Isotrope
WIRELESS
Thinking outside the sphere

Mr James Bradshaw
Audio Division, Media Bureau
Federal Communications Commission
45 L Street NE
Washington, DC 20554

February 26, 2024

Dear Mr. Bradshaw,

WQVR (formerly WGFP) respectfully submits the attached engineering statements in support of nighttime approval of the WQVR High Efficiency Broadband Antenna ("HEBA"). The HEBA is a novel dual-feed antenna design incorporating a flared vertical cylinder positioned above a capacitive plate above an elevated ground plane. In operation it has proven to not only be appropriately efficient, but also immune to seasonal fluctuations in the surrounding ground conditions.

As demonstrated in the attached, the customary method of developing an antenna pattern following 47 CFR 73.160(b) is not a very precise approach and presents additional uncertainty when applied to electrically short antennas. Consequently, we propose to apply 47 CFR 73.160(c), which requires the presentation of an equation to describe the vertical pattern and a "complete derivation" thereof.

Using the precise and reliable method of moments modeling with NEC version 5 software ("NEC-5"), the WQVR engineering team has developed a vertical pattern and the resulting equation. NEC-5 has the capability, not previously available, to efficiently model plate surfaces, such as are part of the HEBA design.

NEC-5 tells us the electrical length of the WQVR antenna is 32.9°. This is explained in the engineering statements. Pursuant to 47 CFR 73.160(c), we have derived a formula that describes the NEC-5 vertical pattern.

The WQVR HEBA antenna pattern formula is:

$$f(\theta) = \frac{\cos(G\sin(\theta)) - \cos(G)}{(1 - \cos(G)) - \cos(\theta)} \qquad \text{Where } G = 32.9°$$

We file the 32.9° value as the electrical length of record with the understanding that it is an essential component of our derived formula. It is not an estimated electrical length pursuant to 47 CFR 73.160(b).

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In addition to using this value in the formula for the WQVR vertical pattern, we respectfully request to adjust the current electrical length of record for the daytime license to match this value. This is a *de minimis* change because the daytime authorization is not dependent on calculations relating to this value.

The first engineering statement is by the NEC-5 modeling team, providing the complete derivation of the WQVR HEBA antenna vertical pattern formula specifically for the dimensions and operating frequency of WQVR.

The second engineering statement completes the application by demonstrating that the current nighttime authorization for WQVR's conventional antenna can be transferred to the HEBA with no change in power.

On behalf of the licensee, we are grateful for the Commission's responsiveness to this novel antenna, and we respectfully submit this application.

Yours truly,

David Maxson
Principal
Isotrope, LLC
PO Box 52437
Boston, MA 02205

Engineering Statement
WQVR High Efficiency Broadband Antenna
Nighttime pattern derivation

February 2024

Introduction

The High Efficiency Broadband Antenna (HEBA) is approved for daytime operation at WQVR, 940 kHz. While the HEBA is structurally a novel design, with a more complex geometry than that of a simple vertical element, the basic physics are the same. This document outlines the derivation of the vertical pattern formula for nighttime approval pursuant to §73.160(c).

Application engineering history

Beginning in 2018, the WQVR (formerly WGFP) engineering team began a quest for a verifiable description of the vertical pattern to support an application for nighttime authorization. Using various conventional and unconventional methods to derive an estimated electrical height of the radiator, mildly different results were obtained. Moreover, because of the unique and novel nature of the HEBA geometry and dual-feed configuration, it was not certain that the canonical formulas for thin-wire monopole patterns would be applicable. The formulas in 47 CFR 73.160(b) require the estimation of electrical length, typically using the current distribution method. For two reasons, this proved particularly challenging for the HEBA. First, measurement of the large diameter, flared cylinder would be a complex undertaking, if it were practicable to do so at all. Second, like all short antennas, the use of the current distribution method is challenged by the subtle, if not nonexistent, changes in current on the vertical radiator.

Assuming the HEBA behaves as a short radiator, methods were tried emulating those applied to the earlier Valcom and Kinstar efforts, which were also deemed electrically short antennas. The physical dimensions of the Valcom and Kinstar short antennas were ultimately accepted by the Commission as proxies for their electrical heights. Consistent with this, the actual physical dimensions of the HEBA were used to calculate an approximate electrical height. The result was input to the 47 CFR 73.160(b) formulas to produce estimated vertical patterns. However, the novel dual-feed configuration and the complex geometry of the HEBA raised the question as to whether the practices approved for Valcom and Kinstar are indeed applicable to the HEBA.

This created a conundrum for identifying a way to prove the assumption that the HEBA is a short antenna subject to the same principles of radiation and computation as Valcom and Kinstar. Two options remained: 1) Perform NEC modeling to confirm the assumption, or 2) Measure the vertical pattern in the field.

The prospect of doing direct measurements of the vertical pattern was considered experimentally but it was determined that there is good reason why there is no generally accepted protocol for field measurement of AM broadcast vertical patterns for licensing purposes.

In August 2022, new HEBA engineering team members completed a NEC-5 model of the HEBA. NEC-5 had been recently released with new plate-surface modeling tools. Prior to this, NEC required a computationally demanding simulation of plate surfaces that made evaluation of the HEBA next to impossible.

As was done in the Valcom and Kinstar antenna evaluations, a NEC model was prepared for the HEBA. In the Valcom and Kinstar cases, the applicants compared their NEC results with the approximation using the §73.160(b) formulas. Because the Valcom and Kinstar applications were for a class of antennas spanning some or all of the AM band, validation of the 47 CFR 73.160(b) approach was necessary. In the HEBA case, because of the complexity of the design, the approach evaluates only the HEBA dimensions and frequency used at WQVR.

The approach

The NEC-5 HEBA pattern resembles the family of §73.160(b) patterns. It was decided to seek the §73.160(b) pattern with the best match to the HEBA pattern. A laborious process of successive approximations identified the best match. The best match required the electrical length variable to be 32.9 degrees.

Note that electrical length of any antenna is not something that is directly measured. It is a derived value that is convenient for estimating things like vertical patterns. Therefore, it is appropriate to say that the HEBA NEC-5 model matches the equation for an ideal thin-wire monopole in which the monopole has an electrical length of 32.9 degrees. The “electrical length” of the HEBA is not precisely estimable using current distribution or physical dimensions. However, an estimated electrical length is not being used to satisfy §73.160(b). It is apt to describe it this way instead: An NEC-5 model was developed and from it a §73.160(c) formula was developed that matches the NEC-5 model. That formula, conveniently, is based on the same thin-wire equation that is used for conventional antennas under §73.160(b). The constant in the resulting formula is equivalent to the electrical length of a thin-wire antenna with the same pattern.

Detailed Background

§73.160(b) provides standard equations for estimating the vertical pattern of an AM vertical monopole, with or without top-loading or sections. Its input is the “apparent electrical height ([the variable] G based on current distribution).” Traditionally, a new tower that is a substantial proportion of the station’s wavelength is evaluated with a current distribution measurement, if such information is not already on the record from prior towers of the same design. The electrical height (G) is approximated with the current distribution method. G is used in the appropriate formula in §73.160(b) to generate a best estimate of the vertical pattern. Prior short antenna projects were approved for §73.160(b) evaluation after being compared to their NEC models and found to have only minor discrepancies.

The customary derivation of the G value for any antenna type is merely an approximation rather than a precise description of an electromagnetic characteristic of that antenna. Likewise, the §73.160(b) equation ($f(\theta)$) is also an approximation, using an ideal thin-wire formula as a proxy for the formula for a physical antenna structure. It has been demonstrated with NEC modelling that even tall-tower vertical radiation patterns are not perfectly represented using the G estimation method and the thin-wire formula. See, e.g., engineering submittals in the Kinstar proceeding showing how the $f(\theta)$ patterns of certain tall towers have sometimes substantial discrepancies compared to precise NEC models. The Commission accepted such discrepancies and uncertainties as having little consequence and continued to rely procedurally on the 73.160(b) approximations.

Therefore, we propose in the case of the HEBA to dispense with the uncertainties and errors of the estimation of the G value and the approximation using a thin-wire equation and rely directly on NEC-5 analysis.

The crux of the present analysis is a two-step process:

1) the reliance on NEC-5 modelling to produce a pattern,
2) successive approximation of $f(\theta)$ in increments of G until the best match is achieved.

The rationale for reliance on NEC-5 modelling as the reference for the vertical pattern is based on the record with the Kinstar and Valcom initiatives. In his analysis, Rackley noted the difficulties with the current-distribution method for estimating the electrical height of short towers. He also noted the substantially more reliable results obtained from NEC modelling. Rackley showed in the Kinstar application that NEC was more accurate. He said the NEC model "accounts for more terms, including effects of the relatively wide wire spacing in the antenna on the phase velocity, and thus produces a more accurate result than either of the other methods [the $f(\theta)$ formula and the current distribution analysis], which are based on mathematical approximations." The same goes for an NEC-5 model of the HEBA.

Present Effort

NEC-5 modeling demonstrates the HEBA is merely a short antenna mounted on an elevated ground plane, with a conical shape and a novel dual-feed arrangement involving a capacitor at the base. Its daytime performance was sufficient for daytime approval, confirming that it is working as a well-designed short antenna should.

Complete derivation and sample calculations

Herein is a description of the "complete derivation and sample calculations" as called for in §73.160(c). Since we are proposing nighttime authorization of only one HEBA for only one station, there is but one antenna size and frequency, and the variable G becomes a constant. We have identified the formula with the best constant to produce a pattern matching the NEC-5-derived pattern for this specific antenna.

To develop a formula for the WQVR HEBA antenna pattern we first asked whether the shape of the pattern calculated by NEC-5 would match any pattern that could be generated by the $f1(\theta)$

formula (§73.160(b)(1)). To do so, the NEC-5 pattern was compared with iterations of the $f1(\theta)$ formula.

At each increment of G, we subtracted the directivity of the NEC-5 data from the $f1(\theta)$ value, determined its absolute difference, and for the range of elevations from 0 to 88 degrees determined the maximum difference. By taking the difference rather than creating a ratio, the differences remain normalized to the maximum directivity. Further, it is well recognized that radiation toward the vertical is both challenging to represent mathematically and irrelevant to the issue of nighttime interference to distant stations. Thus, the comparison terminated at 88 degrees elevation. (Nevertheless, as shown below, the deviation even at 90 degrees is trivial.)

By plotting the maximum deviation between the NEC-5 data and the $f1(\theta)$ formula for G values between 29 and 36 degrees (*Figure 1*), there is a clear unique match at 32.9 degrees showing that the $f1(\theta)$ formula with a G value of 32.9 degrees is an excellent representation of the reference NEC vertical pattern. The NEC-5 vertical pattern and the WQVR HEBA formula are compared graphically in *Figure 2*.

The WQVR HEBA antenna pattern formula is:

$$f(\theta) = \frac{\cos(G\sin(\theta)) - \cos(G)}{(1 - \cos(G)) - \cos(\theta)} \qquad \text{Where } G = 32.9^\circ$$

The present formula applies only to the HEBA with dimensions used at WQVR and on a frequency of 940 kHz. Since this applies to one design at one frequency, the required sample calculations are limited to evaluating one pattern at various elevations. Sample calculations are provided in the WQVR Formula column of Table 1 and are compared to the modeled values in the WQVR NEC-5 column.

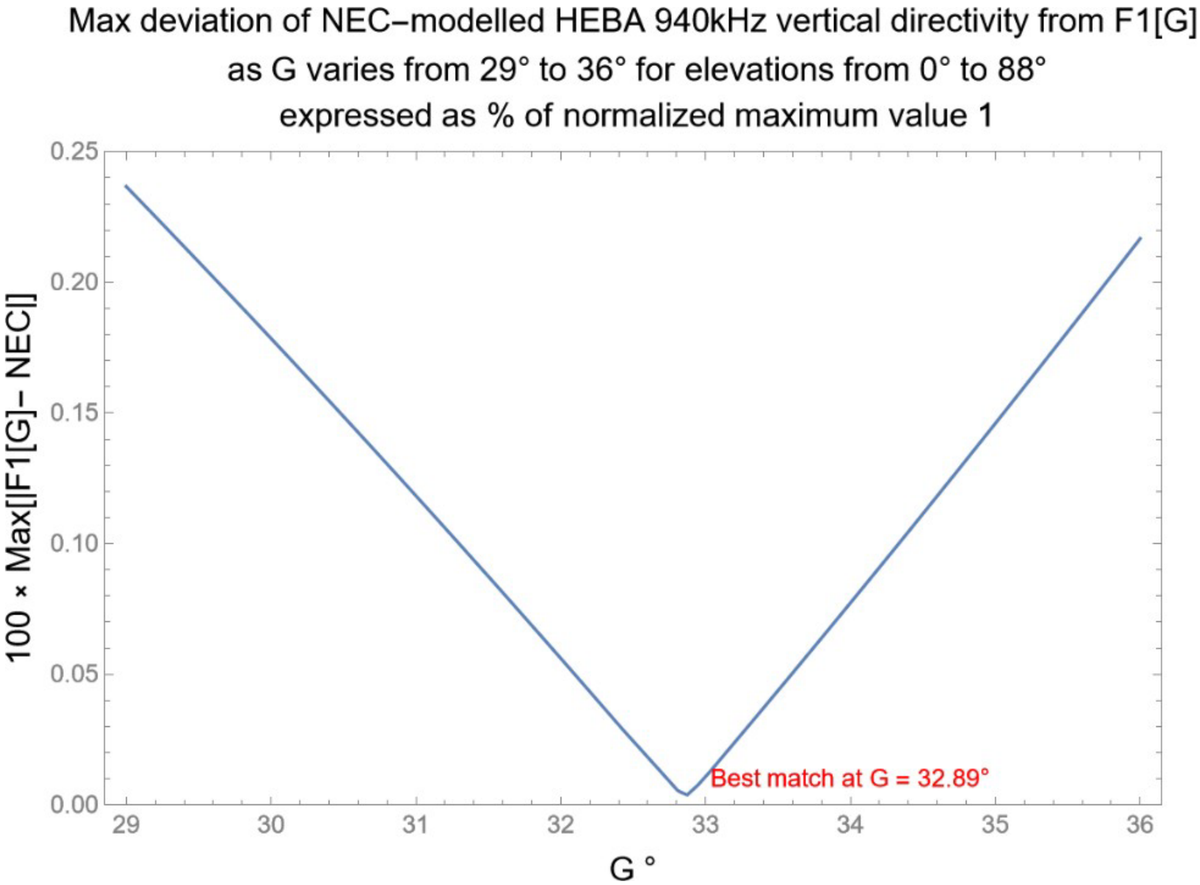

Figure 1 - WQVR HEBA Formula Best-Fit Search Results

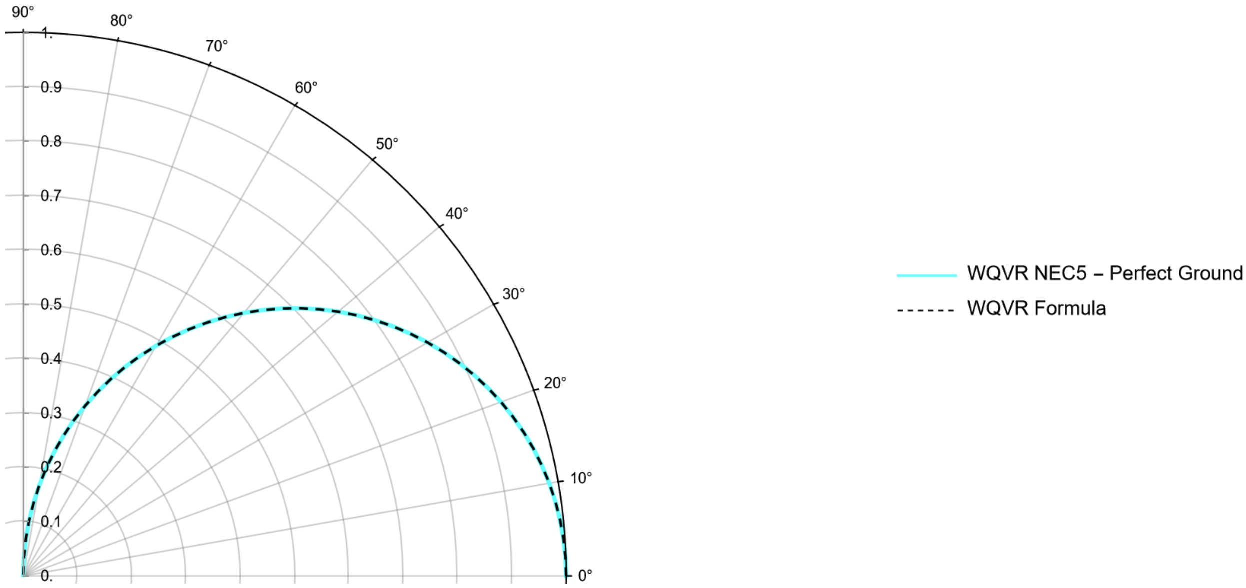

Figure 2 - WQVR Vertical Pattern Comparison: NEC-5 model and WQVR HEBA formula

Table 1 - WQVR HEBA Vertical Pattern Comparison: NEC-5 model and WQVR HEBA formula

Elevation (°)	WQVR NEC5 (reference)	WQVR Formula (estimate)	Elevation (°)	WQVR NEC5 (reference)	WQVR Formula (estimate)
0	1.0000	1.0000	46	0.6847	0.6847
2	0.9993	0.9994	48	0.6589	0.6589
4	0.9974	0.9974	50	0.6323	0.6323
6	0.9942	0.9942	52	0.6051	0.6051
8	0.9897	0.9897	54	0.5772	0.5771
10	0.9840	0.9840	56	0.5486	0.5485
12	0.9769	0.9770	58	0.5194	0.5194
14	0.9687	0.9687	60	0.4896	0.4896
16	0.9592	0.9592	62	0.4593	0.4593
18	0.9485	0.9485	64	0.4286	0.4286
20	0.9366	0.9366	66	0.3974	0.3973
22	0.9236	0.9236	68	0.3657	0.3657
24	0.9094	0.9093	70	0.3337	0.3337
26	0.8940	0.8940	72	0.3013	0.3013
28	0.8776	0.8775	74	0.2686	0.2686
30	0.8600	0.8600	76	0.2356	0.2356
32	0.8415	0.8414	78	0.2024	0.2024
34	0.8219	0.8218	80	0.1690	0.1690
36	0.8013	0.8012	82	0.1354	0.1354
38	0.7798	0.7797	84	0.1016	0.1017
40	0.7573	0.7572	86	0.0678	0.0678
42	0.7339	0.7339	88	0.0339	0.0339
44	0.7097	0.7097	90	0.0017	0.0000

The excellence of the match (within ~0.004%) clearly demonstrates this is an accurate formula for the vertical radiation pattern of this specific HEBA.

Interference analysis

The WQVR HEBA formula was applied to a new nighttime interference analysis by Mr. Hecht (attached engineering statement). WQVR is presently licensed for nighttime operation at 0.004 kW on the conventional antenna. The new analysis confirms that the WQVR interference contour is within the necessary limits when basing the calculation on the NEC-5 formula.

Environmental emissions

In addition to the analysis in prior submissions regarding the theoretical safe distances for an antenna radiating the WQVR licensed power, on-site measurement using a Narda 8718 meter with broadband conformal electric and magnetic probes demonstrates compliance with §1.1307(b) *et seq.* in all uncontrolled areas around and under the HEBA antenna assembly. Controlled areas are accessible only to trained personnel.

Conclusion

The NEC-5 modeling of the WQVR HEBA antenna reliably confirms the HEBA behaves like all short radiators in this part of the spectrum. It has the distinct advantage of being immune to seasonal variations in ground conductivity. Its vertical pattern is precisely predicted by NEC-5. Through successive approximations it is determined that the WQVR HEBA vertical radiation pattern is described exactly by the $f1(\theta)$ formula with a G of 32.9 degrees. This engineering statement satisfies the requirements of §73.160(c) to provide a "special formula" with a "complete derivation and sample calculations." The HEBA can operate at nighttime with the same nighttime power currently authorized for the conventional broadcast antenna.

Respectfully submitted,

David Maxson
Principal
Isotrope, LLC
PO Box 52437
Boston, MA 02205

Engineering services of Peter Zollman, Chartered Engineer (FIET, SMIEEE) provided in the development of the NEC-5 model.

Isotrope WIRELESS

Thinking outside the sphere

Mr James Bradshaw
Audio Division, Media Bureau
Federal Communications Commission
45 L Street NE
Washington, DC 20554

February 15, 2024

Dear Mr. Bradshaw,

WQVR (formerly WGFP) respectfully submits the attached engineering statements in support of nighttime approval of the WQVR High Efficiency Broadband Antenna (“HEBA”). The HEBA is a novel dual-feed antenna design incorporating a flared vertical cylinder positioned above a capacitive plate above an elevated ground plane. In operation it has proven to not only be appropriately efficient, but also immune to seasonal fluctuations in the surrounding ground conditions.

As demonstrated in the attached, the customary method of developing an antenna pattern following 47 CFR 73.160(b) is not a very precise approach and presents additional uncertainty when applied to electrically short antennas. Consequently, we propose to apply 47 CFR 73.160(c), which requires the presentation of an equation to describe the vertical pattern and a “complete derivation” thereof.

Using the precise and reliable method of moments modeling with NEC-5 software, the WQVR engineering team has developed a vertical pattern and the resulting equation. NEC version 5 has the capability, not previously available, to efficiently model plate surfaces, such as are part of the HEBA design.

NEC-5 tells us the electrical length of the WQVR antenna is 32.9°. This is explained in the engineering statements. Pursuant to 47 CFR 73.160(c), we have derived a formula that describes the NEC-5 vertical pattern.

The WQVR HEBA antenna pattern formula is:

$$f(\theta) = \frac{\cos(G\sin(\theta)) - \cos(G)}{(1 - \cos(G)) - \cos(\theta)} \qquad \text{Where } G = 32.9°$$

We file the 32.9° value as the electrical length of record with the understanding that it is an essential component of our derived formula. It is not an estimated electrical length pursuant to §47 CFR 73.160(b).

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In addition to using this value in the formula for the WQVR vertical pattern, we respectfully request to change the current electrical length of record for the daytime license to match this value. This is a *de minimus* change because the daytime authorization is not dependent on calculations relating to this value.

The first engineering statement is by the NEC-5 modeling team, providing the complete derivation of the WQVR HEBA antenna vertical pattern formula. This formula applies only to the HEBA whose dimensions and operating frequency are those belonging to WQVR. Future HEBA antennas will require individual analysis using NEC modeling of their frequencies and dimensions.

The second engineering statement completes the application by demonstrating that the current nighttime authorization for the station's conventional antenna can be transferred to the HEBA with no change in power.

On behalf of the licensee, we are grateful for the Commission's responsiveness to this novel antenna, and we respectfully submit this application.

Yours truly,

David Maxson
Principal
Isotrope, LLC
PO Box 52437
Boston, MA 02205

Engineering Statement
WQVR High Efficiency Broadband Antenna
Nighttime pattern derivation

February 2024

Introduction

The High Efficiency Broadband Antenna (HEBA) is approved for daytime operation at WQVR, 940 kHz. While the HEBA is structurally a novel design, with a more complex geometry than that of a simple vertical element, the basic physics are the same. This document outlines the derivation of the vertical pattern formula for nighttime approval pursuant to §73.160(c).

Application engineering history

Beginning in 2018, the WQVR (formerly WGFP) engineering team began a quest for a verifiable description of the vertical pattern to support an application for nighttime authorization. Using various conventional and unconventional methods to derive an estimated electrical height of the radiator, mildly different results were obtained. Moreover, because of the unique and novel nature of the HEBA geometry and dual-feed configuration, it was not certain that the canonical formulas for thin-wire monopole patterns would be applicable. The formulas in 47 CFR 73.160(b) require the estimation of electrical length, typically using the current distribution method. For two reasons, this is particularly challenging for the HEBA. First, measurement of the large diameter, flared cylinder would be a complex undertaking, if it were practicable to do so. Second, like all short antennas, the use of the current distribution method is challenged by the subtle if not nonexistent changes in current on the vertical radiator.

Assuming the HEBA behaves as a short radiator, methods were tried emulating the methods applied to the earlier Valcom and Kinstar efforts, which were also deemed electrically short antennas. The physical dimensions of the Valcom and Kinstar short antennas were ultimately accepted by the Commission as proxies for their electrical heights. Consistent with this, the actual physical dimensions of the HEBA were used to calculate an approximate electrical height. The result was input to the 47 CFR 73.160(b) formulas to produce estimated vertical patterns. However, the novel dual-feed configuration and the complex geometry of the HEBA raises the question as to whether the practices approved for Valcom and Kinstar are indeed applicable to the HEBA.

This created a conundrum for identifying a way to prove the assumption that the HEBA is a short antenna subject to the same principles of radiation and computation as Valcom and Kinstar. Two options, if available, remained: 1) Perform NEC modeling to confirm the assumption, or 2) Measure the vertical pattern in the field.

The prospect of doing direct measurements of the vertical pattern was considered experimentally. It was determined that there is good reason why there is no generally accepted protocol for field measurement of AM broadcast vertical patterns for licensing purposes.

In August 2022 new HEBA engineering team members completed a NEC-5 model of the HEBA. NEC-5 had been recently released with new plate-surface modeling tools. Prior to this, NEC required a computationally demanding simulation of plate surfaces that made evaluation of the HEBA next to impossible.

As was done in the Valcom and Kinstar antenna evaluations, a NEC model was prepared for the HEBA. In the Valcom and Kinstar cases, the applicants compared their NEC results with the approximation using the §73.160(b) formulas. Because the Valcom and Kinstar applications were for a class of antennas spanning some or all of the AM band, validation of the 47 CFR 73.160(b) approach was necessary. In the HEBA case, because of the complexity of the design, the approach evaluates only the HEBA dimensions and frequency used at WQVR.

The approach

The NEC-5 HEBA pattern resembles the family of §73.160(b) patterns. It was decided to seek the §73.160(b) pattern with the best match to the HEBA pattern. A laborious process of successive approximations identified the best match. The best match required the electrical length variable to be 32.9 degrees.

Note that electrical length of any antenna is not something that is directly measured. It is a derived value that is convenient for estimating things like vertical patterns. Therefore, it is appropriate to say that the HEBA NEC model matches the equation for an ideal thin-wire monopole in which the monopole has an electrical length of 32.9 degrees. The "electrical length" of the HEBA is not precisely estimable using current distribution or physical dimensions.

It may seem to be circular logic to use the §73.160(b) formula "backwards" to derive an electrical length and apply that electrical length to the §73.160(b) formula to satisfy the requirements. However, an estimated electrical length is not being used to satisfy 73.160(b). It is apt to describe it this way instead: An NEC model was developed and from it a §73.160(c) formula was developed that matches the NEC model. That formula, conveniently, is based on the same thin-wire equation that is used for conventional antennas under §73.160(b). The constant in the resulting formula is equivalent to the electrical length of a thin-wire antenna with the same pattern.

Detailed Background

§73.160(b) provides standard equations for estimating the vertical pattern of an AM vertical monopole, with or without top-loading or sections. Its input is the "apparent electrical height ([the variable] G based on current distribution)." Traditionally, a new tower that is a substantial proportion of the station's wavelength is evaluated with a current distribution measurement, if such information is not already on the record from prior towers of the same design. The electrical height (G) is approximated with the current distribution method. G is used in the appropriate formula in §73.160(b) to generate a best estimate of the vertical pattern. Prior short antenna projects were approved for §73.160(b) evaluation after being compared to their NEC models and found to have only minor discrepancies.

The customary derivation of the G value for any antenna type is merely an approximation rather than a precise description of an electromagnetic characteristic of that antenna. Likewise, the §73.160(b) equation ($f(\theta)$) is also an approximation, using an ideal thin-wire formula as a proxy for the formula for a physical antenna structure. It has been demonstrated with NEC modelling that even tall-tower vertical radiation patterns are not perfectly represented using the G estimation method and the thin-wire formula. See, e.g., engineering submittals in the Kinstar proceeding showing how the $f(\theta)$ patterns of certain tall towers have sometimes substantial discrepancies compared to precise NEC models. The Commission accepted such discrepancies and uncertainties as having little consequence and continued to rely procedurally on the 73.160(b) approximations.

Therefore, we propose in the case of the HEBA to dispense with the uncertainties and errors of the estimation of the G value and the approximation using a thin-wire equation and rely directly on NEC-5 analysis.

Short antennas have been brought to the Commission from time to time, with some uncertainty regarding the applicability of the §73.160(b) equation. Mr. Rackley brought two short antenna designs to the Commission for approval – the "Valcom" and the "Kinstar."

The Valcom triggered a detailed review by Mr. Chase of the FCC. In his report, titled The Electrically Short Monopole Used for AM Broadcast – Engineering Analysis using NEC-MoM Software, Chase concluded in general,

> The results show that the vertical radiation pattern for this class of monopoles is practically independent of current distribution, loading and antenna height when used at frequencies that make them electrically short. The results also show that the normalized patterns are practically independent of the number of buried radial wires that may be used to improve antenna efficiency.

It is important to note that while Valcom was the application on the table, Chase's analysis concerned the general applicability of NEC modelling to this "class of antennas" (i.e. electrically short):

> *In many cases*, and particularly that of the Valcom proposal, antenna analysis using *NEC modeling will provide data in sufficient detail for the construction of formulas characterizing vertical plane radiation*. (emphasis added)

The crux of the present analysis is a two-step process:

1) the reliance on NEC modelling to produce a pattern,
2) successive approximation of $f(\theta)$ in increments of G until the best match is achieved.

The rationale for reliance on NEC modelling as the reference for the vertical pattern is based on the record with the Kinstar and Valcom initiatives. In his analysis, Rackley noted the difficulties with the current-distribution method for estimating the electrical height of short towers. He also noted the substantially more reliable results obtained from NEC modelling. Rackley showed in the Kinstar application that NEC was more accurate. He said the NEC-5 model "accounts for more terms, including effects of the relatively wide wire spacing in the antenna on the phase velocity, and thus produces a more accurate result than either of the other methods [the $f(\theta)$ formula and the current distribution analysis], which are based on mathematical approximations." The same goes for an NEC model of the HEBA.

Rackley also said that the NEC 4.1 analysis of the Kinstar short antenna "demonstrates that the departure of the Kinstar antenna's performance from the ideal thin-wire current distribution model assumed for AM antenna analysis is within the range typical of tower antennas that have been routinely authorized by the FCC for decades and that are presently in common use." Note that Rackley was comparing the results of the deterministic NEC model with a pattern based on a rough estimate of the electrical length.

Essentially, Rackley found that while NEC modelling is the gold standard, the approximations using the $f(\theta)$ formulas could be a proxy for the actual Kinstar patterns, with acceptable discrepancies. This traditional approach was particularly valuable because Kinstar was seeking blanket approval to use §73.160(b) on the Kinstar when it is physically scaled to any frequency in the AM band.

Present Effort

NEC-5 modeling demonstrates the HEBA is merely a short antenna mounted on an elevated ground plane, with a conical shape and a novel dual-feed arrangement involving a capacitor at the base. Its daytime performance was sufficient for daytime approval, confirming that it is working as a well-designed short antenna should.

Complete derivation and sample calculations

Herein is a description of the "complete derivation and sample calculations" as called for in §73.160(c). Since we are proposing nighttime authorization of only one HEBA for only one station, there is but one antenna size and frequency, and the variable G becomes a constant. We have identified the formula with the best constant to produce a pattern matching the NEC-5-derived pattern for this specific antenna.

To develop a formula for the WQVR HEBA antenna pattern we first asked whether the shape of the pattern calculated by NEC-5 would match any pattern that could be generated by the $f1(\theta)$ formula (§73.160(b)(1)). To do so, the NEC-5 pattern was compared with iterations of the $f1(\theta)$ formula.

At each increment of G, we subtracted the directivity of the NEC data from the $f1(\theta)$ value, determined its absolute difference, and for the range of elevations from 0 to 88 degrees determined the maximum difference. By taking the difference rather than creating a ratio, the differences remain normalized to the maximum directivity. Further, it is well recognized that radiation toward the vertical is both challenging to represent mathematically and irrelevant to the issue of nighttime interference to distant stations. Thus, the comparison terminated at 88 degrees elevation. (Nevertheless, as shown below, the deviation even at 90 degrees is trivial.)

By plotting the maximum deviation between the NEC data and the $f1(\theta)$ formula for G values between 29 and 36 degrees (*Figure 1*), there is a clear unique match at 32.9 degrees showing that the $f1(\theta)$ formula with a G value of 32.9 degrees is an excellent representation of the reference NEC vertical pattern. The NEC-5 vertical pattern and the WQVR HEBA formula are compared graphically in *Figure 2*.

The WQVR HEBA antenna pattern formula is:

$$f(\theta) = \frac{\cos(G \sin(\theta)) - \cos(G)}{(1 - \cos(G)) - \cos(\theta)} \qquad \text{Where } G = 32.9°$$

The present formula applies only to the HEBA with dimensions used at WQVR and on a frequency of 940 kHz. Since this applies to one design at one frequency, the required sample calculations are limited to evaluating one pattern at various elevations. Sample calculations are provided in the WQVR Formula column of Table 1 and are compared to the modeled values in the WQVR NEC-5 column.

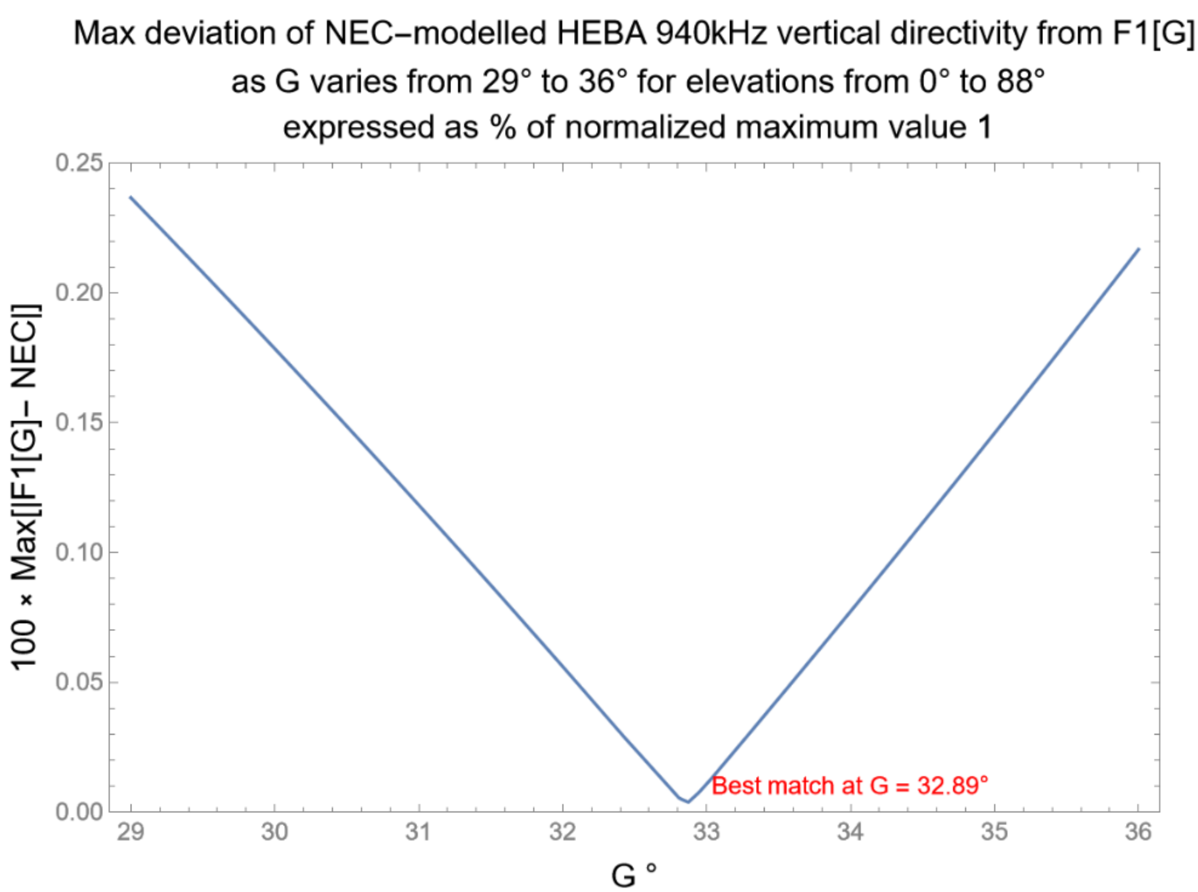

Figure 1 - WQVR HEBA Formula Best-Fit Search Results

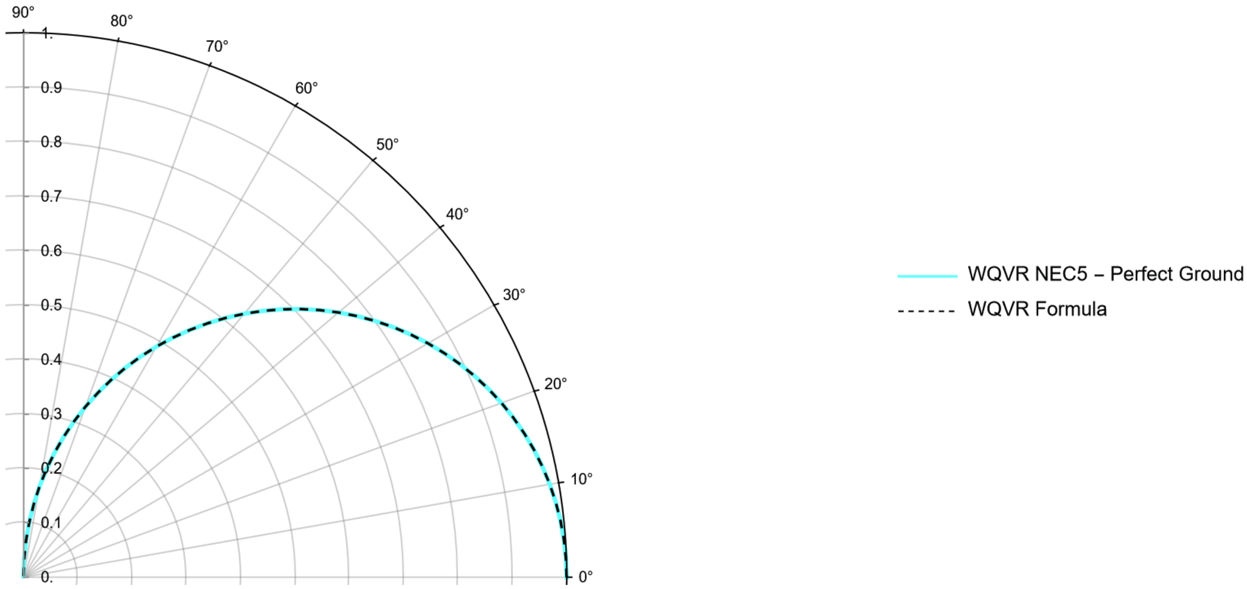

Figure 2 - WQVR Vertical Pattern Comparison: NEC-5 model and WQVR HEBA formula

Table 1 - WQVR HEBA Vertical Pattern Comparison: NEC-5 model and WQVR HEBA formula

Elevation (°)	WQVR NEC5 (reference)	WQVR Formula (estimate)	Elevation (°)	WQVR NEC5 (reference)	WQVR Formula (estimate)
0	1.0000	1.0000	46	0.6847	0.6847
2	0.9993	0.9994	48	0.6589	0.6589
4	0.9974	0.9974	50	0.6323	0.6323
6	0.9942	0.9942	52	0.6051	0.6051
8	0.9897	0.9897	54	0.5772	0.5771
10	0.9840	0.9840	56	0.5486	0.5485
12	0.9769	0.9770	58	0.5194	0.5194
14	0.9687	0.9687	60	0.4896	0.4896
16	0.9592	0.9592	62	0.4593	0.4593
18	0.9485	0.9485	64	0.4286	0.4286
20	0.9366	0.9366	66	0.3974	0.3973
22	0.9236	0.9236	68	0.3657	0.3657
24	0.9094	0.9093	70	0.3337	0.3337
26	0.8940	0.8940	72	0.3013	0.3013
28	0.8776	0.8775	74	0.2686	0.2686
30	0.8600	0.8600	76	0.2356	0.2356
32	0.8415	0.8414	78	0.2024	0.2024
34	0.8219	0.8218	80	0.1690	0.1690
36	0.8013	0.8012	82	0.1354	0.1354
38	0.7798	0.7797	84	0.1016	0.1017
40	0.7573	0.7572	86	0.0678	0.0678
42	0.7339	0.7339	88	0.0339	0.0339
44	0.7097	0.7097	90	0.0017	0.0000

The excellence of the match (within ~0.004%) clearly demonstrates this is an accurate formula for the vertical radiation pattern of this specific HEBA.

Interference analysis

The WQVR HEBA formula was applied to a new nighttime interference analysis by Mr. Hecht (attached engineering statement). WQVR is presently licensed for nighttime operation at 0.004 kW on the conventional antenna. The new analysis confirms that the WQVR interference contour is within the necessary limits when basing the calculation on the NEC 5 formula.

Environmental emissions

In addition to the analysis in prior submissions regarding the theoretical safe distances for an antenna radiating the WQVR licensed power, on-site measurement using a Narda 8718 meter with broadband conformal electric and magnetic probes demonstrates compliance with §1.1307(b) *et seq.* in all uncontrolled areas around and under the HEBA antenna assembly. Controlled areas are accessible only to trained personnel.

Conclusion

The NEC modeling of the WQVR HEBA antenna reliably confirms the HEBA behaves like all short radiators in this part of the spectrum. It has the distinct advantage of being immune to seasonal variations in ground conductivity. Its vertical pattern is precisely predicted by NEC. Through successive approximations it is determined that the WQVR HEBA vertical radiation pattern is described exactly by the $f1(\theta)$ formula with a G of 32.9 degrees. This engineering statement satisfies the requirements of §73.160(c) to provide a "special formula" with a "complete derivation and sample calculations." The HEBA can operate at nighttime with the same nighttime power currently authorized for the conventional broadcast antenna.

Respectfully submitted,

David Maxson
Principal
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PO Box 52437
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Engineering services of Peter Zollman, Chartered Engineer (FIET, SMIEEE) provided in the development of the NEC-5 model.

ENGINEERING REPORT COVERING

NIGHTTIME SKYWAVE INTERFERENCE CALCULATIONS

USING ISOTROPE VERTICAL PATTERN FORMULA

FOR WQVR 940 KILOHERTZ

WEBSTER, MASSACHUSETTS

DECEMBER 2023

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SUMMARY

The engineering report of which this statement is part was prepared in support of construction permit application BP-20180529ACD for AM station WQVR[1] Webster, Massachusetts. WQVR is licensed to operate on a frequency of 940 kilohertz on an unlimited basis using a non-directional antenna system. Power is 1 kilowatt during the daytime hours and .004 kilowatts during the nighttime hours. The license authorizes operation with a High Efficiency Broadband Antenna System (HEBA), daytime hours only. This application seeks to obtain nighttime HEBA operation using the HEBA with power of .004 kilowatts from the existing site. The purpose of this engineering report is to demonstrate compliance with nighttime skywave protection requirements using the formula established by Isotrope, LLC derived pursuant to Section 73.160(c) of the FCC rules.

[1] Formerly identified as WGFP.

NIGHTTIME ALLOCATION CONSIDERATIONS

The primary nighttime allocation consideration for WQVR is Canadian Class A co-channel station CFNV Montreal, Quebec. The US Canadian Agreement requires WQVR to protect the CFNV 0.5 mV/m Region 2 50% skywave contour in Canada and at the Canadian-US border where the 0.5 mV/m skywave contour extends into the US by limiting WQVR radiation to 0.025 mV/m computed using the Region 2 10% curves at the contour or at the border when the contour extends into the US.

CALCULATION OF VERTICAL RADIATION FROM THE HEBA ANTENNA

WQVR is licensed to operate with .004 kilowatts during the nighttime hours based on an RMS efficiency of 289.7 mV/m/km. The licensed HEBA 1 kilowatt daytime antenna system RMS is 263.4 mV/m/km as documented in file number BP-20161216AAJ. Based on these values, an allocation study was conducted for the licensed and proposed WQVR operations. The allocation study for the licensed facility was based on Section 73.160(c) and the proposed WQVR nighttime facility was based on the Isotrope formula. Both studies were conducted at the calculated departure angle of 28.5 degrees toward CFNV. The licensed WQVR operation at the CFNV 28.5 degree departure angle produces a voltage ratio of 0.863 as compared to the horizontal plane radiation. The proposed operation, based on computations employing the Isotrope formula and compared to the horizontal plane value, shows a measured voltage ratio of 0.873. The study results can be found in Tables 1 and 2 of this report and are plotted on Figure 1. As shown on these exhibits, the proposed HEBA nighttime operation will not cause interference to CFNV.

Therefore, it can be safely concluded the proposed HEBA nighttime operation will not cause interference to CFNV. In fact, as shown on Figure 1, compared to the licensed WQVR nighttime operation, radiation toward CFNV will be reduced. The proposed WQVR HEBA operation will not increase the nighttime limit of any foreign or domestic station.

DECLARATION

The foregoing was prepared by or under the immediate supervision of Charles A. Hecht of Charles A. Hecht & Associates, Inc., Freehold, New Jersey, whose qualifications are a matter of record with the Federal Communications Commission. All statements herein are true and correct of his knowledge except such statements made on information and belief, and as to those statements, he believes them to be true and correct under the penalty of perjury.

Respectfully submitted,

Charles A. Hecht

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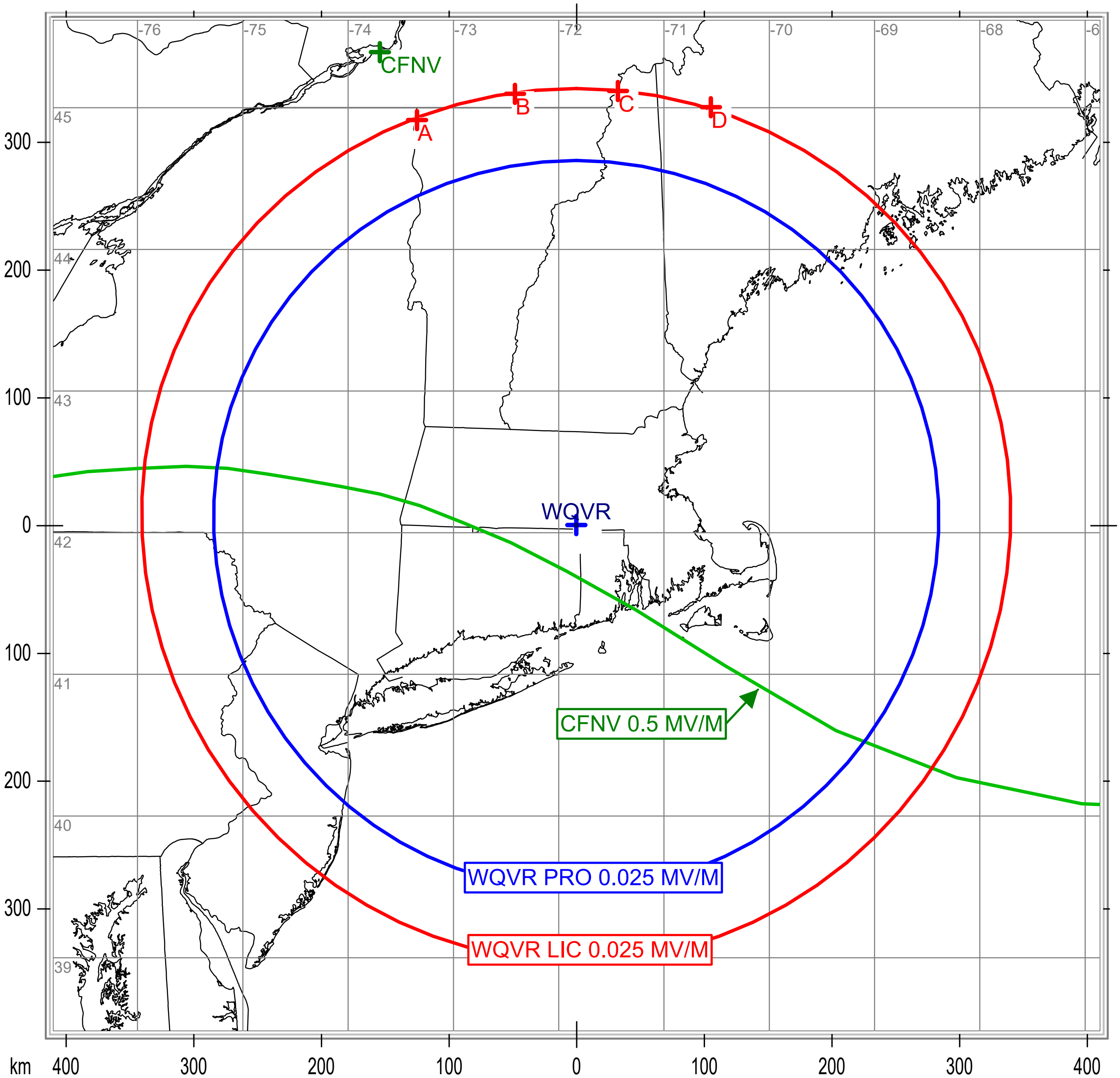
December 19, 2023

FIGURE 1 - NIGHTTIME ALLOCATION MAP

SHOWING REGION 2 SKYWAVE SERVICE AND INTERFERENCE CONTOURS



WQVR 940 KILOHERTZ .004 KW ND WEBSTER, MASSACHUSETTS

State Borders   Lat/Lon Grid

Map Scale: 1:5000000   1 cm = 50.00 km   V|H Size: 790.93 x 820.08 km   CHARLES A. HECHT & ASSOCIATES, INC. - DECEMBER 2023

TABLE 1 – WGFP/CFNV AM NIGHT ALLOCATION STUDY
LICENSED

Coordinates: 42-03-17.0 N 71-50-00.0 W
Frequency: 940 Kilohertz
Initial PWR: 0.004 Kw
Initial Inv Field: 18.32 mV/M

SITE INFO

POINT	AZIMUTH DEG	SL DIST KM	DIST KM	GEOMAG MIDPT	AZIMUTH DEG	GND RAD MV/M	MIN ELEV DEG	MAX ELEV DEG	MAX RAD MV/M	SWAVE FLD MV/M	LIMIT MV/M
C	5.2	396.3	342.1	55.1	5.2	18.3	28.5	28.5	15.8	0.158573	0.500
D	17.0	397.7	343.7	55.0	17.0	18.3	28.4	28.4	15.8	0.158027	0.499
A	339.5	394.8	340.4	55.0	339.5	18.3	28.6	28.6	15.7	0.159132	0.501
B	352.3	395.8	341.6	55.1	352.3	18.3	28.5	28.5	15.8	0.158745	0.500

TABLE 2 – WGFP/CFNV AM NIGHT ALLOCATION STUDY
PROPOSED

Coordinates: 42-03-17.0 N 71-50-00.0 W
Frequency: 940 Kilohertz
Initial PWR: 0.004 Kw
Initial Inv Field: 16.85 mV/M

SITE INFO

POINT	AZIMUTH DEG	SL DIST KM	DIST KM	GEOMAG MIDPT	AZIMUTH DEG	GND RAD MV/M	MIN ELEV DEG	MAX ELEV DEG	MAX RAD MV/M	SWAVE FLD MV/M	LIMIT MV/M
C	5.2	396.3	342.1	55.1	5.2	16.8	28.5	28.5	14.7	0.158573	0.466
D	17.0	397.7	343.7	55.0	17.0	16.8	28.4	28.4	14.7	0.158027	0.465
A	339.5	394.8	340.4	55.0	339.5	16.8	28.6	28.6	14.7	0.159132	0.467
B	352.3	395.8	341.6	55.1	352.3	16.8	28.5	28.5	14.7	0.158745	0.466