AN EFFICIENCY COMPARISON: AM/MEDIUM WAVE SERIES-FED VS. SKIRT-FED RADIATORS

PRESENTED AT:

**NATIONAL ASSOCIATION OF BROADCASTERS
ENGINEERING CONFERENCE
APRIL 16, 1996**

BY:

RONALD D. RACKLEY, P.E.	**duTreil, Lundin & Rackley, Inc.**
BOBBY L. COX, PhDEE	**Kintronic Laboratories, Inc.**
JAMES R. MOSER, MSEE	**Kintronic Laboratories, Inc.**
TOM F. KING, MSEE	**Kintronic Laboratories, Inc.**

AN EFFICIENCY COMPARISON: AM/MEDIUM WAVE SERIES-FED VS. SKIRT-FED RADIATORS

Abstract

This paper will address a comparison of the radiating efficiency of a single AM/Medium Wave mast configured as a base insulated radiator and as a skirt-fed ("folded monopole") grounded radiator each with three ground system configurations, including a standard 120-radial copper wire system, a 30-radial copper wire system and a single copper ground rod. Measured results for two tower electrical heights of 98.3 degrees and 61.5 degrees for both the base insulated and the folded monopole cases will be presented. Each radiator configuration will be analyzed using method of moments computer modeling. These analytical results will be compared with actual field strength measurement results accompanied with the associated ground radial current distribution measurements. The relative merits of the series-fed versus skirt-fed AM radiators and the associated ground system options for each will be discussed with definitive modeling and test results to substantiate any conclusions that will be presented. All experimental tests were conducted at the new expanded band frequency of 1680 Khz with a transmitter power of 400 watts.

Introduction

Folded unipole is the name given to a method of shunt-feeding an AM tower. The tower of a folded unipole does not require a base insulator, making it possible to install numerous antennas for other services on it without the need for isocouplers or the use of a quarterwave isolation stub. The electrical service necessary to operate tower lights or other tower-mounted equipment may be connected directly without the need for isolation chokes or a ring transformer at its base. It provides a direct static drain path to ground without the necessity of a static drain choke. The folded unipole avoids the slight asymmetrical far-field radiation characteristics of the "slant-wire" type of shunt feed. It can be adjusted to alter the input impedance of a tower radiator.

The folded unipole employs a cage of three or more wires surrounding its tower. The cage is shorted to the tower either at the top or at a lower level and is insulated from the tower from the short point down to the bottom, where it is fed.

The point at which the wire cage is shorted to the tower may be adjusted to change the input impedance at the feedpoint. Sometimes, the spacings of the wires from the tower are also adjusted for the same purpose.

Purpose of Research

The folded unipole is sometimes viewed as having beneficial characteristics beyond its utility for shunt feeding towers which must be grounded at their bases. One common belief is that a folded unipole produces significantly higher radiation than a series-fed tower of the same height. Two additional, related beliefs are that a folded unipole does not require a ground system and that, if the wire cage dimensions can be adjusted to produce a much higher input resistance than for the series-fed case (meaning lower input current), the current flowing in the ground system can be reduced. It is also commonly believed that folded unipoles have better bandwidth than series-fed towers. A test plan was devised to evaluate the performance of a folded unipole in comparison with a series-fed tower within these areas of interest.

Scope of Tests

The antenna test range at Kintronic Labs permits characterization of both full scale and scale models of broadcast antennas for use in the shortwave, medium wave and FM bands. The tests for this paper were conducted on a full-scale antenna at an FCC-authorized test transmitter site located on the property of the Kintronic Laboratories manufacturing plant near Bluff City, Tennessee. The frequency of the test transmitter was 1680 Khz, and the power was 400 watts. Tower heights of just over 1/4 wavelength (160 feet, or 98.3 electrical degrees) and approximately 1/6 wavelength (100 feet, or 61.5 electrical degrees) were employed for the tests. To implement the folded unipole or skirt-fed radiator, a Kintronic Labs Model FMK-6-36/12//6 six-wire folded monopole kit was installed on the baseline tower. The skirt wires were 0.162 inches in diameter and were spaced 36 inches from the tower legs by fiberglass angle insulators. The antenna tuning unit consisted of a tunable wideband "TEE" network with sufficient adjustment range to permit matching to all of the antenna configurations. Ground systems consisting of 120 wire radials (#10 AWG, 150 feet long) and no radials with a single ground rod were tested for each case. Field strength, input impedance, and ground current measurements were made for each tower height with both series and folded unipole excitation.

Test Results

The test results will be summarized by topic. Discussion of the findings will appear under each topical heading.

Improved Radiation for Folded Unipoles ?

To evaluate the radiation levels produced by the various antenna types which were tested, a reference antenna was established and measurements were made on it at numerous points along eight equally-spaced radials of azimuth. The measurements were graphically analyzed in accordance with the procedures outlined in the FCC Rules and the pattern was found to be omnidirectional, with an unattenuated field strength of 310 mV/M at one km for 1.0 kW of power at all eight azimuths.

The field strengths were measured with a Potomac Instruments FIM-41 field strength meter at check points numbering between four and ten on each of the eight radials for the alternate antenna configurations tested. The field strength measurements were made under similar environmental conditions for all of the cases. They were analyzed for each case by ratioing each check point measurement to its corresponding reference antenna value and averaging the ratios for each radial and multiplying each radial average ratio by the reference antenna unattenuated field value to determine the radial's unattenuated field value. To evaluate overall antenna efficiency for each case, the eight radial fields were averaged and compared with the reference antenna value.

Field strength measurements were made with the 160 foot and 100 foot towers for the following conditions: 120 ground radials (each 150 feet long), series feed (the reference); 120 ground radials, folded unipole; no ground radials (grounded only through a ground rod), series feed; and no ground radials, folded unipole. Figure 1 is a bar graph summarizing the findings of the tests in percent of field relative to the reference antenna (at 100 percent) while Figure 2 expresses the values in dB.

No major differences in field strength between the folded unipole and series-fed cases were found for any of the configurations tested. The differences were within 1/2 dB for each case with the exception of the 160 foot tower with 120 ground radials, when the folded unipole was found to produce 0.7 dB less radiation than the reference antenna.

Folded Unipole ground losses

As is apparent from Figures 1 and 2, the ground losses with no ground radials are approximately the same for both the series-fed and folded unipole cases. It is commonly believed that folded unipoles are not as subject to ground system losses as are series-fed towers, particularly with electrically short towers, because the wire cage dimensions and stub point can be adjusted to yield much higher input resistance values. It is reasoned from circuit theory that the lower input current necessary to drive an antenna which has a higher input resistance means that the ground currents are reduced correspondingly and, therefore, the ohmic losses are reduced. The flaw in this reasoning is that circuit theory only deals with conduction currents, and displacement currents are neglected. A given level of displacement current (the type of current that "flows" through the space between the plates of a capacitor) must be present in the region surrounding an antenna of a given height for a given amount of power to be radiated, according to Maxwell's Equations.

The field strength test measurements do not challenge Maxwell's Equations, as no major difference in radiation was found for the worse case tested, the 100 foot tower with no ground radials. To explore this matter further, current measurements were made as shown on Figure 3 along four ground radials, one from along each quadrant of the 120 in place surrounding the tower after its height had been decreased to 100 feet. Four radials were measured because the ground surrounding the tower is not completely flat. Measurements were made along each of the four ground radials starting at a distance of 1 foot from the base pier strap in 20-foot intervals out to the end of the radial. The currents at each distance were averaged for the four radials and their values appear on Figure 4. Figure 5 illustrates the theoretical relationship of antenna and ground currents for a vertical radiator above a ground plane.

The base resistance for the 100 foot tower with 120 radials was 16.8 ohms and the base current for 400 watts was 4.88 amperes. The input resistance of the folded unipole was 43.5 ohms and the input current was 3.03 amperes, or 62 percent of the corresponding 400 watt value for the series-fed tower. Figure 4 not only does not reflect a corresponding reduction in ground current for the folded unipole case, it actually shows the value to be higher. Clearly, the higher input resistance for the folded unipole case results from shunt effects of the wire cage rather than an increase in the actual radiation resistance.

Folded Unipole Bandwidth

To evaluate the input impedance bandwidth of the folded unipole in comparison with the series-fed tower, input impedance "sweeps" were made +/- 30 Khz of carrier frequency for each case tested. The impedance measurements were made with the equipment configured as shown on Figure 6.

Figure 7 shows the measured impedance values for the 160 foot tower with 120 ground radials for the series-fed case while Figure 8 shows the values for the corresponding folded unipole. It should be noted that the folded unipole input resistance remains within a range of 0.5 ohm over the entire 60 Khz span. This is not uncommon for folded unipoles and it often leads, erroneously, to the conclusion that they provide ultra-broadband performance. This conclusion ignores the importance of sideband reactances in determining bandwidth. Figure 9, a plot showing how the "ultra-flat" input impedance of Figure 8 would appear at the input of a 45-degree, 50-ohm transformer. This would be the load impedance presented to a transmitter connected to the antenna through a perfect (not effecting bandwidth) tuning unit and transmission line totaling an odd multiple of 1/8 wavelength in phase delay. The slopes of the resistance and reactance curves "change places" through the transformer, illustrating that both are important for evaluating bandwidth and that the input resistance characteristic of the folded unipole is due to the impedance transforming action of the wire cage's shunt effect rather than to the antenna's inherent characteristics.

Sideband VSWR is the only acceptable way to express the impedance bandwidth characteristics of an antenna. It includes the bandwidth-influencing effects of both the resistive and reactive components of impedance. Figure 10 shows a comparison of sideband VSWR for the two impedance sweeps of Figures 7 and 8. The differences between the two antenna feed methods is negligible out to +/- 15 Khz from carrier frequency and, to the extent that the folded unipole exhibited slightly better impedance bandwidth near the +/- 30 Khz extremes, the improvement is believed to be due to the larger effective radius of the wire cage in comparison with the bare tower of the series-fed case.

To evaluate the bandwidth improvement possible by increasing the effective radius of a series-fed tower with a wire cage, input impedance sweeps were made on the 100 foot tower, with 30 ground radials in place, for the series-fed, folded unipole, and series-fed with shorted wire cage cases. The latter case utilized the wire cage of the folded unipole with both the upper and lower ends shorted to the tower. The sideband VSWR values determined from these measurements are shown on Figure 11. Clearly, the case with the wire cage shorted at both ends to increase the effective radiating element radius exhibited impedance bandwidth characteristics superior to the other two cases.

There is much confusion about whether folded unipoles should be expected to produce the type of input impedance bandwidth improvement which is characteristic of halfwave folded dipoles such as are used at HF, VHF, and UHF frequencies.

The choice of the name folded unipole is unfortunate, since it implies a kinship to the folded dipole. The folded unipole is not simply half of a folded dipole with the other half supplied by the ground image, as the name implies. Unlike folded dipoles, which consist of parallel conductors spaced side-by-side at an appreciable portion of a wavelength, folded unipoles consist of towers surrounded by close-spaced wire cages. Because the conductors of a folded dipole are equally exposed to the "outside world," they each carry radiation-mode current which contributes to the far-field radiation of the antenna, as well as transmission-mode current. Because the radiation-mode current is divided between the conductors, much higher radiation resistance (four times that of a dipole where two conductors of equal radius are employed) and improved bandwidth result.

Because the wire cage of a folded unipole tends to shield the tower from the "outside world," the radiation-mode current flows principally on the cage and the tower primarily carries transmission-mode current, which opposes the transmission mode current flowing also on the wire cage. Any modification to the input impedance of a folded unipole is primarily due to the shunt effect of the reactance produced across the feedpoint by what is effectively a coaxial transmission line consisting of the wire cage as the outer conductor and the tower as the inner conductor, an effect that could also be produced by placing a reactance in parallel at the base of a series-fed tower.

The improvement in input impedance bandwidth possible with a folded unipole is primarily due to the fact that the wire cage which principally carries the radiation-mode current has a larger effective radius than the tower alone. Figure 11 shows that utilizing the wire cage to increase the effective radius of the series-fed tower gave the best bandwidth performance of all, indicating that the stored energy in the fields between the tower and wire cage of the folded unipole actually serve to decrease its input impedance bandwidth.

NEC-4.1 Antenna System Analysis

All of the various cases of antenna and ground system configuration that were measured in the experimental phase of the program were also modeled using the Numerical Electromagnetics Code, version 4.1. (NEC-4.1). This latest version of the well known method of moments program was developed by Dr. Gerald J. Burke of the Lawrence Livermore National Laboratory [1]. Since NEC-4.1 is capable of accurately modeling electrically very short wires and conductors buried in finite (lossy) ground, the program is particularly well suited for modeling the small physical details of a folded unipole antenna as well as investigating the effects of using various ground systems. NEC-4.1 was employed in this particular test program in order to validate the accuracy of Kintronic Laboratories' computer modeling techniques using actual measured data. The antenna models that were used gave computed antenna characteristics that fell well within the design specifications that are normally used at Kintronics in designing both series-fed and folded unipole antenna systems. This supports our belief that computer modeling is a valuable engineering tool for arriving at accurate antenna system designs.

The primary parameters that were studied in the computer modeling phase of the program are antenna driving point impedances, generated field strengths, and ground system currents. The computed results were compared directly with measured results for the 120 ground radial cases and the ground stake cases. Cases for 30 ground radials were also investigated via computer modeling to go beyond the measured cases and investigate the effects of a sparse ground system. Due to space constraints, only the cases of the 98.3° tall towers with 120 radials are presented here for direct comparison to measured results. The relative field strengths are compared for all configurations selected and other results are presented.

98.3° Series-fed Tower With 120 Ground Radials

The 98.3° series-fed tower structure was modeled with NEC-4.1 using a wire model as shown in Figure 12. The three legs of the triangular cross section tower are modeled as well as 21 sets of horizontal crossmembers. The physical leg sizes and crossmember sizes are used for the wire radii. The three vertical wires are brought together to a point one foot above the ground to represent the tapered base section of the tower. A single wire at the base of the tapered tower bottom then connects the tower to 120 equally spaced radial ground wires, each 150 feet in length (not shown in Figure 12). The ground wires were modeled buried 6 inches into lossy soil to represent a typical full ground system. A total of 1,935 wire segments are used in this particular NEC-4.1 model.

The results for computed antenna impedance showed good agreement with the corresponding measured impedance. One feature of the antenna that was not modeled in the NEC-4.1 model was the single turn drip loop in the feed tube between the antenna tuning unit in which the impedance measurement was made and the tower. This loop added approximately 25 to 35 ohms of inductive reactance to the measured impedances for the series-fed tower configurations. The measured antenna impedance at 1,680 Khz was 69.5 + j 156 Ω and the computer model resulted in an antenna impedance of 74.4 + j 124.5 Ω. When the drip loop of the antenna is taken into account, the results agree reasonably well.

The current in the ground radials were also analyzed with the NEC-4.1 model. The current magnitude in each of the wire segments of one ground radial were averaged to give a computed value of 16.6 mA. The measured ground currents for the 36 total test points along the four test ground radials were also averaged giving a value of 17.0 mA. Again the numerically modeled result and the measured result agree very well within the measurement and computer model prediction accuracies.

98.3° Folded Unipole With 120 Ground Radials

The 98.3° folded unipole was modeled with NEC-4.1 using a wire model as shown in Figure 13. The tower structure itself is the exact same tower structure model as that used for the series-fed case. Added to the series-fed wire model is the six-wire skirt which is shorted to the tower at the top and at the shorting stub position. The skirt wires are commoned together at the bottom with a commoning loop from which a feed wire extends down to the base of the tower connecting at the intersection with the 120 ground radials. The ground radials are again not shown in the figure. The feed wire of the folded unipole kit that was actually constructed and tested did not use a single-turn drip loop, and thus no additional inductive reactance was included in the measured antenna impedance for this configuration. The measured antenna impedance for this particular folded unipole configuration was 41.5 + j 173.2 Ω and the computer model resulted in an antenna impedance of 42.2 + j 169.5 Ω. Again close agreement was achieved between the computer model and the physical measurement. The computed average current for the ground radial wires was 17.5 mA for the NEC-4.1 model and 15.8 mA for the physical measurements. Although the difference in these values is greater than that for the series-fed case, the computer modeled ground current is still reasonably close to the values that were actually measured.

Field Strength Comparisons

The relative electrical field strengths of the various antenna system configurations were also analyzed using the NEC-4.1 model to check the accuracy of the computer modeled field strengths as compared to measured data. The measured field strength data values for the drive-to points, which were all normalized to the baseline case of the 98.3° tall series-fed tower with 120 ground radials, were averaged over all 8 of the measurement radials. Since the NEC-4.1 model does not include variations in the field strength due to terrain, the vertical component of the electrical field at only one point 1 km from the antenna was used for comparing the various antenna system configurations. This is sufficient since all antenna system configurations analyzed in this work are omnidirectional. The field strengths from the computer model were normalized to the modeled baseline case of the 98.3° tall series-fed tower with 120 ground radials. The measured and computer modeled field strengths were normalized independently since there was no set of several drive-to measurement points all located

1 km from the antenna that would allow averaging of the field strength measurements at 1 km to eliminate the variations due to terrain.

The values of the relative field strengths are illustrated in Figure 14. The independent normalization forces the modeled and measured values for the baseline case to both be 1.0. However, the graph illustrates that the NEC-4.1 model tracked the measured results for relative field strength reasonably well. Some discrepancies are present that reveal that the computer model is still in need of refinement. Despite the small discrepancies, the modeling results support one very important conclusion that was made based on the measured data in that it points to the clear need for a good ground system for best antenna system efficiency.

One additional set of cases that were not physically measured in the test program due to time limitations were modeled with NEC-4.1. These were the cases using 30 ground radials. The relative field strengths arrived at via the computer model are compared in Figure 15. These results reveal that the field strength was not diminished significantly by going from 120 to 30 radials for any of the four antennas. The field strength generated by the taller towers is less affected by the removal of 90 radials than is the field strength generated by the shorter towers. Also, the removal of all ground radials diminishes the field strength of the shorter antennas to a greater degree than for the taller towers. All cases reveal a typical loss in field strength of 25% when no ground radial wires are used in the antenna system.

Current Comparisons for 61.5° Tall Antennas With 120 Ground Radials

As previously mentioned, the currents in the radial ground wires that were measured for the 61.5° tall series-fed and folded unipole antennas with 120 ground radials were very similar in magnitude despite the fact that the base current for the folded unipole was only 62% as high as that for the series-fed case (see Fig. 5). The NEC-4.1 model permits analysis of the currents on the antenna structure and ground system. The computed currents in the ground radials from the models of these two antenna system configurations are plotted in Figure 16. The model's results again support the conclusion that the two cases result in very similar currents in the ground system. It was also noted that the driving point impedance and the resulting base currents in the models for these two configurations were quite close to those measured. The computed and measured impedances for the series-fed case were 17.6 - j 113.1 Ω and 16.8 - j 45.8 Ω, respectively. The computed and measured impedances for the folded unipole case were 47.3 + j 202.3 Ω and 43.5 + j 226.2 Ω respectively. As a result, the base current for the folded unipole was 61% as high as that for the series-fed case in the modeled results, which is very close to that which was measured. Discrepancies do exist between the measured and modeled reactances for these two cases. This is not unexpected however since these two cases are highly reactive configurations with high reactances that are difficult to accurately measure and model. The impedances calculated by the model are still well within normal design tolerances to make the model very useful as an engineering tool.

The NEC-4.1 model also allows analysis of currents on the antenna structure itself that are not easily measured. This allows greater insight into the electromagnetic characteristics of the various antenna systems that were tested. Figures 17 and 18 illustrate the currents that flow on the folded unipole and series-fed 61.5° tall towers with 120 radials. Figure 17 shows the magnitude of the current flowing in one vertical leg of the three tower legs in the series-fed configuration. As would be expected for this antenna, the current is greatest at the base and decreases to zero at the top of the antenna. Note that the current is not shown actually going to zero since the currents in NEC-4.1 are computed at wire segment centers rather than at their endpoints. The current at the top of the tower at the 100 foot level is understood to be zero. The current magnitude at the base is also noted to be 1/3 of the total base current for the tower, which is reasonable since the current divides equally between the three legs of the triangular cross section tower.

Figure 18 illustrates the computed current along the same vertical leg of the tower structure for the corresponding folded unipole configuration. Also illustrated is the current along one of the six skirt wires of the antenna. The sharp discontinuity in the current along both wires corresponds to the position of the shorting stub that electrically connects the skirt wires to the tower structure at the 32 foot level above ground. It should be noted that despite the fact that the base current of the folded unipole configuration is only 61% as high as that for the series-fed tower in the computer model, the current flowing on the tower structure below the shorting stub is actually higher for the folded unipole than it is for the series-fed case. This suggests that the folded unipole configuration does not yield lower resistive losses than the series-fed configuration simply because it has a lower base current.

Conclusions

No major differences in field strength between the folded unipole and series-fed test cases were found for any of the configurations tested. The folded unipole was not found to have a significantly better radiation efficiency than the series-fed for a given tower height and ground system. The ground currents for the folded unipole are found to be approximately equivalent to those for a series-fed tower despite the unipole's lower driving point current, which results from a higher input resistance. No major differences in bandwidth were found between the folded unipole and series-fed tower when sideband VSWR was observed rather than simply input resistance. Furthermore, with the wire cage connected to the tower at the top and bottom, the antenna was found to have even wider bandwidth than for either the standard series-fed or unipole skirt-fed tower.

The NEC-4.1 models of the various antenna and ground system configurations were found to give results that are in good agreement with measurements. The computer modeling was shown to be a valuable design and research tool allowing investigation of a variety of antenna systems that could not otherwise be studied in an economical way. The need for a good ground system has been confirmed by both measured and modeled results. The modeling also agreed with measurements in that series-fed and folded unipole antennas don't differ significantly in radiation efficiency for a given tower height and ground system. Field intensity differences between the folded unipole and the series-fed antenna of less than 9% were consistently computed as well as measured.

ACKNOWLEDGMENTS

We would like to express our sincere appreciation to the following firms for their participation in support of this project and without which this project would not have been possible:

1. duTreil, Lundin & Rackley, Inc. -- Preparation of application for FCC experimental license and loan of field strength meter.
2. Paul Whitney & Associates -- Baseline field strength measurements , establishment of far field measurement locations, and loan of field strength meter.
3. Cohen, Dippell and Everist Consulting Engineers -- loan of field strength meter.

---

1 Brown, G.H.; Lewis, R.F. and Epstein, "Ground Systems As a Factor In Antenna Efficiency", Proceedings of the I.R.E., Volume 25, Number 6, June 1937.

2 Burke, G.J., Numerical Electromagnetics Code-NEC-4, Method of Moments, Part I: User's Manual, Lawrence Livermore National Laboratory, January 1992.

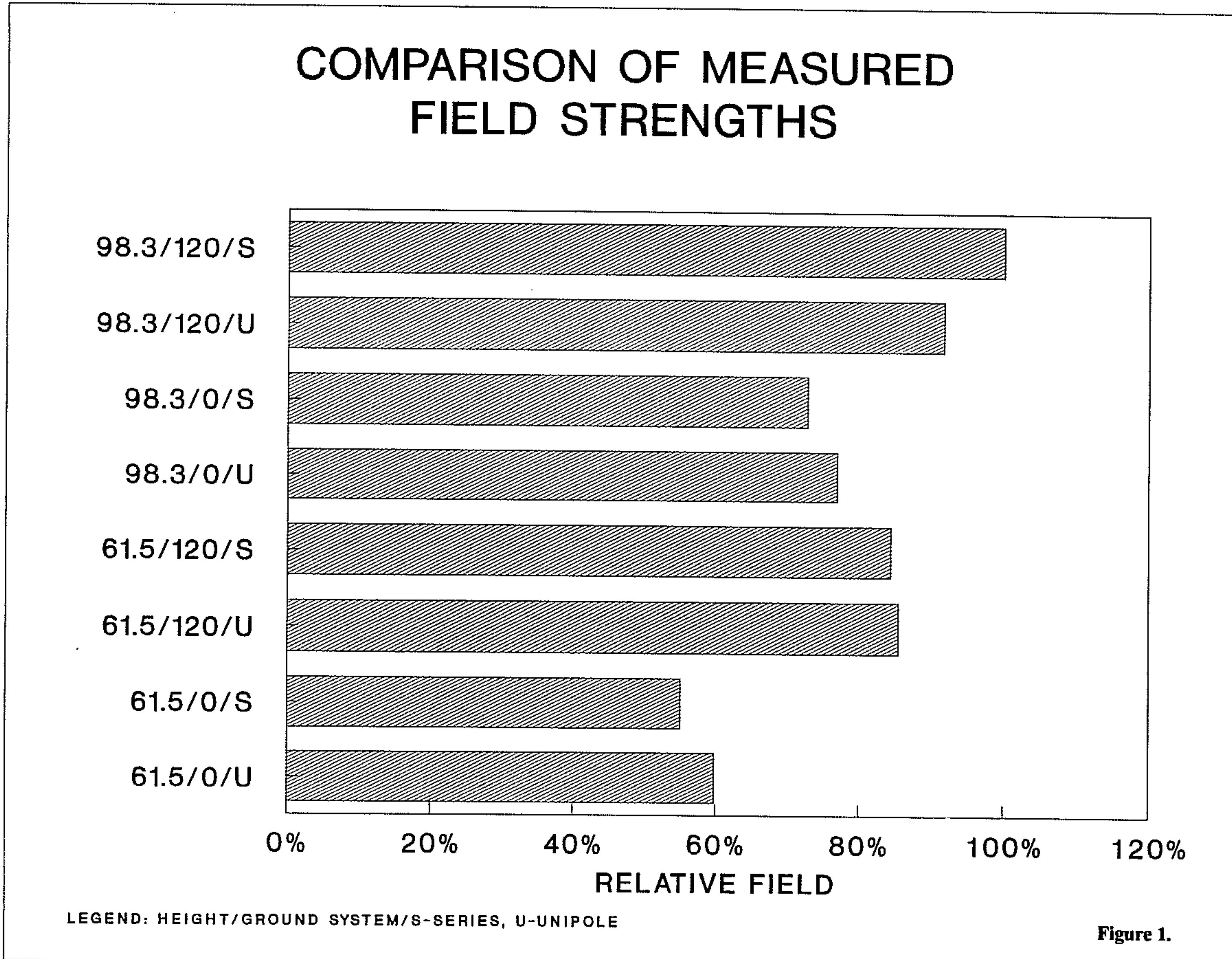

COMPARISON OF MEASURED
FIELD STRENGTHS
98.3/120/S
98.3/120/U
98.3/0/S
98.3/0/U
61.5/120/S
61.5/120/U
61.5/0/S
61.5/0/U
0%
20%
40%
60%
80%
100%
120%
RELATIVE FIELD
LEGEND: HEIGHT/GROUND SYSTEM/S-SERIES, U-UNIPOLE

Figure 1.

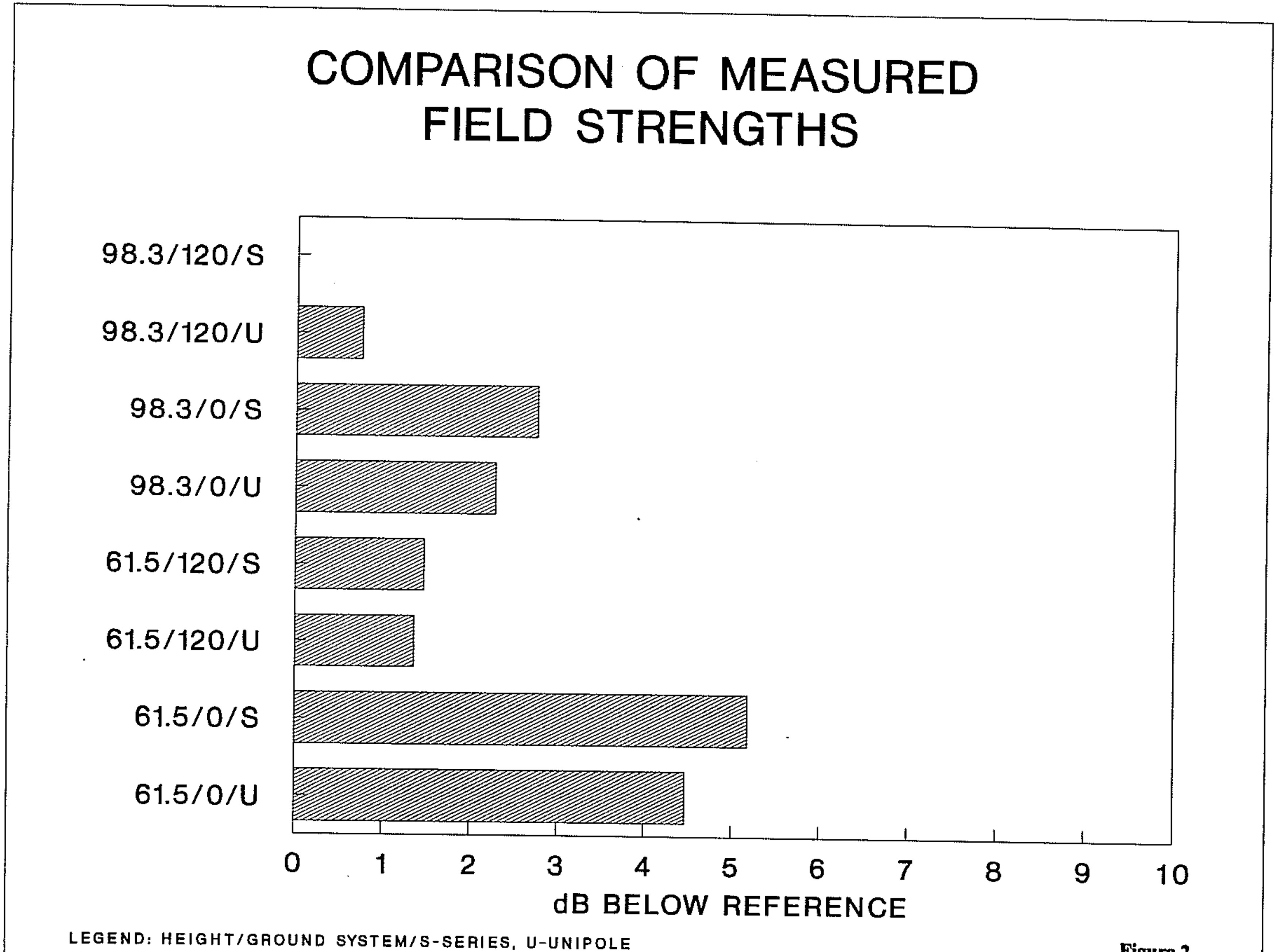

COMPARISON OF MEASURED
FIELD STRENGTHS
98.3/120/S
98.3/120/U
98.3/0/S
98.3/0/U
61.5/120/S
61.5/120/U
61.5/0/S
61.5/0/U
0
1
2
3
4
5
6
7
8
9
10
dB BELOW REFERENCE
LEGEND: HEIGHT/GROUND SYSTEM/S-SERIES, U-UNIPOLE

Figure 2.

GROUND CURRENT MEASUREMENT TECHNIQUE

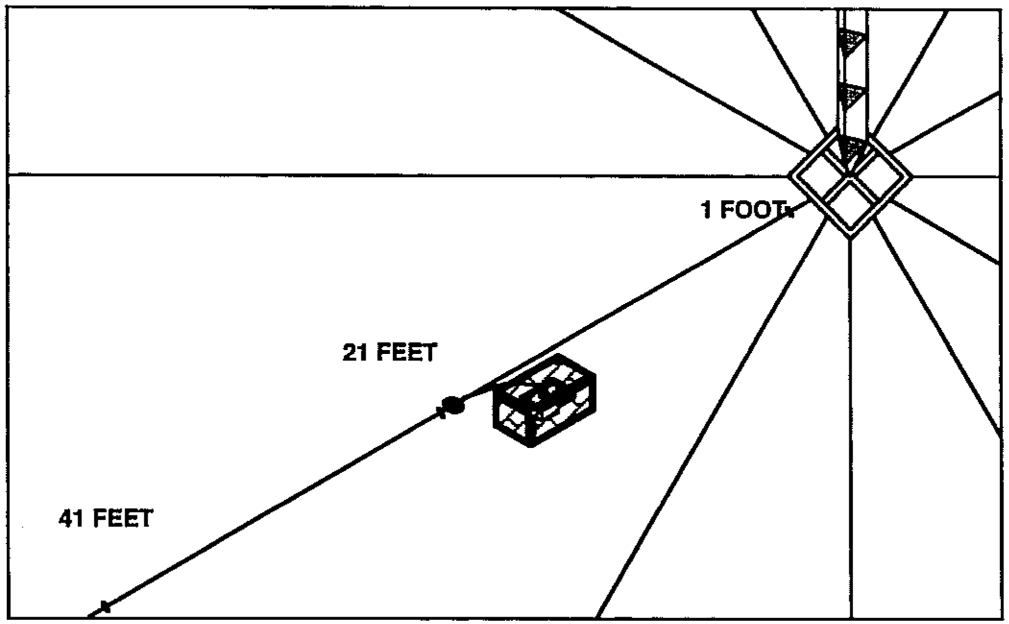
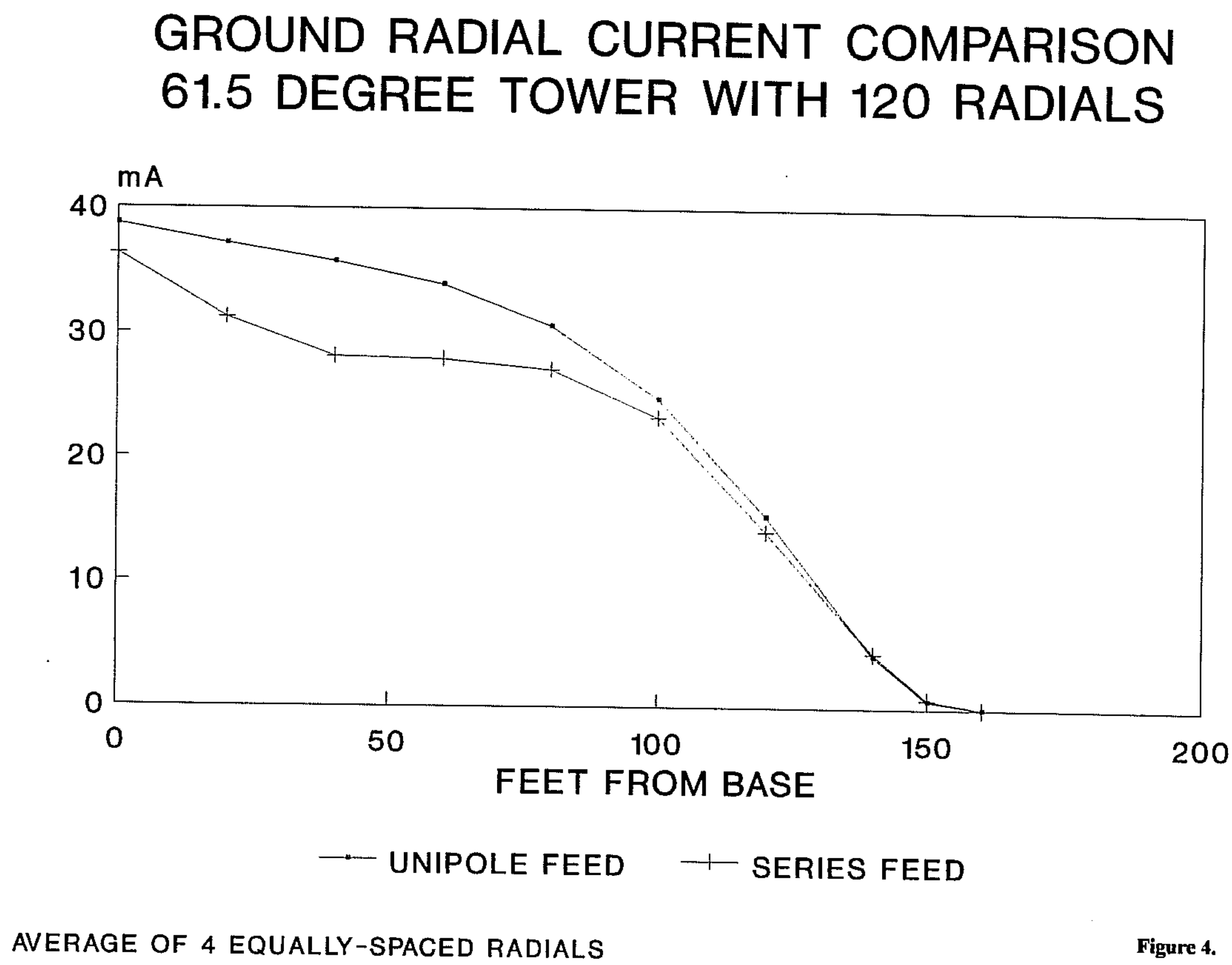


Figure 3.



GROUND RADIAL CURRENT COMPARISON
61.5 DEGREE TOWER WITH 120 RADIALS
mA
40
30
20
10
0
0
50
100
150
200
FEET FROM BASE
UNIPOLE FEED
SERIES FEED
AVERAGE OF 4 EQUALLY-SPACED RADIALS

Figure 4.

FIELDS AND CURRENTS SURROUNDING A MEDIUM WAVE RADIATING TOWER

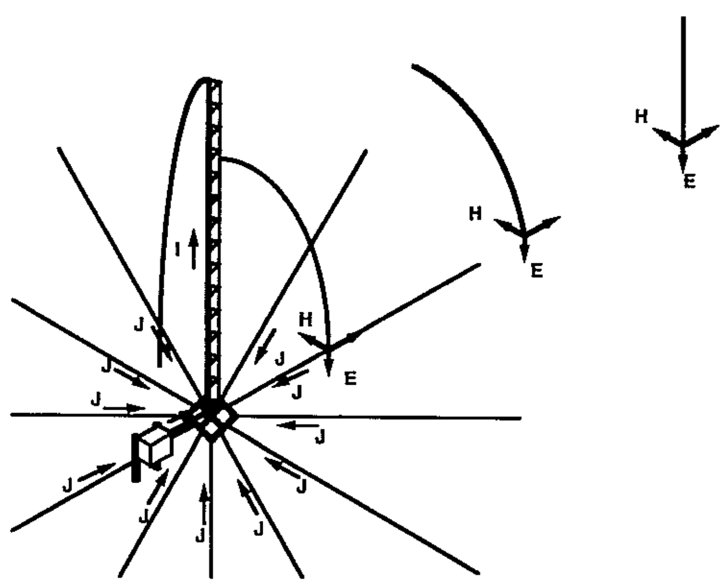


Figure 5.

IMPEDANCE MEASUREMENT EQUIPMENT

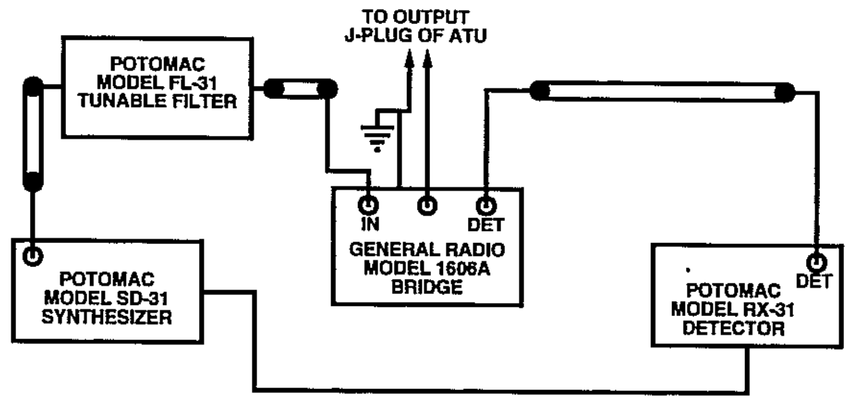
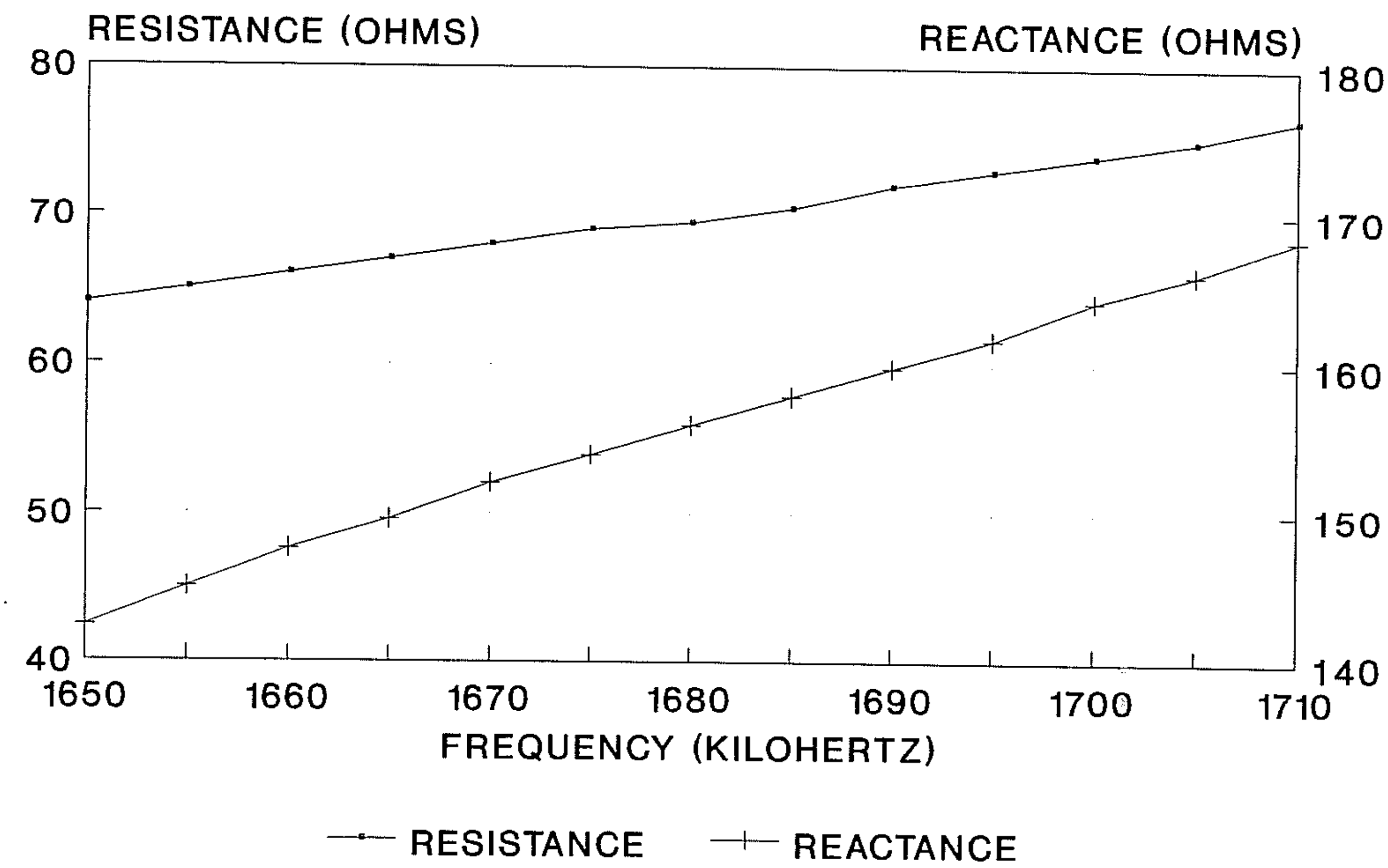


Figure 6.

MEASURED INPUT IMPEDANCE OF 98.3 DEGREE SERIES-FED TOWER WITH 120 RADIALS



Fiqure 7.

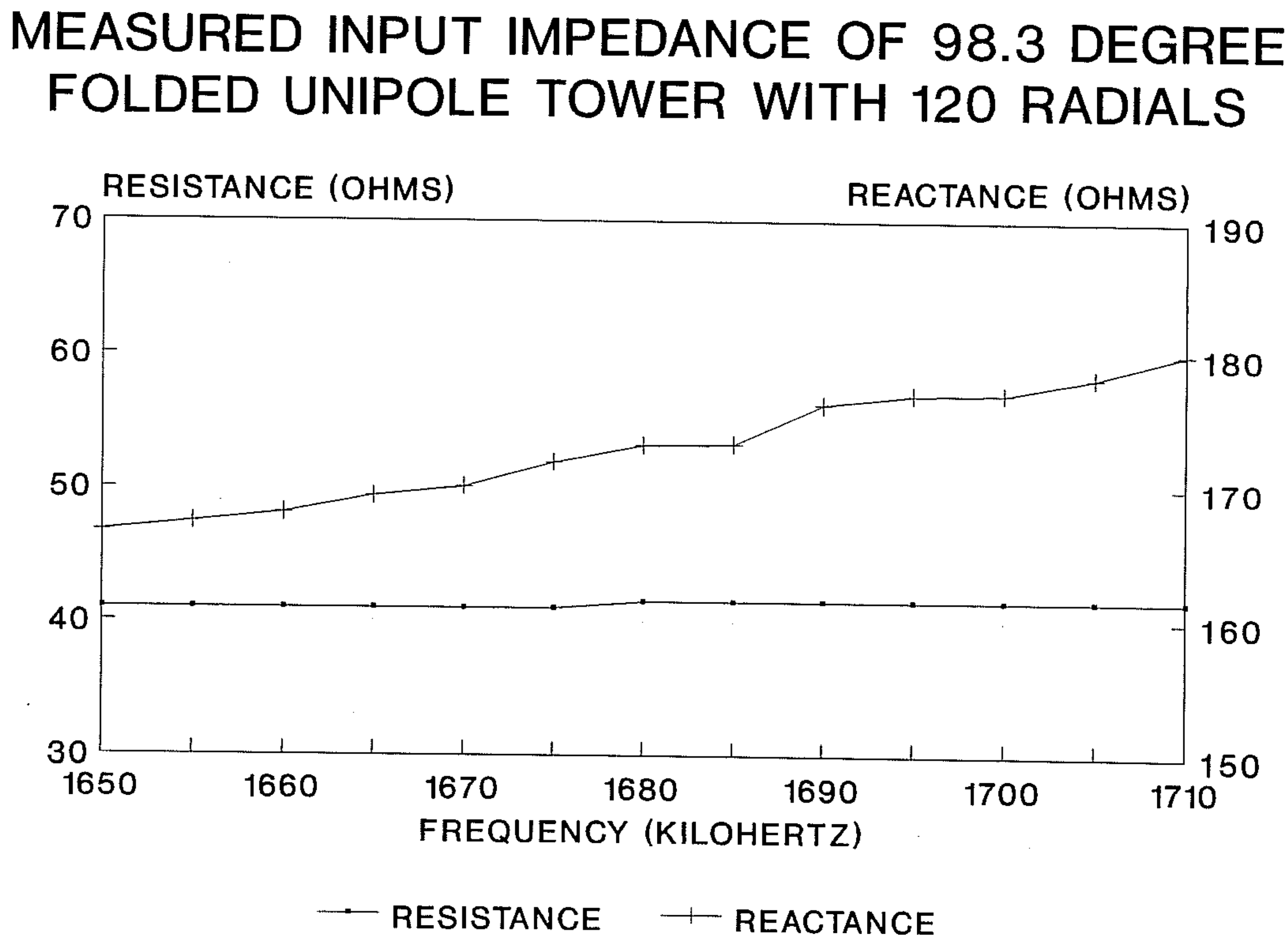

MEASURED INPUT IMPEDANCE OF 98.3 DEGREE
FOLDED UNIPOLE TOWER WITH 120 RADIALS
RESISTANCE (OHMS)
REACTANCE (OHMS)
70
60
50
40
30
190
180
170
160
150
1650
1660
1670
1680
1690
1700
1710
FREQUENCY (KILOHERTZ)
RESISTANCE
REACTANCE

Figure 8.

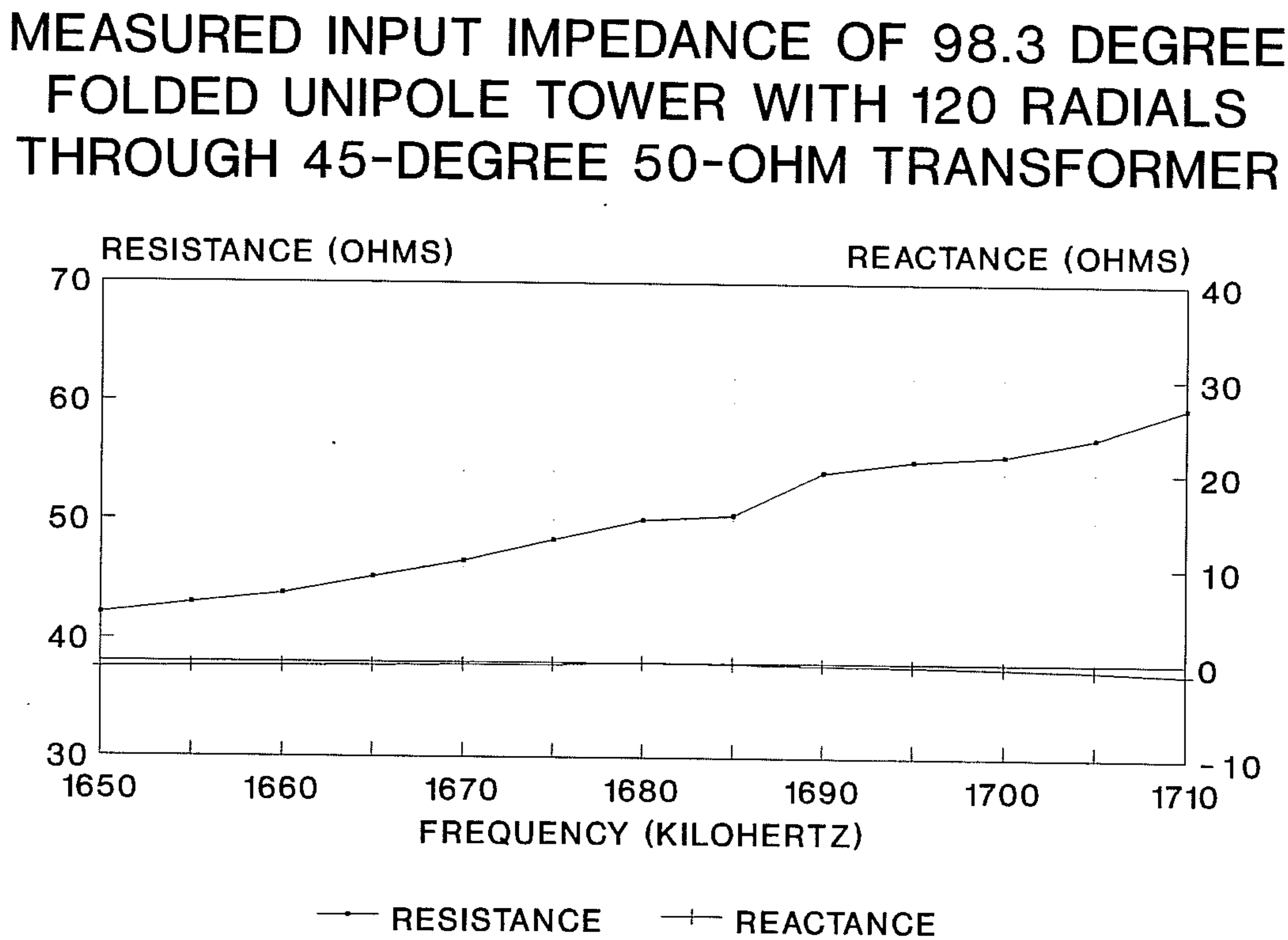

MEASURED INPUT IMPEDANCE OF 98.3 DEGREE
FOLDED UNIPOLE TOWER WITH 120 RADIALS
THROUGH 45-DEGREE 50-OHM TRANSFORMER
RESISTANCE (OHMS)
REACTANCE (OHMS)
70
60
50
40
30
40
30
20
10
0
-10
1650
1660
1670
1680
1690
1700
1710
FREQUENCY (KILOHERTZ)
RESISTANCE
REACTANCE

Figure 9.

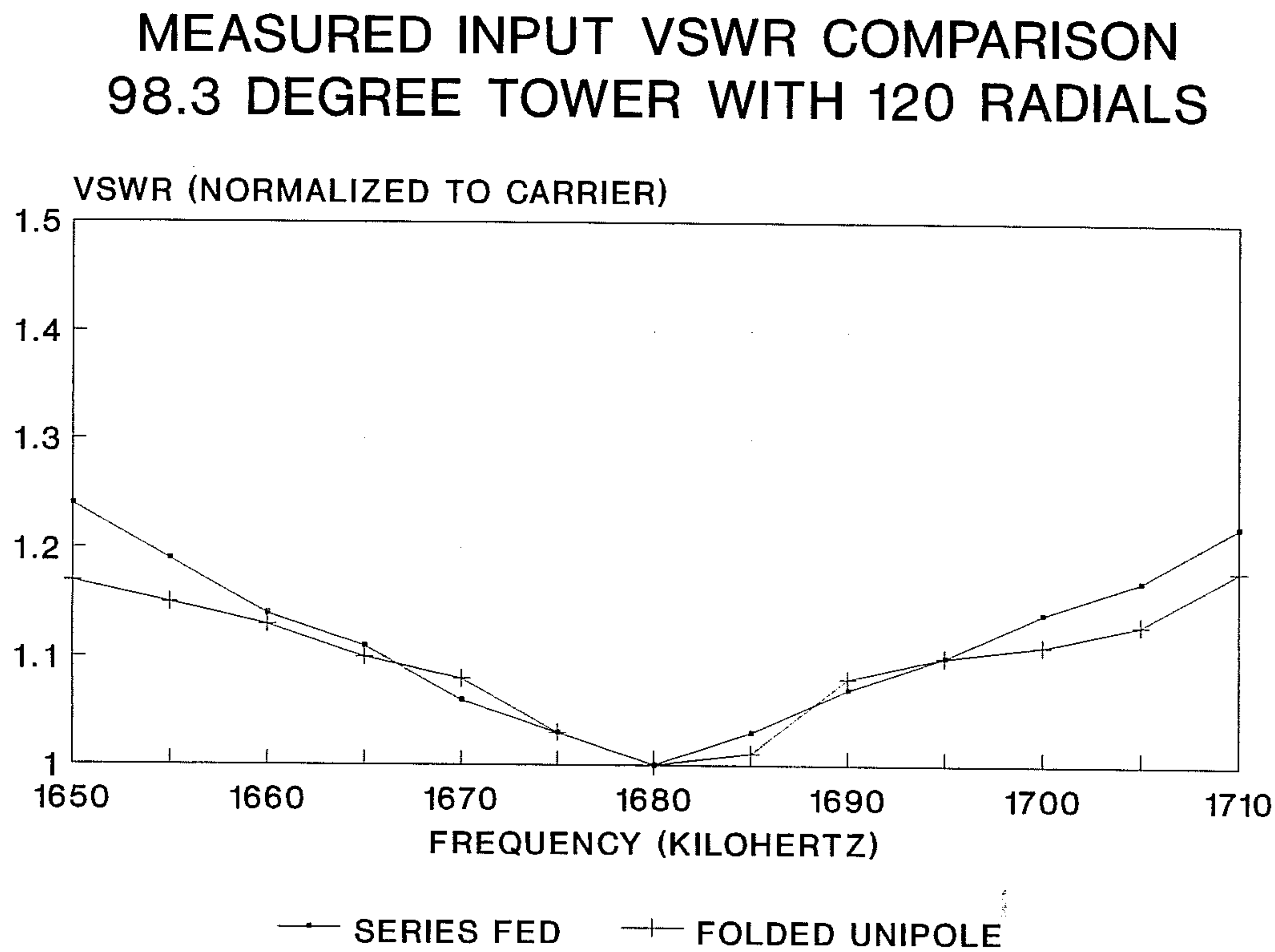

MEASURED INPUT VSWR COMPARISON
98.3 DEGREE TOWER WITH 120 RADIALS
VSWR (NORMALIZED TO CARRIER)
1.5
1.4
1.3
1.2
1.1
1
1650
1660
1670
1680
1690
1700
1710
FREQUENCY (KILOHERTZ)
SERIES FED
FOLDED UNIPOLE

Figure 10.

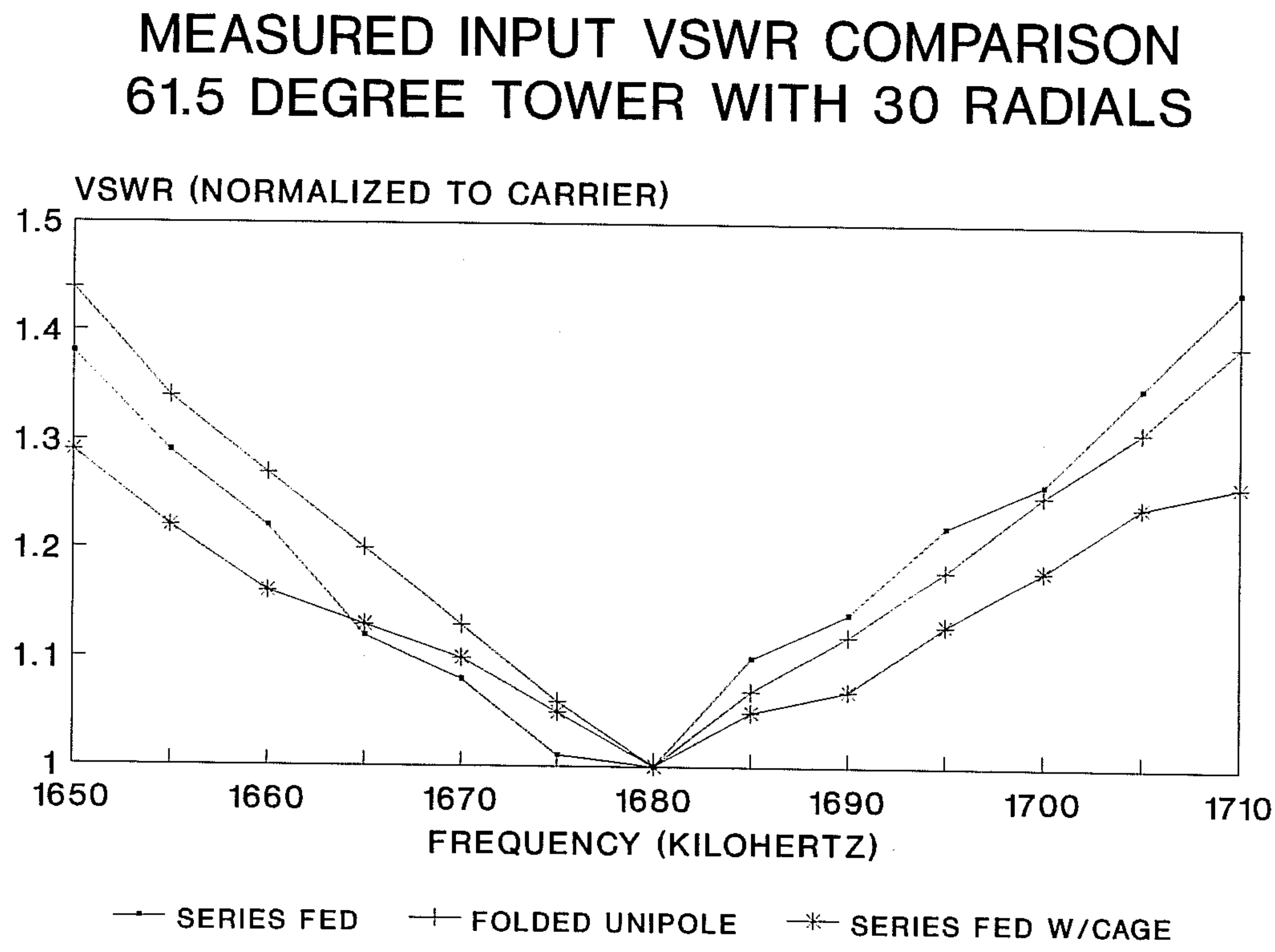

MEASURED INPUT VSWR COMPARISON
61.5 DEGREE TOWER WITH 30 RADIALS
VSWR (NORMALIZED TO CARRIER)
1.5
1.4
1.3
1.2
1.1
1
1650
1660
1670
1680
1690
1700
1710
FREQUENCY (KILOHERTZ)
SERIES FED
FOLDED UNIPOLE
SERIES FED W/CAGE

Figure 11.

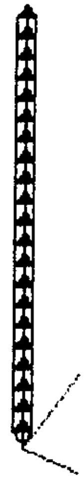


Figure 12 Screen Capture of NEC 98.3° Series-Fed Tower..

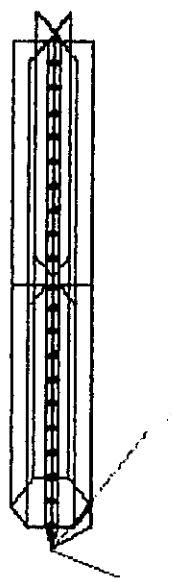


Figure 13 Screen Capture of 98.3° Tower With Folded Unipole.

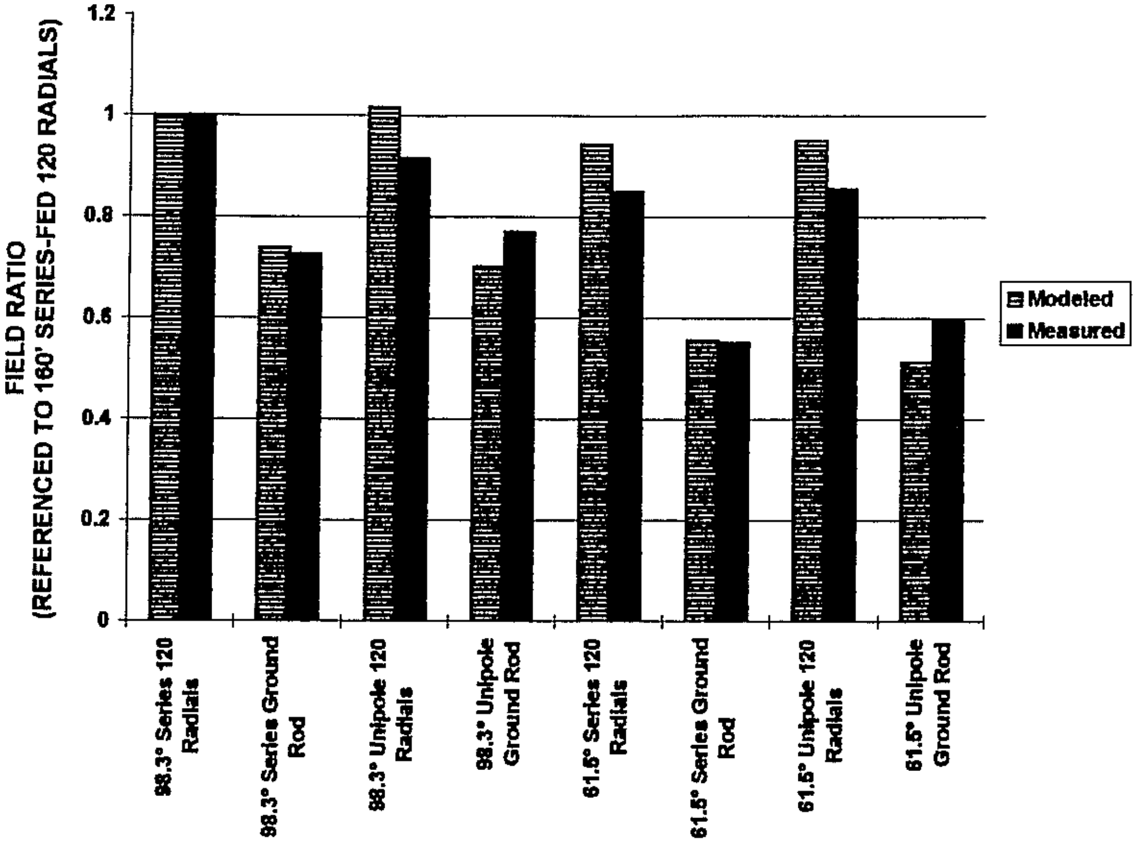


Figure 14 Modeled vs. Measured Field Strength Comparisons.

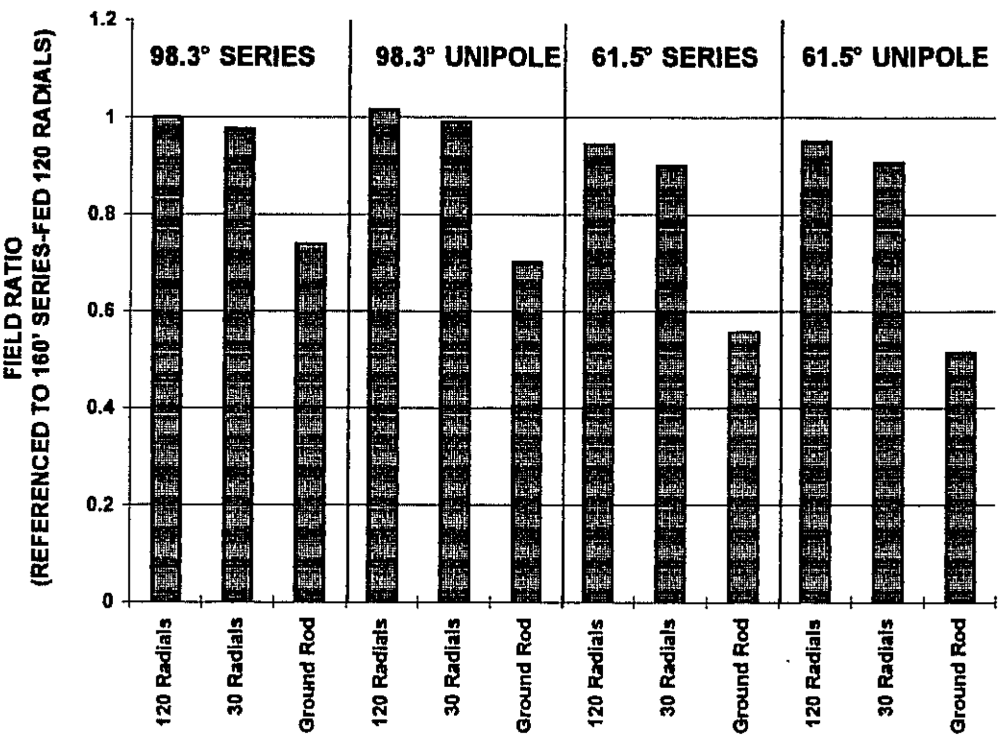


Figure 15 Modeled Field Strength Comparison As a Function of Ground System Variations.

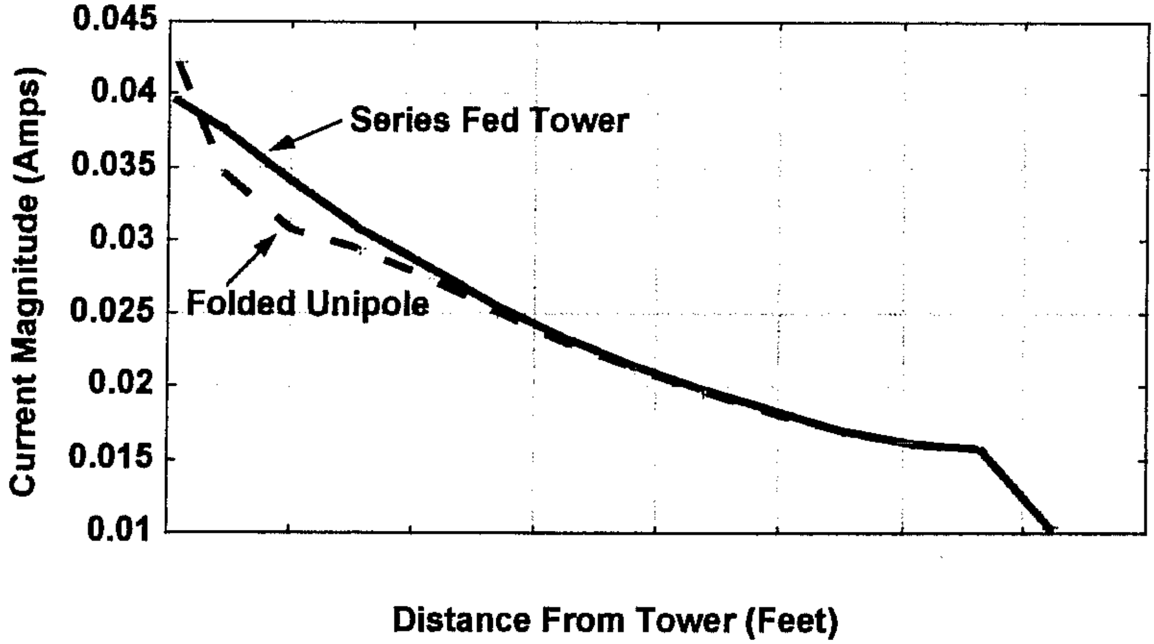


Figure 16 Computed Current Along One Ground Radial Wire For 61.5° Tower With 120 Radials.

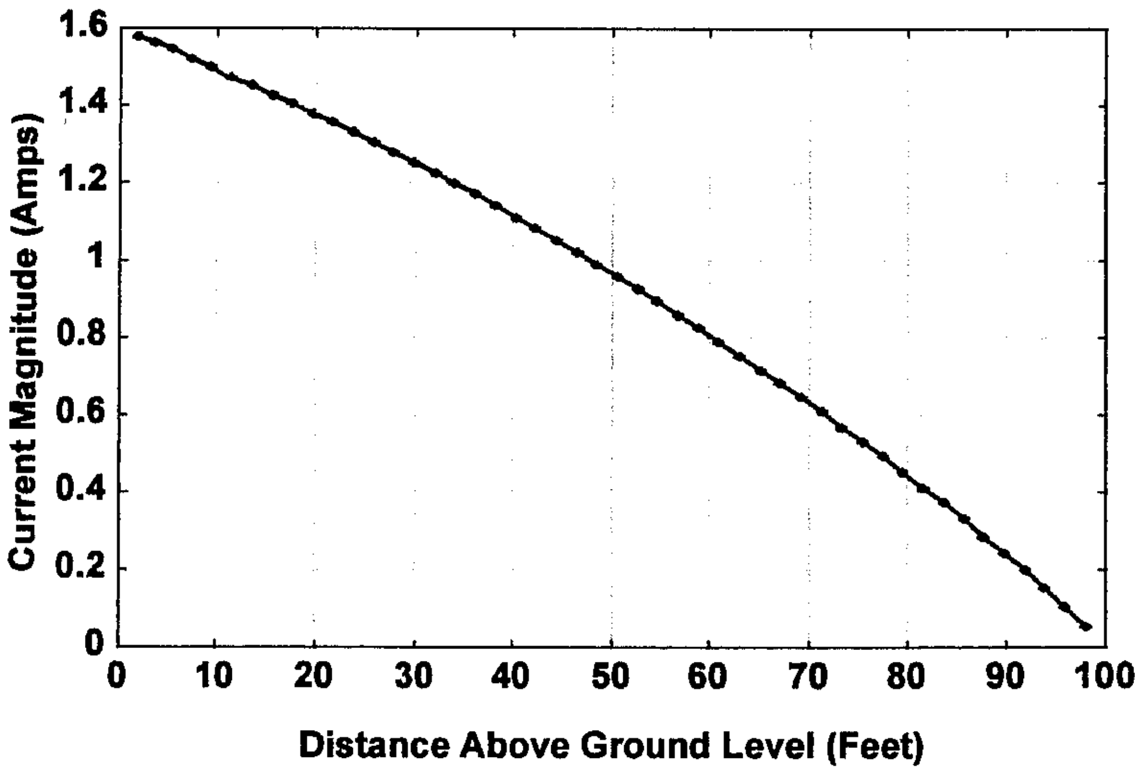


Figure 17 Computed Current In One Leg Of Series Fed 61.5° Tower With 120 Radials.

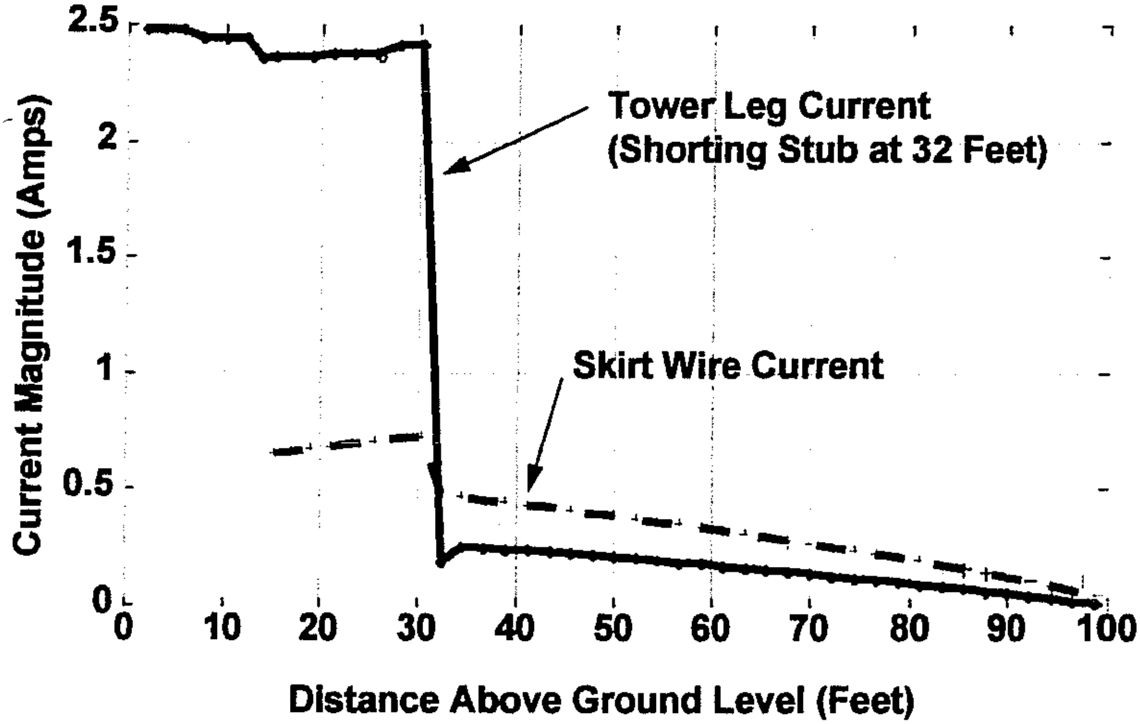


Figure 18 Computed Current In One Tower Leg and In One Skirt Wire of 61.5° Folded Unipole With 120 Ground Radials.