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OFFICE OF ENGINEERING AND TECHNOLOGY ANNOUNCES UPDATES TO *FMModel* SOFTWARE

Today, the FCC's Office of Engineering and Technology (OET) announces updates to its *FMModel* software to increase its utility for determining potential exposure from FM broadcast station radiofrequency (RF) electromagnetic fields. The *FMModel* software was developed by the FCC in 1997 as a standalone executable program to calculate RF power density at ground level from a single FM broadcast station antenna, given the height, power, and type of antenna on a tower. The new release we announce today brings *FMModel* into the modern age by making it available as a webpage,[1] enabling the capability to work with a wider variety of operating systems, and streamlining the antenna types offered to more accurately represent the measured data published in 1985 by the Environmental Protection Agency (EPA).[2]

Additionally, we improve the method used by *FMModel* to approximate near-field exposure by adjusting the way array factors are calculated to better estimate the effects of antenna null shallowing and offset. This updated *FMModel* also incorporates improved precision in the way separation distance is determined by using the actual distances to each antenna element, rather than the distance to the antenna's radiation center. While most predictions using this updated *FMModel* will be similar to the previous version, this correction could result in significant differences from the previous model, primarily at short separation distances from the bottom element of an antenna array, where accurate exposure estimation is most critical. Appendix A contains a brief description of these changes. The updated *FMModel* does not readily address antenna beam-tilt or null-fill, just as the previous version of *FMModel* did not. However, we believe that users can draw a line through the local maxima of *FMModel*'s output (*i.e.*, "connect the dots") rather than relying on specific values at particular distances. In doing so, we believe that users can produce a reasonable approximation that will not underestimate the fields for common beam-tilt angles, null-fill percentages, and mounting methods.

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[1] This new version of *FMModel* is available at https://www.fcc.gov/oet/software/fmmodel. Prior to this release, *FMModel* was available on OET's webpage as a standalone executable compatible with Microsoft Windows releases XP or earlier. We offer this updated version of *FMModel* as a webpage rather than a standalone executable to avoid future compatibility issues and to promote transparency.

[2] *See* Gailey, P. C., Tell, R. A., *An Engineering Assessment of the Potential Impact of Federal Radiation Protection Guidance on the AM, FM, and TV Broadcast Services*, United States Environmental Protection Agency, Las Vegas, Nevada, 1985, EPA 520/6-85-011.

Another improvement incorporated into the updated *FMModel* is a feature that displays a message and will not show results when, based on the FM broadcast channel wavelength, a combination of antenna height and element spacing would result in a portion of the antenna at or below the spatial region two meters above the ground. We believe that displaying this dialog box will provide a logical check to users that a particular FM broadcast antenna requires further evaluation, such as conducting physical measurements of its fields.

Although we believe that *FMModel* accurately predicts the fields for the vast majority of FM antennas, OET cautions that the results of *FMModel* may not accurately represent all antennas or environments, such as those with elements located near the ground or a rooftop. Use of *FMModel* does not relieve licensees from conducting measurements as necessary to determine compliance with FCC RF exposure limits.

The *FMModel* software was originally based on measured data published in 1985 by the EPA.[3] That data characterized the performance of single-element FM antennas using five different element designs. The EPA used that data to construct an envelope around the local maxima of standard array factors in an attempt to account for the near-field effects of null shallowing and offset, as well as to account for use of electrical beam-tilt and null-fill by some FM stations to improve coverage. The Commission did not implement these envelope patterns and instead combined the measured element patterns with standard array factors and other information to produce an antenna's far-field radiation pattern, including any nulls.

Since *FMModel* was originally released, OET, in response to user requests, has occasionally added additional element patterns to the model. However, those additions were not based on data measured in the same way as EPA's method, which more accurately captured the possibility of interactions with metallic supporting structures and resulting pattern variations that may occur due to the variety of mounting configurations used by broadcasters in practice. Therefore, the added patterns may not be representative of antennas as installed. For this reason, the updated *FMModel* includes only the five original EPA element types. We will entertain requests to include additional element patterns in *FMModel*, but only if accompanied by measurement data obtained in a way consistent with the original EPA data.[4] Requests to include new element types must include a description of the element design and measurement method, as well as a justification why the design is significantly different from the element types already specified.[5]

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3 *Id*.

4 We specifically encourage the submission of data under the EPA measurement method for vertical dipole antenna elements, which in free-space have a theoretical downward-facing null but may behave differently when mounted to a tower, as such antennas were not included in the five original EPA element types.

5 *Id* at Appendix A, Section 1. Measurements of these elements were performed in several configurations, including at four different azimuth angles, in each plane of polarization, and with the full scale element measured in free-space, face-mounted on a tower section, and leg-mounted on a tower section. The resulting element patterns were then combined to obtain a worst-case composite element pattern envelope to represent the element.

Based on its review of various references, OET has associated current antenna models with one of the five EPA element types; a list of those associations is attached as Appendix B.[6] Element designs that are not listed in Appendix B because they were not specifically evaluated by EPA, *e.g.*, panel antennas, vertical dipoles, *etc*., will tentatively be treated as Type 1, which is worst-case of the five EPA element types. We invite antenna manufacturers, broadcasters, consultants, and others to suggest corrections to Appendix B, as well as to augment that list with information on historical or current antenna models that we may have inadvertently overlooked or categorized incorrectly.

FMModel is available at https://www.fcc.gov/oet/software/fmmodel.

For further information, please contact Martin Doczkat at (202) 418-2435 or e-mail martin.doczkat@fcc.gov.

– FCC –

[6] Inclusion of antenna models on this list does not constitute an endorsement of those manufacturers or their products by the Federal Communications Commission.

Appendix A – Development of FM Broadcast Antenna Radiating Near-Field Approximation

The far-field antenna gain of an FM broadcast antenna consists of two components: 1) an antenna element gain (the gain of an individual antenna element in a particular direction); and 2) an antenna array factor (the gain resulting from an array of individual antenna elements taken together as one). The total antenna gain is determined by taking the product of these two antenna gains. Antenna array factors can be readily calculated if geometry and phase conditions are known, whereas antenna element gains must generally be measured, especially when taking into account potential exposure in the radiating near-field region of an antenna.[7]

The antenna array factor for a particular FM antenna can be estimated by assuming a typical geometric antenna configured, as a vertically-stacked uniform array of individual antenna elements, fixed-mounted on an antenna structure. The antenna gain patterns of the individual antenna elements have been measured by the EPA, representing five broad types of antennas, and are incorporated in the *FMModel* software. The goal of *FMModel* software is to estimate the radiofrequency (RF) power density at ground level from a single FM broadcast station antenna, consisting of an array of uniformly-spaced individual antenna elements, given the height, power, and type of antenna.

The total antenna gain of an FM antenna in a particular direction is rudimentarily determined in the previous version of *FMModel* by taking the product of the contribution of antenna gain by an individual antenna element and the far-field antenna array factor.[8] The far-field antenna array factor in the previous version of *FMModel* was determined by multiplying N times the path from the array centerpoint to an evaluation point in space P, as shown in the following figure:[9]

7 *See* Gailey, P. C., Tell, R. A., *An Engineering Assessment of the Potential Impact of Federal Radiation Protection Guidance on the AM, FM, and TV Broadcast Services*, United States Environmental Protection Agency, Las Vegas, Nevada, 1985, EPA 520/6-85-011.

8 The power density is then determined by squaring the total antenna gain, scaling by the effective radiated power and the inverse square of distance to the center of the antenna array, normalizing by the impedance of free-space, and increasing this result by a fixed ground reflection factor.

9 N is the number of individual antenna elements in the array.

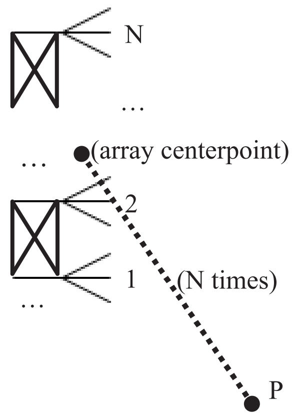

Figure 1 – Far-Field Array Factor in Previous Version of FMModel.

However, this simple derivation based on the far-field antenna array factor is not appropriate for approximating an antenna's radiating near-field (*i.e.*, at distances close to the antenna). Using that methodology, the error in phase due to non-parallel paths to an evaluation point from each antenna element and the error in distance and associated amplitude introduced by assuming separation from the center of the array rather than with respect to each antenna element can be significant. Thus, instead of simplifying the calculation to a single path and multiplying by the far-field antenna array factor as was done in the previous version of *FMModel*, this updated *FMModel* sums the individual contributions from each antenna element along each individual path to evaluation point P, as shown in the following figure:

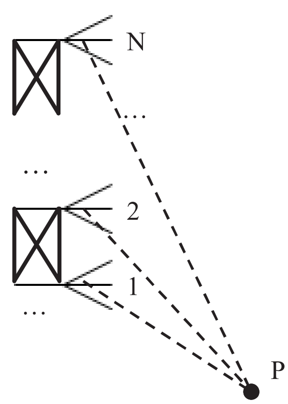

Figure 2 – Near-Field Array Factor Approximation in Updated Version of FMModel.

The total near-field antenna gain in a particular direction is then determined in the updated version of *FMModel* by taking the sum of the electric field strengths of the antenna element pattern at each evaluation point, P (depicted in the figure above).[10] However, this updated approach still assumes each antenna element is fed by a signal of equal power and phase. This assumption limits the validity of the model if applied to antennas with electrical beam-tilt and null-fill that is implemented primarily by phase-shifting the input signals at each element. In addition, as stated in the rationale for the model developed by the EPA in its April 1985 report, provided in Appendix A of [7], while the effects of mutual coupling between antenna elements may be ignored for full-wave element spacing, it is impossible to predict its exact effects without extensive additional analysis and measurement, and such an effort would likely not encompass all combinations of feed systems and antenna geometries, as well as interactions with the supporting tower structure, particularly at element spacings less than a wavelength. For those situations where FMModel has limited validity, antenna measurements should be conducted to determine compliance with the Commission's RF exposure rules.

Nonetheless, to verify the updated *FMModel*, calculations have been compared to the results of the field study conducted by the EPA in August 1982, provided in Appendix B of [7]. The EPA measured power densities around six FM stations representing the antenna types described in Figures 52 through 57 below.[11] Shown in green are the results using the previous *FMModel* and shown in blue are the results using the updated *FMModel*. The results of the updated *FMModel* appear to be in reasonable agreement with the curves calculated by the EPA. Similar to the observation by the EPA in its model verification, the measured values exceed the predicted curve in some cases, but in all cases the highest value predicted by the model was not exceeded by the measurements.

[10] The power density is then determined as in the previous version: by squaring the total antenna gain, scaling by the effective radiated power, assuming the impedance of free-space, and increasing this result by a fixed ground reflection factor.

[11] Although out of sequence, the figure numbers here have been preserved for direct comparison with the EPA study.

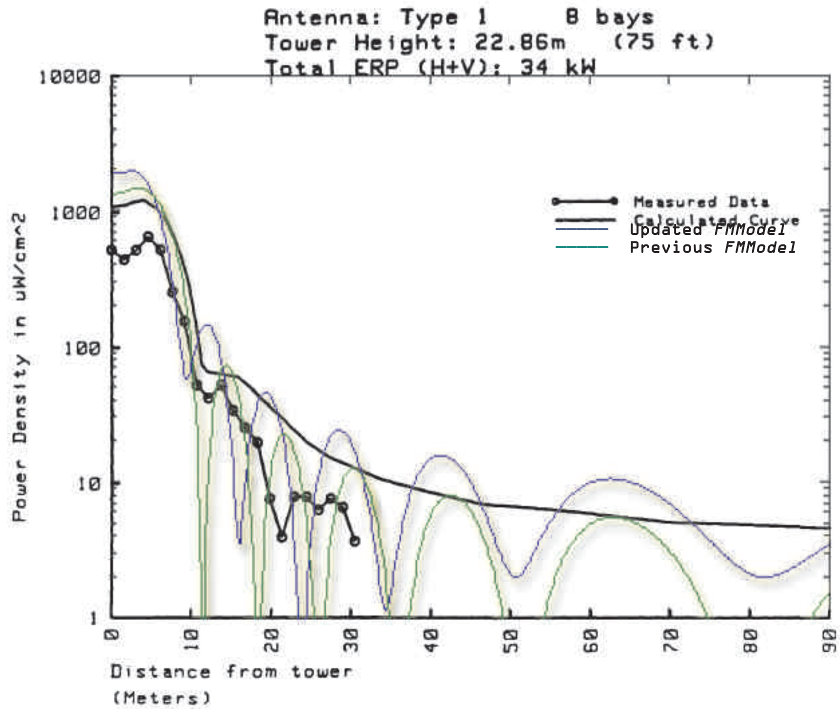

Figure 52. Calculated and measured power densities (free-space equivalent) for an actual FM station.

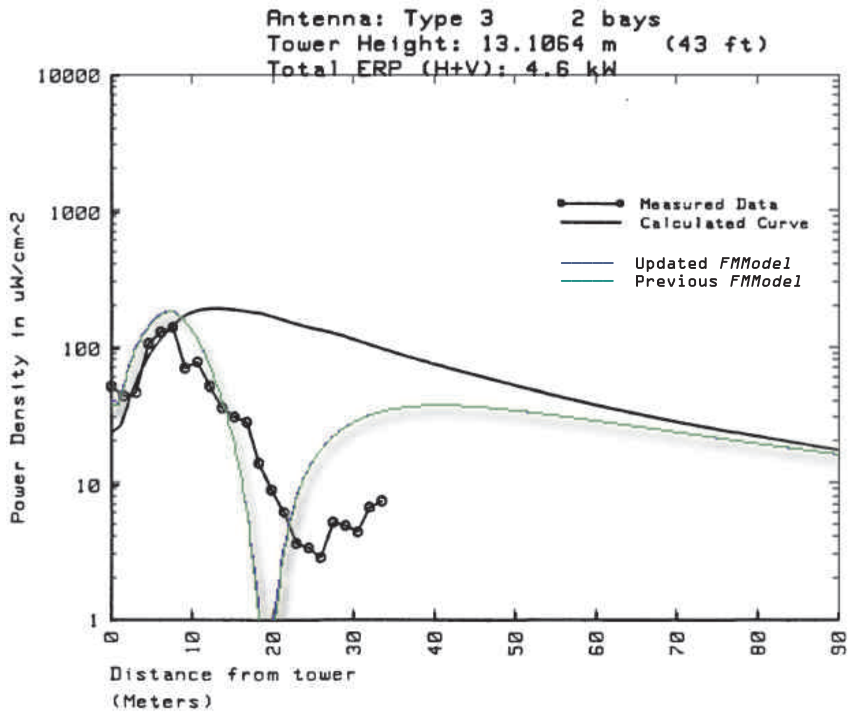

Figure 53. Calculated and measured power densities (free-space equivalent) for an actual FM station.

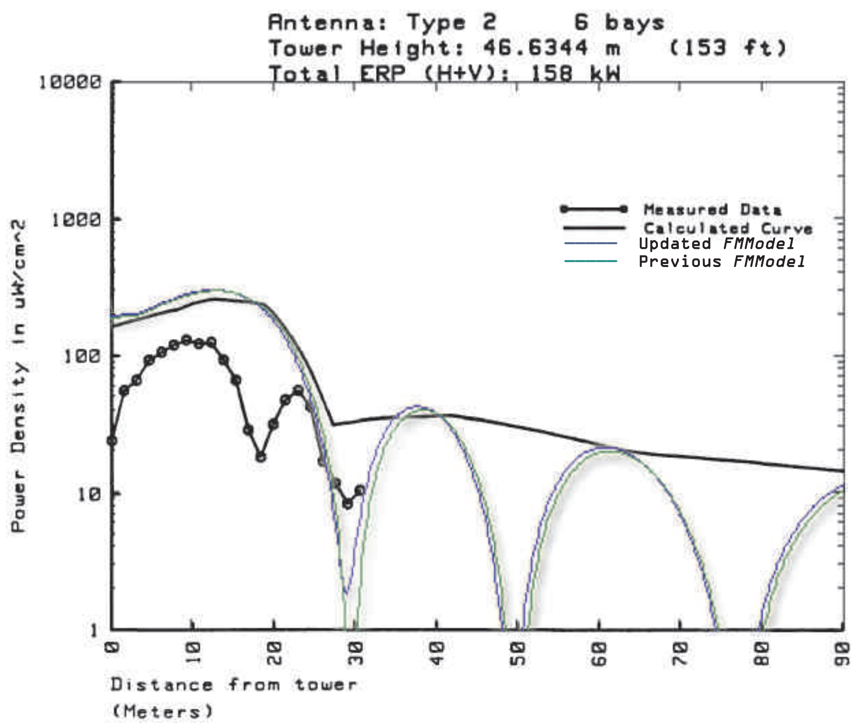

Figure 54. Calculated and measured power densities (free-space equivalent) for an actual FM station.

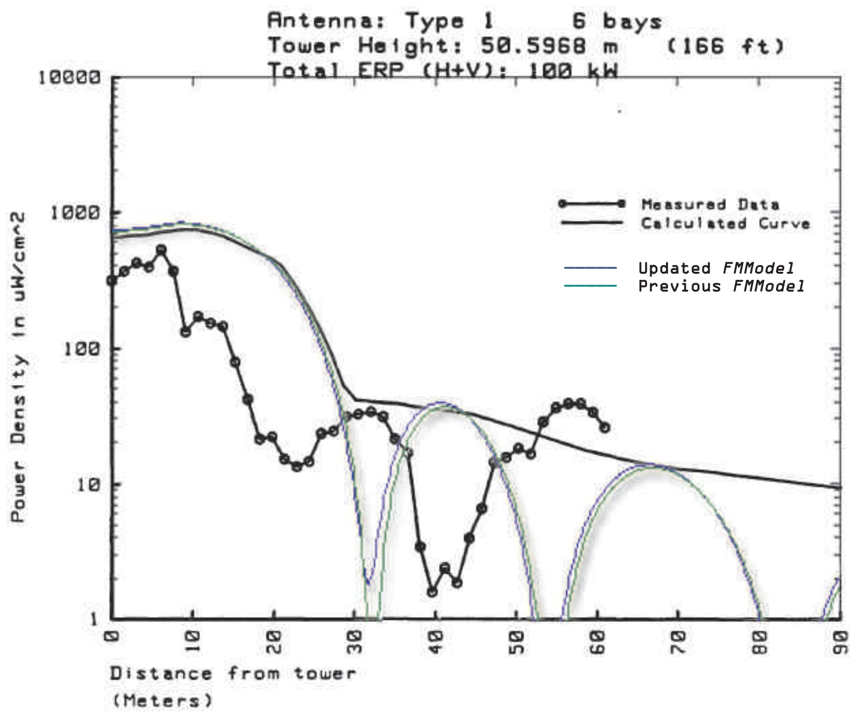

Figure 55. Calculated and measured power densities (free-space equivalent) for an actual FM station.

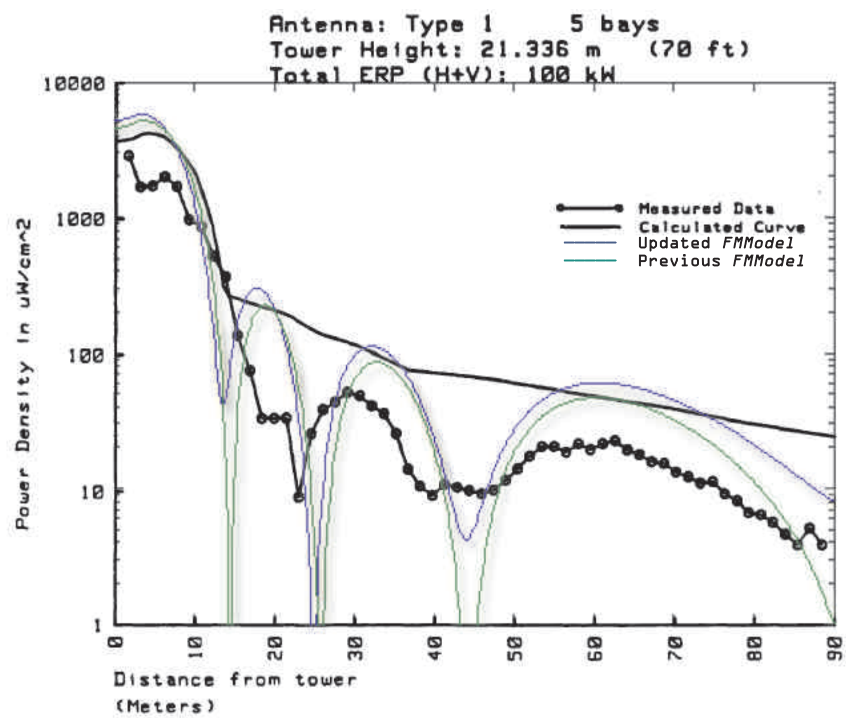

Figure 56. Calculated and measured power densities (free-space equivalent) for an actual FM station.

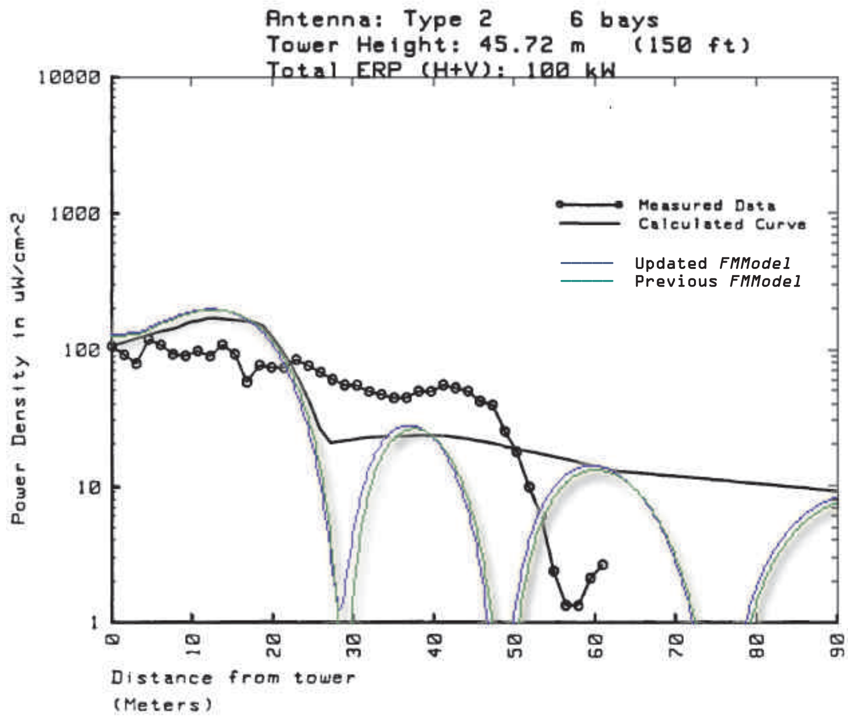

Figure 57. Calculated and measured power densities (free-space equivalent) for an actual FM station.

Appendix B – Cross-Reference of Commercial FM Broadcast Antennas with EPA Element Type

EPA Element	Description	Example Antennas[i]	
		Manufacturer	Model
Type 1	Ring-and-stub, or any type not-otherwise described	BEXT	TFC1K
		Dielectric	DCR-L
		ERI	ECFM G4CPH G4CPL G4CPM LPC 37CP 37M 1105
		Harris	FMC FMS
		NiCOM	BKG88
		Shively	6814 6810 6813 6812
		SWR	FM1
Type 2	Opposed "V" dipole	BEXT	TFC2K
		ERI	100A
		Jampro	JCPB JHCP JHPC JLLP JLPC JMCP JMPC JSCP JSLP
		MCI	AT12
		NiCOM	BKG77
		PSI	FML
		RFS	828
		Shively	6832

EPA Element	Description	Example Antennas[i]	
		Manufacturer	Model
		SWR	FM3 FM10 FMEC FMU
Type 3	Opposed "U" dipole	Armstrong	FMA-737
		BE	BEMP BESP
		ERI	G5CPM G5CPS DI LP LPX MP MPX SHP SHPX
		Harris	FMH FML FMP FMX
		Jampro	JBCP
Type 4	Two-piece spiral	Armstrong	FMA-707/727
		Dielectric	CCA DCR/HDR-C DCR/HDR-H
		Jampro	JLCP
		RFS	CPF
Type 5	Three-piece spiral or Four-piece spiral	Dielectric	DCR-G DCR/HDR-M DCR-Q

[i] Inclusion of antenna models on this list does not constitute an endorsement of those manufacturers or their products by the Federal Communications Commission.