Test and Evaluation of an AM Directional Antenna Tower Base Voltage Sampling System and MOM Proof Methodology For the WAOK Radio Array Utilizing a Mix of Guyed and Self-Supported Towers

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ABSTRACT
This paper will address the laboratory test and evaluation of the new Kintronic Labs Model VSU-1 voltage sampling units; the field testing of this voltage sampling system in the 4-tower, 4.2kW, 1380kHz nighttime array of WAOK-AM radio in Atlanta, Georgia; and the methodology utilized to conduct a Method of Moments(MOM) proof of the WAOK array. By virtue of the fact that the WAOK array consists of two guyed towers and two wide-based self supported towers with the electrical height of the four towers being 179.3°, the use of voltage sampling was the only permissible method whereby a MOM proof of this array could be conducted.

INTRODUCTION
Referring to FCC 08-228 MM Docket No. 93-177 dated September 26, 2008 entitled “An Inquiry Into the Commission Policies and Rules Regarding AM Radio Service Directional Antenna Performance Verification” and Section 73.151(2)(i) of the revised rulemaking relative to Method of Moment proofs of performance of AM base fed directional antenna arrays, the following rulemaking is applicable to the use of voltage sampling: “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.” Realizing the cost savings that can be realized by a broadcast station owner by using a Method of Moments(MOM) proof of performance as compared to a standard proof requiring a large volume of field intensity data, Kintronic Labs undertook the design and development of a voltage sampling system. For this development we established a set of technical specification goals as shown in Table 1 below.

We used the Potomac Instruments Model 1901 digital antenna monitor with an input voltage range of 0.3 to 25 Vrms into a 50 ohm load impedance to define the voltage sampling unit output voltage range. The phase and magnitude specifications were based on the typical specifications for the Delta Electronics current sampling transformers, which are widely used for AM directional antenna current sampling applications.

TABLE 1. TECHNICAL SPECIFICATION GOALS FOR THE VOLTAGE SAMPLING SYSTEM DEVELOPMENT

FREQUENCY RANGE:	0.5-1.8 MHZ
FREQUENCY RESPONSE:	FLAT TO WITHIN +/-0.25dB
ABSOLUTE MAGINITUDE ACCURACY:	+/-2%
ABSOLUTE PHASE ACCURACY	+/-2°
MAGNITUDE TRACKING ACCURACY:	+/-1%
PHASE TRACKING ACCURACY:	+/-1°
PEAK VOLTAGE SAMPLE RANGE:	500-30,000 Vp
AMBIENT TEMPERATURE RANGE:	40 TO +50℃
HUMIDITY:	0 – 95%

RF DESIGN OF VOLTAGE SAMPLING UNIT
To accomplish the desired voltage division to yield the output voltage range for the peak voltage sample range specified, we considered both inductive and capacitive voltage dividers. The application of the voltage sampling units would be largely applicable to existing arrays that are unlicensed and are operating under a special temporary authority(STA). Understanding the need to minimize the impact of the addition of the sampling system to the normal operation of an existing AM directional antenna we chose to develop a voltage sampling system unit that could be installed external to the antenna matching networks directly in shunt with each tower feed in the array.

Due to the susceptibility of an inductive voltage divider to parasitic reactances associated with any grounded surfaces in proximity to the inductive divider and also due to the possibility of self resonance of an inductor at a frequency within the AM band, we chose to develop a capacitive voltage divider design. It is important that we give recognition to preliminary design information that we received from Ronald D. Rackley, PE, regarding some development effort that he had conducted in the test and evaluation of a prototype voltage sampling device.

Based on Mr. Rackley's inputs we selected components that would yield our preliminary design goals. Jennings Technology developed a high voltage vacuum cap in accordance with our specifications as the initial cap in the voltage divider circuit. A ferrite core material was selected and tested based on Mr. Rackley's recommendation. The capacitive voltage divider secondary components were selected with a capacitance tolerance of +/-1% over the required temperature range. The primary-to-secondary turns ratio on the ferrite transformer was designed in conjunction with the capacitive divider to yield the in-to-out ratio required to meet the Potomac antenna monitor limits over the sampled voltage range. An RF schematic of the resulting initial voltage sampling unit design is shown below as Figure 1.

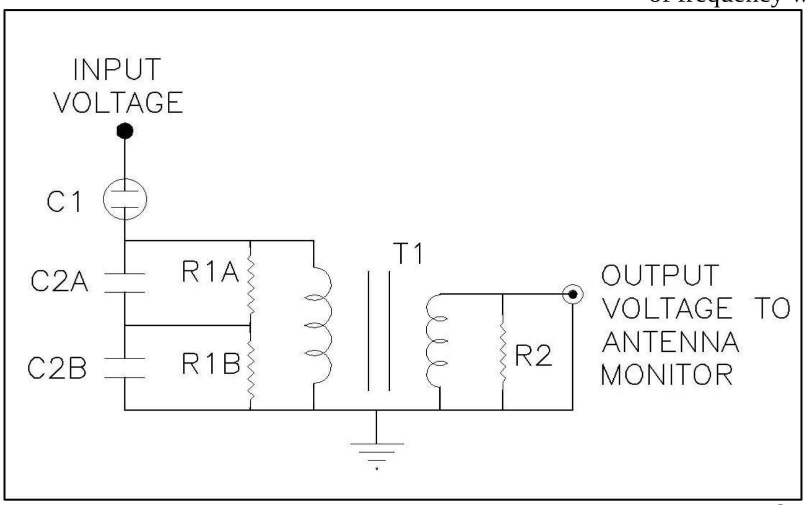

FIGURE 1. Model VSU-1 voltage sampling unit RF schematic.

PRODUCT DEVELOPMENT AND TEST

A prototype voltage divider was developed based on the schematic shown in Figure 1, and tests of this prototype were conducted to confirm suitability of the design to yield the required thermal stability over the 0.5-1.8 MHz frequency band. Following initial verification of the RF design, an enclosure was designed that would accommodate the components while consideration of possible parasitic reactances was taken into account. A J-plug was placed in series with the input feed to the tower to permit impedance measurement of the load that would include any RF busswork from the voltage sampling network output to the tower RF buss connection point. Recognizing that the sampling units will be located directly across each tower feed the vulnerability to lightning must be considered. An input adjustable arc gap and input bowl feedthrough interior corona ring were incorporated in the design for lightning protection.

Three prototype units (S/N FT-G01, FT-G02 and FT-G03) were produced initially for the purpose of testing the unit-to-unit performance versus temperature and frequency. Based on the initial test results we determined that we needed to have some level of calibration adjustment in order to achieve the high level of unit-to-unit tracking that is required. We therefore chose to include two variable capacitors in the design in parallel with two high precision resistors to enable us to achieve the desired unit-to-unit repeatability. The resulting revised RF schematic is shown in Figure 2 below.

Following completion of the first three voltage sampling units (VSU's) we set up instrumentation to measure the input to output voltage ratio as a function of frequency while keeping in mind the technical specifications that had been established. A block diagram of the test set-up is shown as Figure 3 below. An HP Model 33250A sweep generator was used to drive an ENI Model 2100L 100 watt wideband amplifier the output of which was loaded with a Termaline Model 8135 50-ohm, 150 watt load. The RF voltage across the load served as the input voltage to the voltage sample units, which were connected to the voltage source via equal conductor lengths.

The output of each of the three VSU's was coupled to a precision 50-ohm terminating load in series with one of the inputs of a Tektronix Model TDS-3054B 4-channel digital oscilloscope as shown in Figure 3. The fourth oscilloscope channel was coupled to a Tektronix Type P5100 high voltage probe that was used to monitor the input voltage to the VSU's. The VSU with serial number FT-G03 was established as the reference unit. The output amplitude variation of Serial Nos. FT-G01 and FT-G02 were measured relative to FT-G03 for a fixed input voltage as shown in Figure 3. The phase shift variation was measured by disconnecting the cables from the oscilloscope inputs for the two units being compared and reconnecting them to the two channel inputs of an HP Model 3575A Phase Meter. The analog output of the phase meter was coupled into the DCV input of an HP Model 34401A, which yielded a relative phase shift reading accurate to +/- 0.001°.

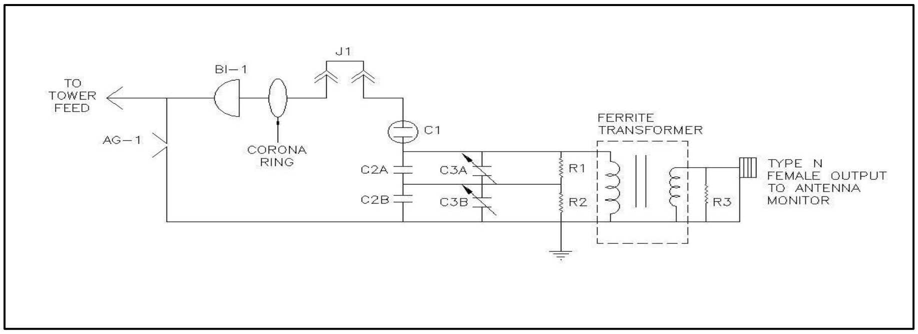

FIGURE 2. Model VSU-1 voltage sampling unit final RF schematic.

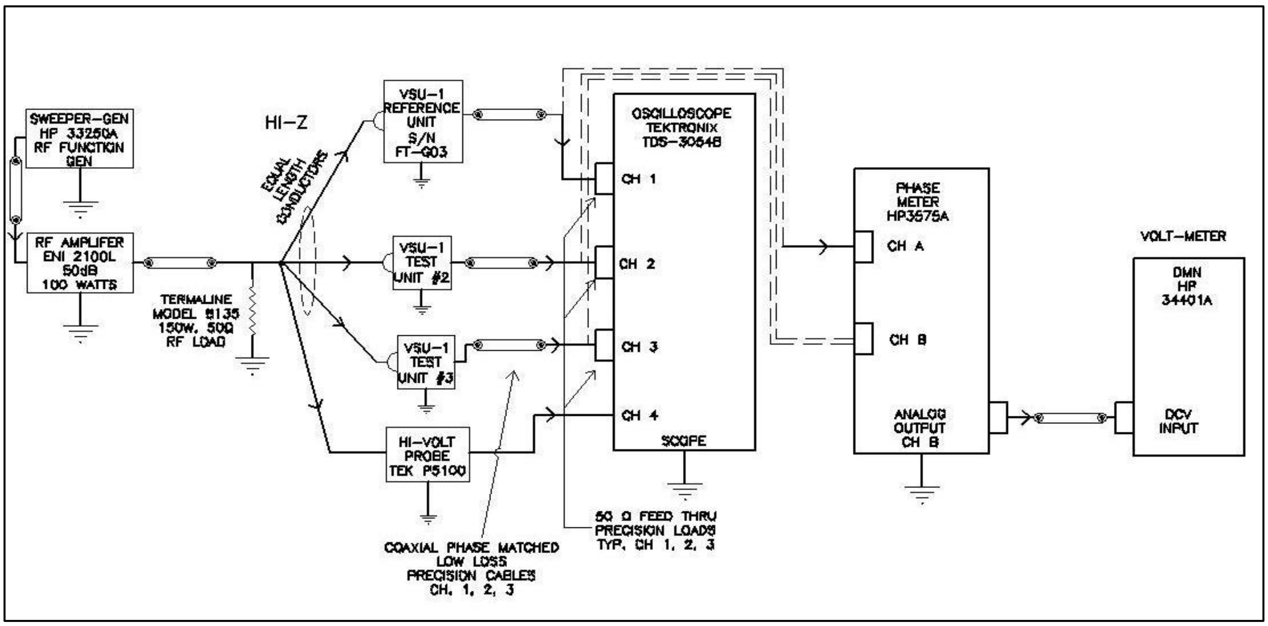

FIGURE 3. Instrumentation set-up for ambient temperature testing of the voltage sampling units.

FIGURE 4. Instrumentation setup for ambient testing of the voltage sampling units.

A photograph of the ambient temperature instrumentation test setup is shown in Figure 4.

The results of the output amplitude and phase variation measured for Unit FT-G02 relative to the reference Unit FT-G03 for an ambient temperature of +22°C and an input voltage of 54 Vrms over the 0.5-1.8 MHz band was a maximum amplitude variation of +0.23% and a maximum phase shift variation of -0.059° to +0.959°, which clearly met our design goals. Similar results were obtained for Unit FT-G01 relative to Unit FT-G03.

TESTS TO QUALIFY VSU UNITS FOR INSTALL AT WAOK-AM

Following completion of these tests of the first three units, an additional two units were produced to enable us to field four units while maintaining a reference unit for future production. Following the confirmation of the intent of CBS Radio to install a voltage sampling system at their WAOK site in the Atlanta, Georgia market, our test efforts were re-directed toward qualifying four units for installation in this 4.2kw, 4-tower, DA-N array operating on 1380kHz. Serial Nos. FT-G02 and FT-G04 were compared to Serial No. FT-G03 over the 1380kHz +/- 20kHz band in output amplitude for a input of 54Vrms at an ambient temperature of 22°C. The results of these measurements are shown in Figure 5 below. This plot serves to demonstrate the conformance of the voltage sampling units to the unit-to-unit magnitude tracking accuracy of +/-1%. The maximum amplitude variation over the band for FT-G02 was +0.15% and for FT-G04 was +0.07%. Similar results were obtained for units FT-G01 and FT-G05.

A plot of the phase shift variation for the same test units over the 1380kHz +/-20kHz channel is shown in Figure 6 . The maximum phase shift difference from the reference for FT-G02 was +0.11° and for FT-G04 was +0.09° exceeding the goal of +/-1°. Similar results were obtained for units FT-G01 and FT-G05.

To test the input voltage capability of the VSU units a Jennings Model JHP-70A Highpot AC Voltage Tester was connected to the input of the VSU unit and was increased to a peak voltage of 40kV without any component failure, corona or arcing.

To qualify the VSU units for temperature a Test Equity Model 1007C temperature chamber was utilized to test a temperature cycled VSU unit relative to the reference Unit FT-G03 at ambient temperature. The input voltage to the test units was 54 Vrms. The output voltage and phase were monitored as a function of temperature. A block diagram of the instrumentation setup for the temperature testing of the VSU units is shown in Figure 7. The temperature was varied from -50°C to +77°C. The maximum output amplitude deviation of unit FT-G02 relative to unit FT-G03 over the temperature range was +0.91%, and the maximum phase shift deviation was +0.4°, both of which exceeded our design goals. Similar results were measured for the FT-G01, FT-G04 and FT-G05 units.

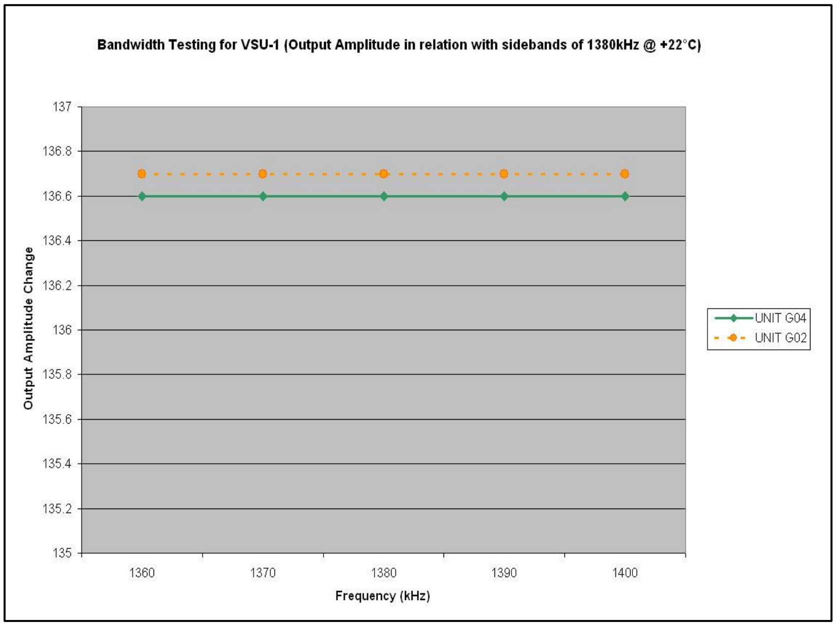

FIGURE 5. Output voltage comparison for FT-G02 and FT-G04 relative to the FT-G03 reference. Note: The vertical scale is in millivolts.

A plot of the output voltage deviation and phase shift deviation of unit FT-G02 relative to reference unit FT-G03 over the -50°C to +77°C temperature range is shown in Figures 8 and 9, respectively.

Following the completion of these qualifying tests of the four VSU units for installation in the WAOK nighttime array, they were shipped and installed at the feed point of the two guyed and two self-supported towers.

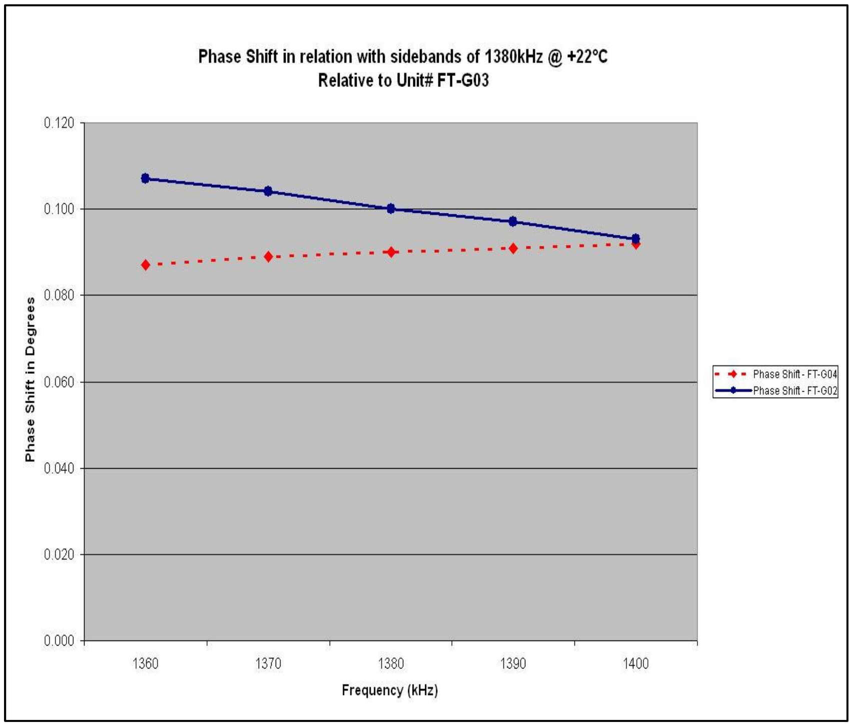

FIGURE 6. Phase shift variation of FT-G02 and FT-G04 relative to the FT-G03 reference.

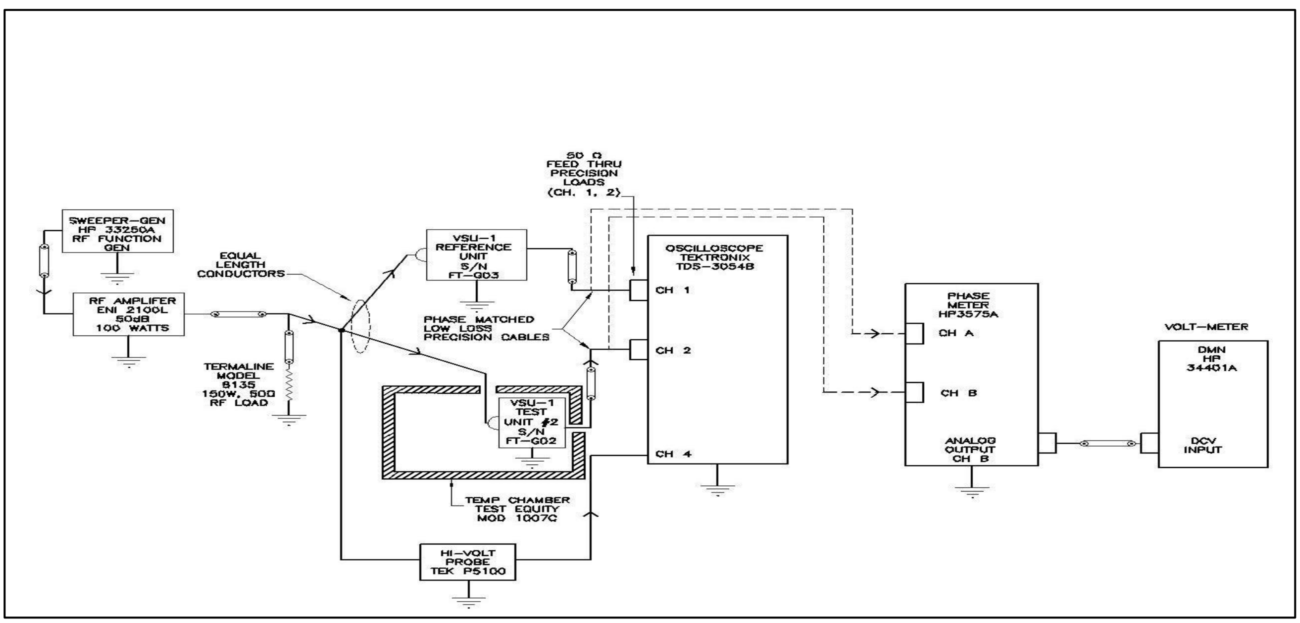

FIGURE 7. Instrumentation setup for temperature extreme qualification of the voltage sampling units.

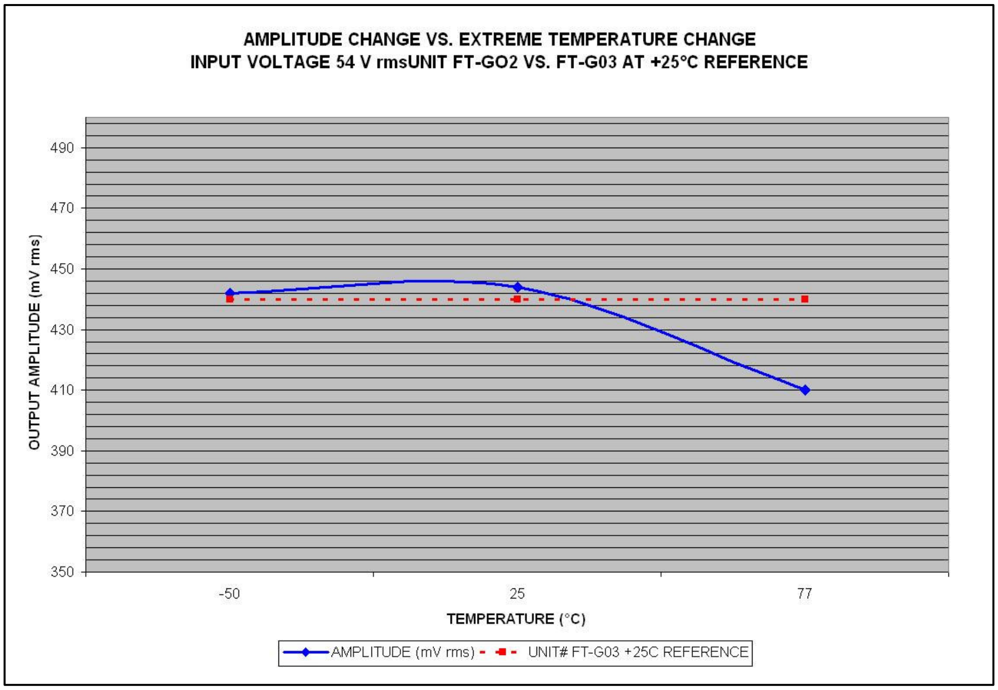

FIGURE 8. Unit FT-G02 output amplitude deviation relative to reference Unit FT-G03 over the -50℃ to +77℃ temperature range.

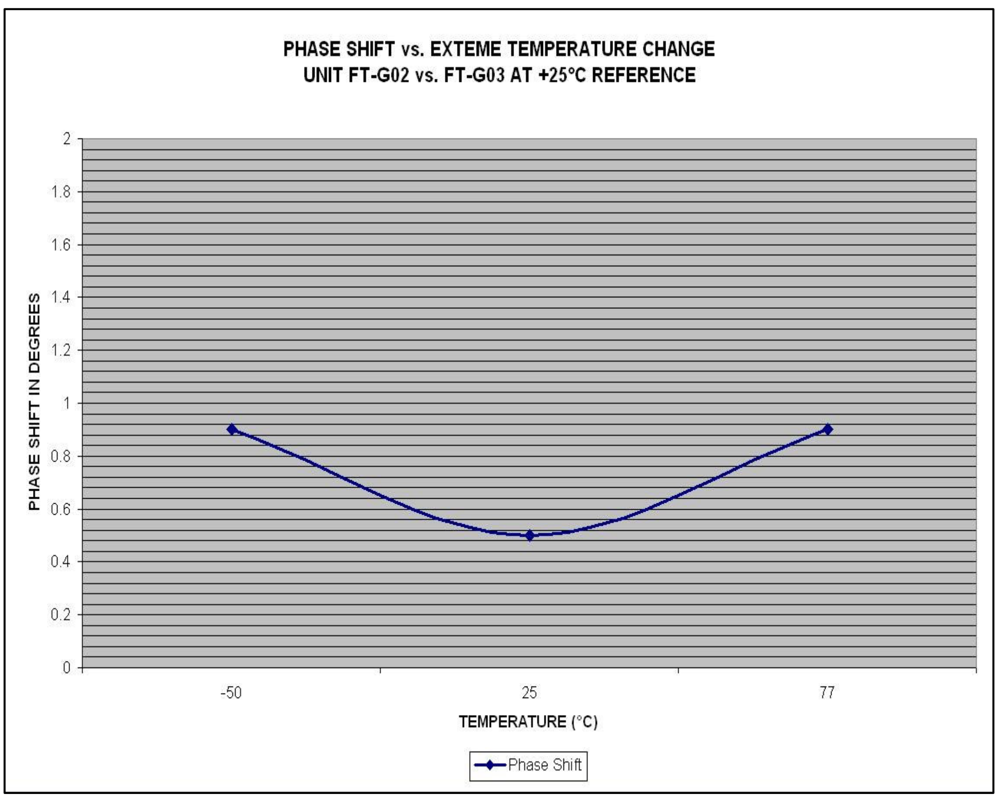

FIGURE 9. Unit FT-G02 phase shift deviation relative to reference unit FT-G03 over the -50℃ to +77℃ temperature range.

METHOD OF MOMENTS PROOF METHODOLOGY

With an array consisting of two guyed towers and two self supported towers all with an electrical height of 179.3°, the WAOK site is an ideal applicant for the installation of a voltage sampling system. A photograph of the WAOK array is shown as Figure 10 below.

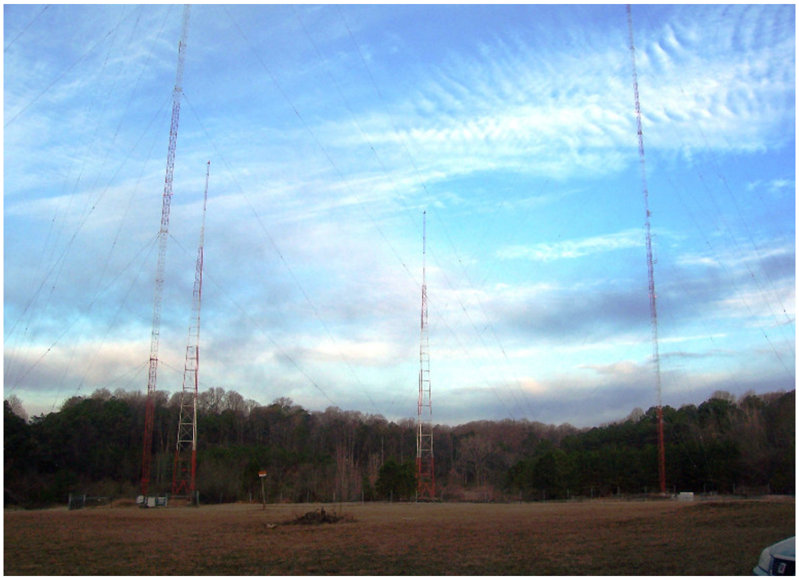

FIGURE 10. A photograph of the WAOK four-tower array consisting of two guyed and two self-supported towers.

Towers 1 and 2 are guyed towers 360 feet above the base insulator with a 30.25 inch face width, and Towers 3 and 4 are self supported with a 24.75 foot base face width that tapers to 30.25 inch face width at the 290-foot level above the base insulators with the remaining 70 feet being uniform cross section with a 30.25 inch face width.

The steps to conduct the Method of Moments (MoM) proof of the WAOK nighttime array using voltage sampling as specified by Don Crain, the commissioning engineer, are as follows:

1. Determine if MoM proof and use of voltage sampling is applicable according to FCC rules for AM directional antenna system.

2. Create basic model of the antenna system from FCC database info and known site physical info(tower face size-and taper schedule on self supporting towers). Model must comply with FCC MoM requirements and software constraints.

3. Measure all tower self impedances at the voltage sampler J plug with one tower driven and all other towers open circuited and short circuited at the base.

4. Measure electrical length and characteristic impedance of all sampling lines with lines open circuited. Trim lengths if necessary to comply with FCC requirements.

5. Measure impedance of each sampling line with the voltage sampler attached.

6. Verify calibration of antenna monitor and voltage samplers.

7. Correct antenna model characteristics to correlate with measured self impedance data by adjustment of lengths and radii, and consideration of shunt and series strays.

8. Create model of directional antenna using the corrected tower characteristics.

9. Derive necessary voltage drives for each tower to result in FCC theoretical directional pattern.

10. Adjust system to derived voltage drives.

11. Adjust system transmission line matches as needed.

12. Adjust and measure system common point impedance.

13. Measure reference field intensity points as required by FCC rules.

Figure 11 below shows the geometric tower model of the WAOK array as developed in the NEC version 4.1 program that was adjusted to conform to the measured self impedance data.

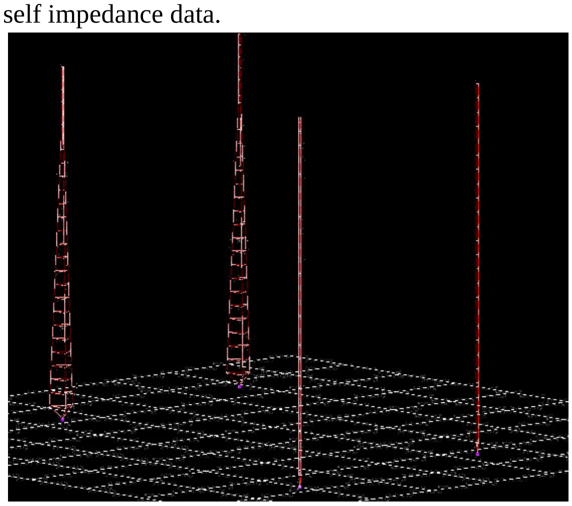

FIGURE 11. NEC 4.1 lattice model of the WAOK 4-tower array.

A plot of the WAOK nighttime pattern for which the MoM proof was to be conducted is shown in Figure 12. A photograph of one of the fully qualified voltage sampling units installed at the WAOK Tower No. 4 feed point is shown in Figure 13 below.

At the time of the deadline for submission of this paper the voltage sampling units were installed at the feed point of each of the four towers in the WAOK array, and Steps 1-6 of the MoM proof process had been completed. The final results of the proof will be available by the time of the presentation at the 2011 NAB Engineering Conference and will be available at Kintronic Labs. The proof results may be obtained via email request to ktl@kintronic.com.

ACKNOWLEDGMENTS

The author would like to express his appreciation to Robert LaFore for his assistance with info pertaining to the WAOK array, to Don Crain for his assistance with the Method of Moments proof procedures, to Ron Rackley, PE, for his encouragement and support in pursuing the development of voltage sampling units and to the Kintronic Labs staff in the provision of test and computer model results.

REFERENCES

[1] FCC 08-228 MM Docket No. 93-177 “An Inquiry Into the Commission’s Policies and Rules Regarding AM Radio Service Directional Antenna Performance Verification”, Second Report and Order and Second Further Notice of Proposed Rulemaking, dated 26 September 2008.

[2] Ronald D. Rackley, PE, “Preliminary Investigation of a Passive Base Voltage Sampling Device Using a Voltage Divider and a Transformer”, Dated 5 February 2009.

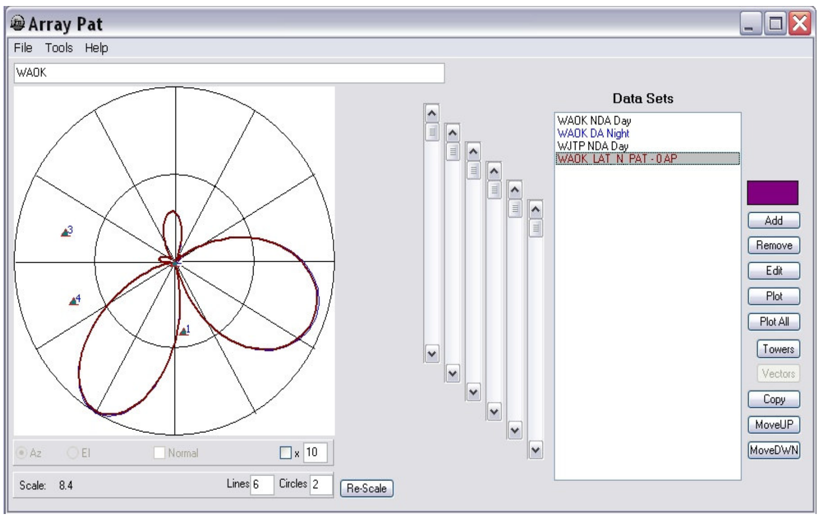

FIGURE 12. A plot of the WAOK nighttime directional pattern.

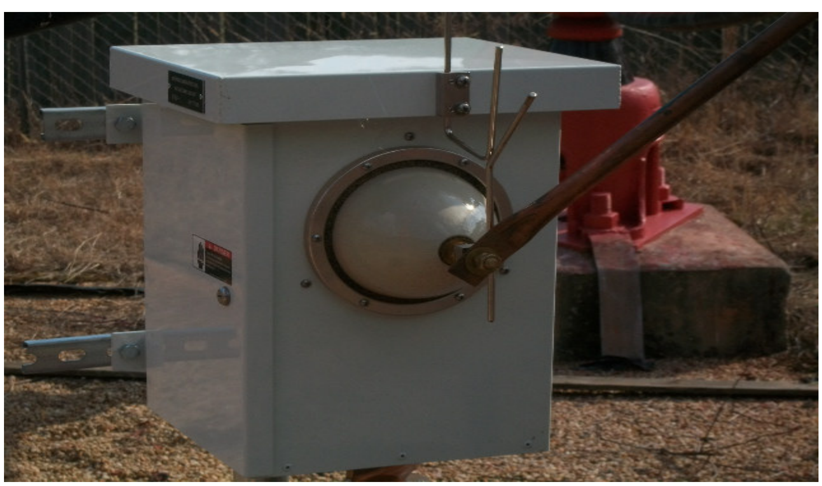

FIGURE 13. Kintronic Labs Model VSU-1 voltage sampling unit typical of the units supplied to WAOK Radio.