ANTENNA BASE REGION GEOMETRY AND VOLTAGE SAMPLING TECHNIQUES FOR MOMENT METHOD AM DIRECTIONAL ANTENNA PROOFS

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ABSTRACT

The base region of a series fed vertical monopole antenna element can be electrically and mechanically complex. The new FCC moment-method antenna proof rules require measurements made at each antenna element's base or feed point, as well as allowing antenna monitoring using sample measurements made at the tower feed point location. If base sampling is used, when the impedance measurements of each tower are made they should be made at the location of the tower sample device. The other towers in the array should be open-circuited or shorted (either procedure is acceptable) at the same location. It's important to include the characteristics of the feed system between the measurement point and the tower base that are included in the measurement in the antenna moment method model as well. Examples and an explanation of the effects of various base circuit elements are shown. The rule provides that sample loops can be used in some circumstances, but only if the towers are identical in cross section structure. An example of the reason for this rule provision shows that even modest geometry differences between towers make significant differences in current pickup. In these situations, for towers greater than 120 and less than 190 degrees tall, base voltage sampling can be employed. A discussion of voltage sampling techniques and examples of voltage sampling systems are provided.

MEASUREMENT LOCATIONS

If loop sampling is used, then the set of measurements prescribed by the rule can be made directly across the tower bases, or at a convenient location at a "J' plug in the antenna tuning unit or tuning house. If base sampling is used, whether it is current or voltage sampling, then the set of measurements should be made at the location of the sample devices. This is normally in the antenna tuning unit or tuning house, although if a weatherproof voltage sampler is used it can be installed directly across the tower base. It is also often useful to make a measurement of the "hookup" reactance of each tower by shorting the base insulator and making a measurement in the tuning unit or tuning house at the location of the sample device.

THE VERTICAL BASE FED MONOPOLE

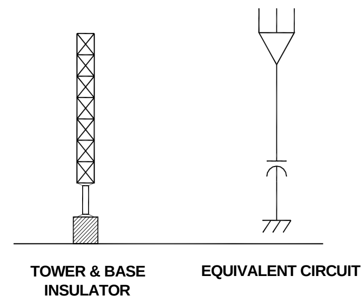


Figure 1

The base fed monopole is insulated from ground by a base insulator (or multiple insulators for free standing towers) and so the inherent impedance of the antenna itself is always paralleled by the reactance of the base insulator, which is necessarily capacitive.

$$\text{Apparent } Z = \frac{1}{[1/(R_{ant} +/- X_{ant}) + 1/X_{insulator}]}$$

If you are modeling an antenna tower with NEC you can include this in the model, but in MININEC it assumes a base load is in series with the feed, and so you must consider this modification of the impedance separately.

OTHER BASE REGION CONDITIONS

But that is not all. The simplest possible antenna feed must include some kind of conductor from the matching equipment (or in rare cases the transmitter itself) to the antenna base.

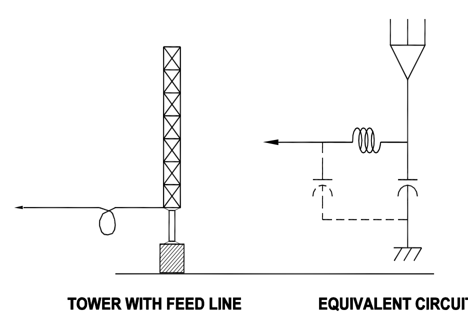


Figure 2

The feed conductor is a series circuit element, and it possesses an inductive reactance. This can be quite small - as little as 8 or 10 ohms - or can be fairly large if the distance is great or if it has a multi-turn (and unnecessary) "lightning loop."

But in addition to its series reactance, the feed conductor contains another circuit element: its capacitance to ground. While this is distributed over the conductor's length, since it is generally quite small it can be considered to be at its input if necessary.

Antenna towers are often lighted, and some are equipped with current transformers for the lighting circuit. These "Austin Ring" transformers are usually installed in such a manner as to be a capacitance in parallel with the base insulator capacitance.

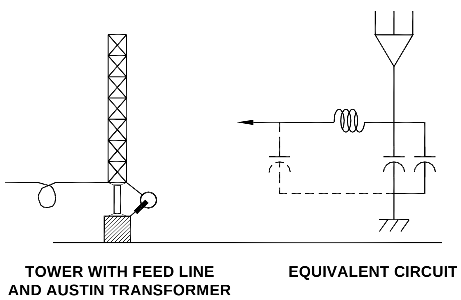
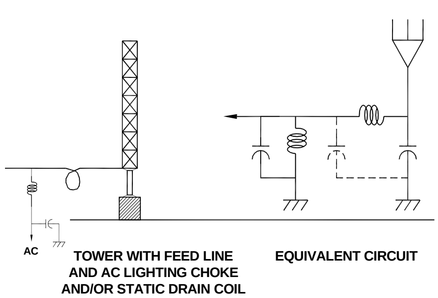


Figure 3

Similarly to the base insulator, the lighting transformer may have very low capacitance and thus high reactance, but a capacitive reactance of ten times the magnitude of the basic tower impedance can create a resistance change of more than 2% and a consequent current change of 1.4%. A bit of manipulation of a Smith Chart will show that even a very small capacitance needs to be considered (in most situations) in the analysis of the relationship between the moment method model and the impedance measurements.

Some tower lighting is accomplished by a lighting choke.

Figure 4



A "choke" or inductor that is many turns of small diameter closely spaced wire may not necessarily be inductive, however. Lighting chokes usually are inductive through the medium wave band's one and a half octaves, but static drain coils frequently are not in the upper half of the band. So the equivalent circuit of these components needs to be a parallel circuit which can exhibit the proper combination of effects.

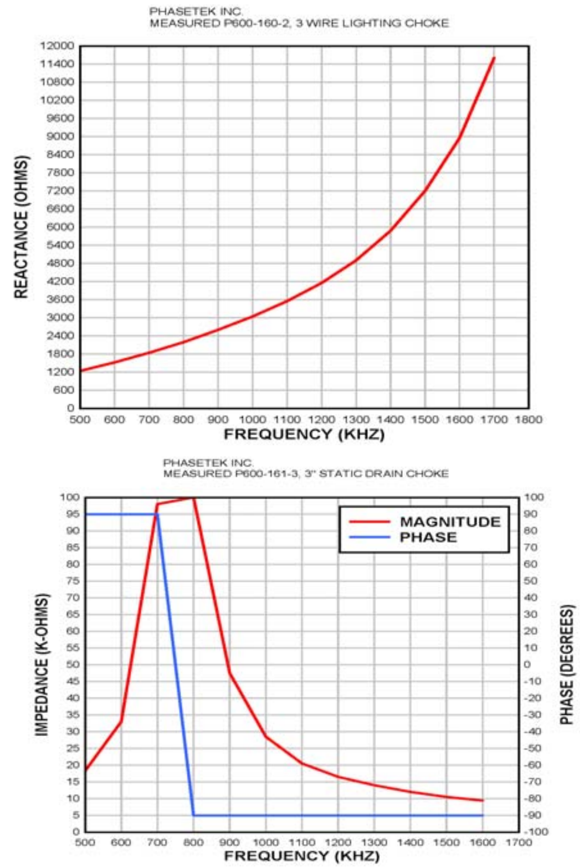


Figure 5

Many AM antennas support VHF and UHF antennas of all sorts, including STLs, TSLs, communications antennas, and FM and even occasionally TV broadcast antennas. In general, these exhibit a small amount of capacitance across the tower base in parallel with the base insulator, and their series inductance can usually be ignored.

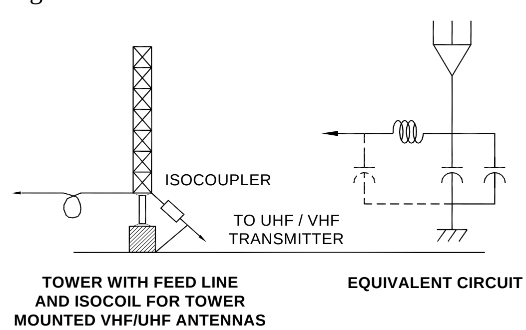
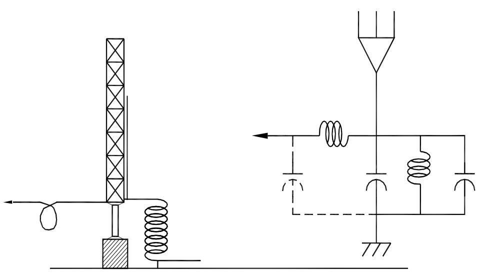


Figure 6

The FCC moment method antenna proof rules limit the total capacitance of all the base shunts to a value of 250 pF unless the manufacturer's data or measurements are greater, but the rule also requires that the total capacitive reactance of the devices must be at least five time the magnitude (Z not R or X) of the tower base operating impedance. This can be a problem if the combination of self impedance and the mutual values for the particular array geometry and radiation pattern result in a drive impedance that is large. It is not common, but there are arrays with tower drive impedances of as much as 1000 -j1000 ohms, which would require total base shunt capacitive reactance of no less than -j7000 ohms, or about 47 pF at the low end of the medium wave band.

In cases where the bandwidth/power requirement to feed an antenna on an AM antenna tower can't be met by a "transformer" type isocoupler, use is sometimes made of a very large isocoil wound of large diameter semi-flexible transmission line. Much like the static drain "choke" the distributed capacitance between the windings of such a coil can cause it to be self-resonant in the middle of the medium wave band, and therefore a shunt capacitance above that point.



TOWER WITH FEED LINE
AND LARGE "ISOCOIL" FOR HIGH POWER / WIDE BANDWITH VHF / UHF OR WI-FI / PCS

EQUIVALENT CIRCUIT

Figure 7

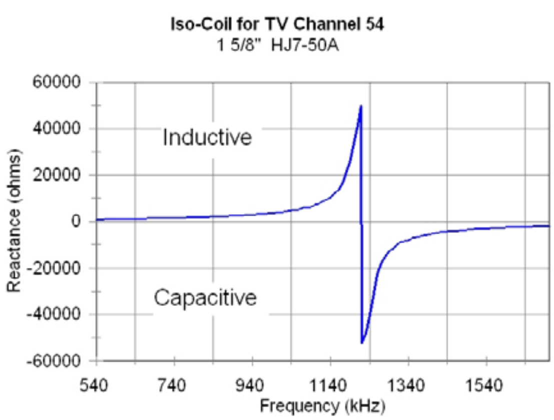
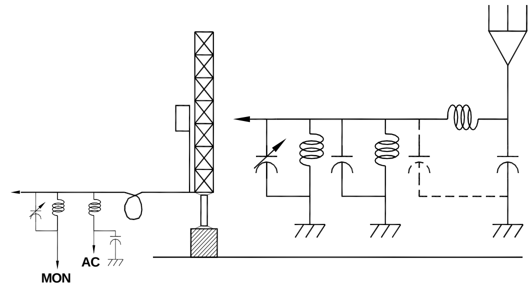


Figure 8

A very similar effect is sometimes the case with a sample system transmission line isolation inductor, which sometimes will not be removed when an existing antenna system is re-proofed using the moment method rules. Frequently these are resonated with a parallel variable vacuum capacitor, and the combination exhibits very high reactance, but in a diplexed array this may be at only one of the carrier frequencies so that a lower value of reactance has to be accounted for at the second frequency.



TOWER WITH FEED LINE
AND SAMPLE LINE ISOLATION INDUCTOR

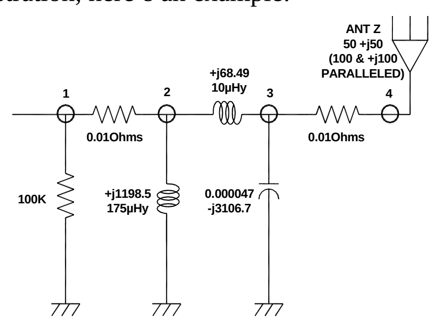
EQUIVALENT CIRCUIT

Figure 9

IMPEDANCE TRANSFORMATION AND PHASE SHIFT

These various circuit elements form networks. The networks transform the impedances seen by the sample devices, and therefore the currents and voltages at the location of the sample device will normally be different than those at the tower base calculated by the moment method program. This transformation affects both the magnitude and angle of the currents and voltages following the normal laws of AC circuits: Ohm's law and Kirchoff's law. The calculations are (in mathematical terms) simple and straightforward. It's sometimes useful to refresh one's memory of vector algebra by consulting a good AC or radio engineering reference work, such as Griffith, or a good mathematics textbook.

For illustration, here's an example:



TYPICAL TOWER BASE CIRCUIT
NODES AND COMPONENT VALUES
ANNOTATED FOR SPICE (OR WCAP)

Figure 10

This hypothetical example shows a simple tower base circuit, with the junctions numbered for use in a typical SPICE program. The series and shunt resistors are for convenience in checking the drive voltage and current. The load is a parallel network that produces a hypothetical antenna impedance of 50 +j 50 ohms. The impedances at each junction can easily be calculated by addition for the series elements and inversion to add the admittances for the shunt elements. Figure 11 shows the results of those calculations.

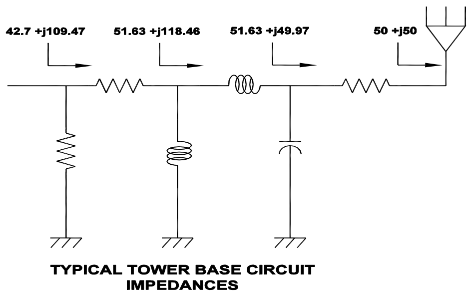


Figure 11

Knowing the terminating impedances at each point, if we drive this with 1 amp of RF at a given frequency we can easily calculate the currents and voltages in vector form. These are shown in Figure 12.

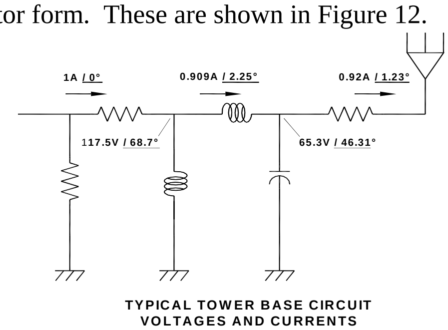


Figure 12

Having calculated the currents and voltages, we can see that if the monitoring device is located at the input of this base network, it will read different magnitudes and angles than if it were at the tower base. So the moment method program calculations of drives necessary for the authorized radiation pattern have to be modified to get the antenna monitor values when base sampling is used.

And, in this example, that difference is not large for the current sample situation: a correction at the antenna monitor of 1.1001/ -2.25°. But the correction if voltage sampling is used is much more substantial:

$$\frac{(117.5\angle 68.69^\circ)}{(65.3\angle 46.31^\circ)} = (1.8\angle 22.4^\circ)$$

at the antenna monitor!

DIFFERENT TOWER GEOMETRY

Sample loops are a tried and true and very straightforward method of determining the relative fields radiated from a tower in an array. If the loops are located at the elevation where the amplitudes and phases of the currents replicate the far field conditions, it's not necessary to calculate the base region transformations for determining the correct antenna monitor readings, only for determining the phase and power budget for the entire feed system. But the new FCC moment method rules don't allow the use of sample loops unless the tower physical geometry in the region of the sample loops is identical.

Here's why. The following photographs show two different towers in an array. They have identical face widths, identical leg sizes, and identical cross member sizes. But because one of the towers is a replacement, put up after failure of the original in a storm, it has a denser cross member pattern, probably because the applicable structural requirements of the building code changed from the time of the original construction of the array.

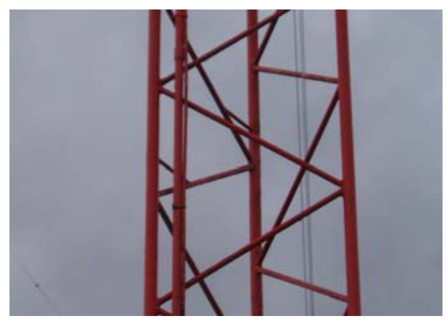


Figure 13a

Figure 13b

A moment method model of the towers and sample loops located at the point of intersection of the legs and cross members shows the difference in pickup. Because the antenna towers have currents flowing in the cross members as well as the legs (even though the horizontal components of those currents do not result in far field radiation but charge the capacitance to ground of the antenna tower and induce currents in the sample loops), the loop pickup amplitude is not the same, although in this example the phase angles are nearly identical. The analysis shows that for sample loops mounted in circumstances as similarly as possible, the phase angle differs by only 0.4 degrees but the amplitude by nearly 5%.

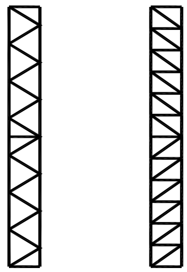


Figure 14

The moment method proof rules therefore don't allow one to use this technique to determine the proper operation of an array. One could, in fact, use the results of this model to normalize the antenna monitor readings to tune up the array, but it would add an additional set of possible errors in the process. The point of the moment method rules is to simplify the internal sampling process and make it as accurate as possible, since it, rather than magnetic far field measurements is the basis for the licensing process. The rule in fact states: "The performance of a directional antenna may be verified either by field strength measurement or by computer modeling and *sampling system verification*." (Emphasis added)

VOLTAGE SAMPLING

1. The KPTK Voltage Sampling Problem

The FCC's moment method rules allow loop sampling for towers of any height, but base current sampling only for towers 120 degrees or shorter or greater than 190 degrees. Base voltage sampling is allowed for towers greater than 105 degrees in height. The towers in the KPTK array are 160 degrees in height, and are the "almost but not quite identical" example shown in Figures 13 and 14. After an analysis of the drive impedances of the day and night patterns employed by KPTK, as well as those of the diplexed operation of KTTH on the same antenna towers, we designed a prototype voltage sample device.

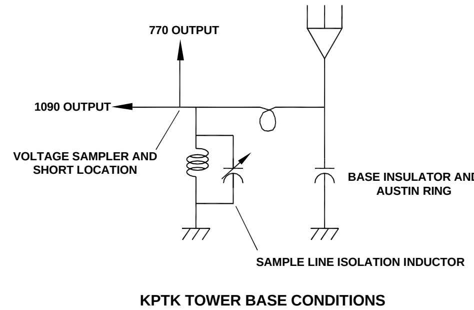


Figure 15

The 1090 kHz drive impedances are high enough that use of a capacitive voltage divider with a very high input impedance could produce a voltage great enough to properly drive the antenna monitor. In contrast the 770 kHz impedances are relatively low, since the towers are only 113 degrees tall at this frequency, and so the sampling device had no measurable effect on the KTTH parameters. A capacitive divider was considered preferable to a resistive divider in order to provide DC isolation from static fields, and because a high voltage vacuum capacitor has a modest degree of "self-healing" immunity to some fault conditions.

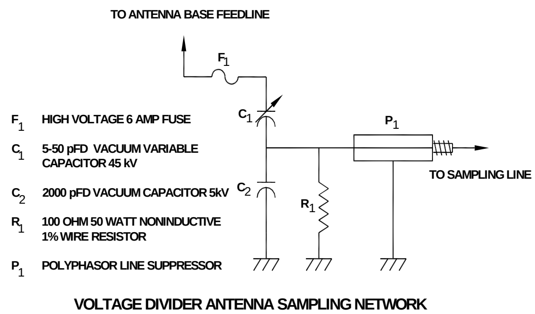
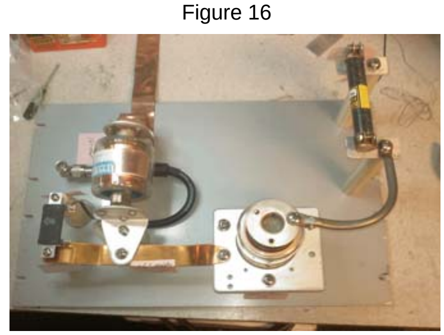


Figure 16



Photograph of Sample Device - Figure 17

The KPTK engineering staff procured the necessary parts and constructed the devices. The high voltage fuse and the line suppressor provide additional protection against atmospheric electrical events, and R_1 provides the proper value of impedance for the lower portion of the divider, resulting in an appropriate input voltage for the antenna monitor. The three units were set up side by side and fed from a common source and calibrated with the antenna monitor by adjustment of

C_1, which was then locked into position. Before the final proof of performance measurements and adjustment were prepared, the units were monitored over about four months in a variety of temperature and environmental conditions, and proved to be very stable.

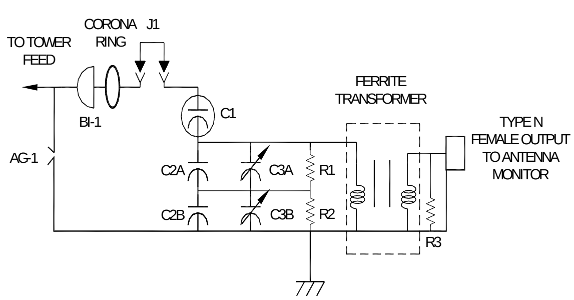
Calibration photo - Figure 18

This system was used in the first moment method proof filed with the FCC using voltage samples.

2. The WAOK Voltage Sampling Problem

A different set of circumstances led to the use of voltage sampling for the antenna array employed by WAOK. The WAOK antenna system employs towers which are dissimilar and not quite 180 degrees in height, both of which disqualify it for use of a sample system with loops or with base current sample devices.

Because the WAOK towers are very close to ½ wavelength in height, the drive impedances of this array are not high. As a result, a simple capacitive divider device is probably not suitable for this situation, or for many other systems with low Z towers and lower operating powers. As a result, Kintronic Laboratories developed a voltage sample device with a capacitive divider and a step-up toroidal transformer.



KTL VOLTAGE SAMPLING UNIT

Figure 19

The Kintronic Laboratories unit is also designed for use in an outdoor environment, where there isn't suitable space in an existing ATU or where there are other mechanical considerations which require a weatherproof housing.

Kintronic Voltage Sampler - Figure 20

CONCLUSION

The adoption of moment method analysis techniques has placed new demands on the analysis of the monitoring circumstances for AM directional antenna systems. Careful evaluation of the base region conditions of the antenna towers in medium wave directional arrays is necessary when base voltage or current sampling is employed. Because base currents are not necessarily a reliable method of monitoring array performance in some situation, use of base voltage monitoring has begun to be employed. Simple voltage dividers allow this, but additional circuit elements may be required to provide adequate sample voltages in some cases.

ACKNOWLEDGMENTS

The KPTK voltage sample system final design, construction, and testing were the result of the exemplary efforts of CBS-Seattle engineers Tom McGinley and Arnie Skoog. Tom King and Don Crain provided the data for the WAOK example.