416	260	0.383	305	0.397	350	0.571
36	0.857	81	0.976	126	0.933	171	0.705	216	0.412	261	0.383	306	0.398	351	0.578
37	0.862	82	0.977	127	0.930	172	0.698	217	0.408	262	0.384	307	0.399	352	0.584
38	0.866	83	0.978	128	0.927	173	0.691	218	0.405	263	0.385	308	0.400	353	0.591
39	0.871	84	0.978	129	0.924	174	0.683	219	0.401	264	0.385	309	0.401	354	0.597
40	0.875	85	0.979	130	0.921	175	0.676	220	0.398	265	0.386	310	0.403	355	0.604
41	0.879	86	0.979	131	0.918	176	0.669	221	0.395	266	0.386	311	0.404	356	0.611
42	0.884	87	0.979	132	0.915	177	0.661	222	0.393	267	0.387	312	0.406	357	0.618
43	0.888	88	0.979	133	0.911	178	0.654	223	0.390	268	0.387	313	0.407	358	0.624
44	0.892	89	0.980	134	0.908	179	0.647	224	0.388	269	0.388	314	0.409	359	0.631