Measurements Necessary for Moment Method Modeled FCC Form 302 Filings

The applicable FCC Rule is 47 CFR 73.151(c).

"(c) Computer modeling and sample system verification of modeled parameters to establish operation of a directional antenna consistent with the theoretical pattern. Each element of the directional array shall be modeled by use of a method of moments computer program, using the physical characteristics of each element to establish a model that does not violate any of the internal constraints of the computer program. Only arrays consisting of series-fed elements may have their performance verified by computer modeling and sample system verification.
(1) A matrix of impedance measurements at the base and/or feed point of each element in the array, with all other elements shorted and/or open circuited at their respective measurement locations, shall be made. The physical model of the individual antenna elements used in the computer program may be varied to match the measured impedance matrix, but the actual spacings and orientations of the array elements must be used. Towers may be modeled using individual vertical wires to represent them, or with multiple wires representing their leg and cross-member sections. The resulting model description (consisting of the length, radius, and number of segments of each wire for arrays using vertical wire sections to represent the towers, or the length, end-point coordinates, and radius of each wire used to represent leg and cross-member sections for arrays using detailed tower structure representations) as well as the assumed input feed and base region stray reactances shall be used to generate the drive impedances and sample system parameter values for the operating directional antenna pattern parameters.
(I) For arrays using vertical wires to represent each tower, the radii of cylinders shall be no less than 80 percent and no more than 150 percent of the radius of a circle with a circumference equal to the sum of the widths of the tower sides.
(ii) For arrays using multiple wires to represent leg and cross-member sections, the individual legs of the tower may be modeled at their actual diameters with appropriate interconnecting segments representing cross-members at regular intervals.
(iii) No less than one segment for each 10 electrical degrees of the tower's physical height shall be used for each element in the array.
(iv) Base calculations shall be made for a reference point at ground level or within one electrical degree elevation of the actual feed point.
(v) For uniform cross-section towers represented by vertical wires, each wire used for a given tower shall be between 75 to 125 percent of the physical length represented.
(vi) For self-supporting towers, stepped-radius wire sections may be employed to simulate the physical tower's taper, or the tower may be modeled with individual wire sections representing the legs and cross members.
(vii) The lumped series inductance of the feed system between the output port of each antenna tuning unit and the associated tower shall be no greater than 10 μH unless a measured value from the measurement point to the tower base with its insulator short circuited is used.
(viii) The shunt capacitance used to model base region effects shall be no greater than 250 pF unless the measured or manufacturer's stated capacitance for each device other than the base insulator is

used. The total capacitance of such devices shall be limited such that in no case will their total capacitive reactance be less than five times the magnitude of the tower base operating impedance without their effects being considered.

(ix) The orientation and distances among the individual antenna towers in the array shall be confirmed by a post-construction certification by a land surveyor (or, where permitted by local regulation, by an engineer) licensed or registered in the state or territory where the antenna system is located.

(2)(I) The computer model, once verified by comparison with the measured base impedance matrix data, shall be used to determine the appropriate antenna monitor parameters. The moment method modeled parameters shall be established by using the verified moment method model to produce tower current distributions that, when numerically integrated and normalized to the reference tower, are identical to the specified field parameters of the theoretical directional antenna pattern. The samples used to drive the antenna monitor may be current transformers or voltage sampling devices at the outputs of the antenna matching networks or sampling loops located on the towers. If sample loops are used, they shall be located at the elevation where the current in the tower would be at a minimum if the tower were detuned in the horizontal plane, as determined by the moment method model parameters used to determine the antenna monitor parameters. Sample loops may be employed only when the towers are identical in cross-sectional structure, including both leg and cross member characteristics; if the towers are of unequal height, the sample loops shall be mounted identically with respect to tower cross members at the appropriate elevations above the base insulator. If the tower height used in the model is other than the physical height of the tower, the sampling loop shall be located at a height that is the same fraction of the total tower height as the minimum in tower current with the tower detuned in the model. Sample lines from the sensing element to the antenna monitor must be equal in both length (within one electrical degree) and characteristic impedance (within two ohms), as established by impedance measurements, including at the open-circuit resonant frequency closest to carrier frequency to establish length, at frequencies corresponding to odd multiples of 1/8 wavelength immediately above and below the open circuit resonant frequency closest to carrier frequency, while open circuited, to establish characteristic impedance, and at carrier frequency or, if necessary, at nearby frequencies where the magnitude of the measured impedance is no greater than 200 ohms with the sampling devices connected. Samples may be obtained from current transformers at the output of the antenna coupling and matching equipment for base-fed towers whose actual electrical height is 120 degrees or less, or greater than 190 electrical degrees. Samples may be obtained from base voltage sampling devices at the output of the antenna coupling and matching equipment for base-fed towers whose actual electrical height is greater than 105 degrees. Samples obtained from sample loops located as described above can be used for any height of tower. For towers using base current or base voltage sampling derived at the output of the antenna coupling and matching equipment, the sampling devices shall be disconnected and calibrated by measuring their outputs with a common reference signal (a current through them or a voltage across them, as appropriate) and the calibration must agree within the manufacturer's specifications. A complete description of the sampling system, including the results of the measurements described in this paragraph, shall be submitted with the application for license.
(ii) Proper adjustment of an antenna pattern shall be determined by correlation between the measured antenna monitor sample indications and the parameters calculated by the method of

moments program, and by correlation between the measured matrix impedances for each tower and those calculated by the method of moments program. The antenna monitor sample indications must be initially adjusted to agree with the moment method model within +/-5 percent for the field ratio and +/-3 degrees in phase. The measured matrix impedances must agree with the moment method model within +/-2 ohms and +/-4 percent for resistance and reactance.
(3) Reference field strength measurement locations shall be established in directions of pattern minima and maxima. On each radial corresponding to a pattern minimum or maximum, there shall be at least three measurement locations. The field strength shall be measured at each reference location at the time of the proof of performance. The license application shall include the measured field strength values at each reference point, along with a description of each measurement location, including GPS coordinates and datum reference."

MEASUREMENTS OF THE ANTENNA SYSTEM

The rule calls for a "matrix" of measurements at the base and/or feed point of each element in the array with all of the other elements shorted and or open circuited at the same locations used for the measurements.

If the antenna sample system uses current transformers, one set of measurements should be made at the closest possible location to the transformers, and as each measurement is made the current sample location at all the other towers should be opened and/or shorted. These measurements should be made with all the other appurtenances that are "downstream" from the sample transformer in place, including isocouplers, lighting transformers, and static drains.

When the moment method model is created to match these measurements, it will generate the conditions at the tower base. Each one of the "modifications" will have to be included in a Spice or WCAP (or hand generated) circuit model, which will allow calculation of the operating impedance at the current sample location, and will allow the calculation of the current (magnitude and angle) at that location as well. In some cases, the base conditions won't be modified significantly, but in some cases they will, depending upon the actual base drive impedance and the equivalent circuit between the base and the sample transformer location. There is usually a "J" plug located at the appropriate place very close to the sample transformer, making the open circuit and short circuit operation fairly easy. The short circuit should be with a low impedance piece of copper strap as short as possible to make the connection, NOT just a normal test lead.

It is almost always useful to make an additional set of "matrix" measurements directly at the tower bases, right across the insulator. These measurements should be made with each tower totally disconnected from its feed. If the antenna system has sample loops, this is the measurement that is used as the reference, but it's useful to have even when current transformers are used. Follow the same procedures, making a measurement at each tower with the others open and/or shortcircuited. Note the presence of any circuit elements that are impossible to remove, like Austin transformers. Note also the model number of the base insulators. The short circuit directly across the base insulator should be a very low impedance connection, using 2 or even 4 inch copper strap and vise-grip pliers or C-clamps or other very sturdy method. Clean up the surfaces on the tower steel and the insulator base or ground strap under the insulator. If the tower has an arc gap with 1 inch or so pipe connections it can be used but a wide strap is best.

If time permits it is also useful to make a measurement at each tower at the "j" plug location with that tower's base insulator shorted.

Although the rule only requires open and/OR short measurement, both sets should be made to provide an error check and in case one or the other set isn't quite a good fit to the model.

MEASUREMENTS OF THE SAMPLE SYSTEM

There are two sets of measurements necessary for the sample system. The first set provides data on the compliance of the system with the rules, and the second set provides a baseline for system verification over time.

Line Length

The sample lines must be equal in length to within 1 electrical degree at the carrier frequency and must be equal in impedance to within 2 ohms. That's a total length range longest to shortest of one degree and total impedance range lowest to highest of no more than 2 ohms.

The procedure for this measurement is very explicit in the rules, and it's not the method most commonly used. It should be followed carefully.

Each line is measured with it open-circuited at the sample device end of the line. The first step is to find the frequency closest to the carrier frequency where the line is *series* resonant, that is, a frequency “zero” where the resistance is very low and the reactance is zero or changes sign.

Then, using this data, the line length is some odd multiple of 90 degrees in length at that frequency. Using the frequency measured for each line, the line length at carrier can be calculated:

Length @ carrier = n90 (Fcarrier/Fmeas)

where n = number of odd multiples of 90 degrees

The approximate length of sample lines is usually known, but if not, use a TDR or the lowest frequency where the line is series resonant to determine the approximate electrical length. This will allow a determination of the value of n.

Line Characteristic Impedance

Once the line length is determined, the next step is to determine the characteristic impedance, Zo, of the line. Most lines of the type required for sample systems by the FCC rules are *nominally* 50 ohms, but they almost never measure exactly that value, and the rule contains an explicit method for this calculation as well.

Using the frequency of series resonance for each line, calculate the frequencies for which the line would be exactly 1/8 wavelength (45 degrees) longer, and shorter. Then, measure the open circuit impedance at each of these two frequencies. This value will be

R + jX and will give the characteristic impedance by calculating its

magnitude Zscalar = $(R^2 + X^2)^{½}$

Because two values will have been determined, 1/4 wavelength apart, they will almost never be equal. Therefore the geometric mean can be considered to be the correct value at the resonant frequency, which is, of course, close to the carrier frequency.

Zgeomean = $(Z_1 \times Z_2)^{½}$

Sample Device Calibration

If current transformer samples are used, they must be calibrated by temporarily connecting them to the same circuit and measuring their output and determining that they meet the manufacturer's specification. The measurement can be made with the antenna monitor using energy from some portion of the antenna system, such as a tower feed line or the transmitter output. The impedance measurements must also include a measurement of each complete sample device and line, from the antenna monitor end, with the sample device in place.

Reference Field Strength Measurements

After a successful moment method model is created and the antenna system is properly adjusted to the moment method derived antenna monitor parameters, it is necessary to make the reference field measurements called for in 73.151(c)(3). The rule calls for three measurements on each radial corresponding to a pattern minimum or maximum, but the staff interprets this as the minima and the major lobe (or lobes if there are two or more equal or "major" lobes.)

In the case of patterns which are bilaterally symmetrical, the number of measured radials can be reduced for symmetrical nulls or minima so that for minima which are not used, the corresponding symmetrical one on the opposite of the line of symmetry is used. So a pattern with 6 minima and a single major lobe would seem to require only 4 or at most 5 radials.