MF AM Folded Monopole Characteristics

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Abstract—Folded monopole antennas have been used for many years in medium frequency amplitude modulation broadcast applications. These antennas offer a grounded radiating structure with a height approximating a quarter wavelength.

Folded monopoles have been studied exhaustively during a recent effort in an attempt to characterize the input impedance and directivity characteristics as a function of monopole height.

As a result it was observed that several impedance regions can be achieved as a function of antenna height and cage diameter. Some of these regions permit a bandwidth operation sufficiently broad to support a high fidelity response for analog or digital transmissions.

This type of antenna can be useful at different heights including a self matching region at the standard 50 ohms impedance. By choosing the appropriate antenna physical dimensions, antenna tuners can be avoided and thus it increases efficiency.

Measurements have been made on a full scale 72 meter tower with a 6 wire cage in order to validate the calculated antenna input impedance and directivity.

The cage and supporting mast make up the equivalent of a transmission line. For this reason different standard triangular towers were analyzed in order to determine their effect on the input impedance. Tower effective radius is determined taking into account the tower width and the tower leg diameter.

At the same time, a minimum antenna height with maximum efficiency has been analyzed to solve the hard problem for installations at places where antenna height is a challenge for the designer.

Index Terms—Antenna measurements, antenna proximity factors, antennas, broadcasting, ground wave propagation, impedance measurement, radio broadcasting, surface wave, transmitting antennas.

I. INTRODUCTION

THE FOLDED monopole was introduced long ago to obtain a high efficiency, simple and grounded radiator for several applications, especially for MF AM stations [1]. Pioneering work with the folded unipole antenna was performed during the 1940s by John Mullaney, P.E. [2], [3].

Although this type of antenna has been in existence for quite some time, almost no technical information is available in the specialized literature.

Fig. 1 shows a folded monopole sketch. In general, the monopole height was chosen close to a quarter wave taking the cage effect into account. The tower and cage constitute a quasi coaxial line, short circuited at the antenna top. If the folded monopole's height is close to a quarter wave, the input impedance between the cage and ground is almost infinite, because tower is generally connected to ground.

The quasi coaxial line characteristic impedance can be calculated. Its value depends on the tower effective radius and
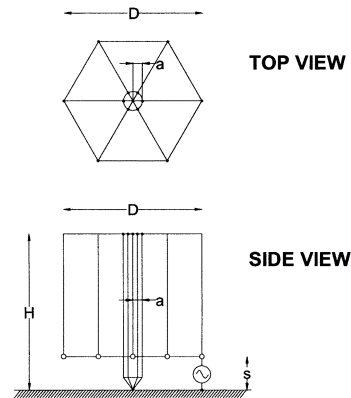
FOLDED MONOPOLE

Fig. 1.　Folded monopole sketch.

the number, size and radius of the cage wires [4], [5]. This impedance is generally higher than 100 ohms. If a resonant frequency is defined as the frequency at which the reactive component of the input impedance is zero, then the folded monopole input impedance exhibits a first resonant frequency lower than the equivalent quarter wavelength transmission line [see Fig. 4]. This lower first resonant frequency depends upon the cage diameter-antenna height (D/H) relationship and generally occurs at a folded monopole height lower than 0.15 λ, for practical cage physical dimensions.

This lower first resonance is attributed exclusively to the folded monopole consideration.

In the standard series fed monopole the first resonance appears close to that corresponding to a quarter wave antenna height and depends on the antenna height–radius (H/a) relationship. For heights lower than a quarter wave its input impedance is capacitive. Lower height–radius (H/a) relationship gives lower capacitive reactances or higher capacitances. For this reason the first resonance frequency occurs at antenna heights slightly lower than a quarter wavelength.

The same effect as in the standard series fed monopole is observed with the folded monopole, where a wider cage diameter produces lower capacitive reactances or higher capacitances. This capacitance is in parallel with the equivalent transmission line input impedance and of course it produces this first resonance, with very high impedance values. [See Figs. 3 and 4.]

In the folded monopole case, the second resonance is equivalent to the standard series fed monopole first resonance where low impedance values are obtained at H/λ slightly less than 0.25.

The grounded tower permits a continuous static discharge and minimizing lightning stoke effects on the tuning systems.

Input antenna impedance can be modified by changing the monopole height and the cage radius for a determined number of cage wires. In this case, six wires cage are used.

Interesting impedance values can be obtained, satisfying the needs for minimum standing wave ratio (less than 1.2), which is very important for a high fidelity low distortion AM operation in the MF AM band. This behavior, of course, could satisfy the requirements of future digital operations. Unfortunately, quarter wave monopoles have poor night time performance thus lowering the nocturnal service area specially for high power stations as compared to the normal diurnal service area [6].

II. INPUT IMPEDANCE

Nowadays, antenna input impedance can be determined by measurements on a real or scaled size models. These input impedance values, at the operating frequency, can be utilized to calculate the impedance matching network, in order to achieve the maximum power transfer between the guided energy in the transmission line and the free space radiated energy.

This technique permits achieving the optimum efficiency for this specific antenna model, but in general, this model could be studied more conveniently by using a computer software program. The antenna geometrical parameters can be varied by simulation, with a P.C., optimizing the antenna characteristics and thus obtaining optimum diurnal and nocturnal service areas.

This computer technique can save time and money before installing the antenna at the operating place.

Of course, before using this software technique, a validation of the software results is paramount. This validation is important because software geometry is not perfect and all the installation details are not perfectly modeled.

When this software validation has been fulfilled, confidence in calculations can be gained by comparing some real measurements with the calculated values.

Generally the agreement is within 10% and for this reason, it is very important to make such calculations when designing the final full scale antenna.

Fig. 2 shows a picture of the full scale measured folded monopole.

Monopole physical dimensions are: Height (H) is 72 meters. The 6 wires cage diameter (D) is 4 meters. Ground-cage separation (S) is 3.0 meters. Wire radius is 8 millimeters (a).

Triangular guyed supporting tower width is 0.45 meter (1.5 feet) (w).

Cage diameter–height factor $D/H = 0.556$.

This monopole was designed for a new AM Station whose assigned frequency is: $f = 1520$ KHz.

Location is approximately 70 miles south of Buenos Aires City and measurements have been made carefully.

During these measurements, there were strong induced voltages on this antenna, due to several high power stations located near Buenos Aires. These induced voltages produced a lot of problems in the impedance measurement, especially with low power generators. A very well shielded field strength meter was used (Singer NM-25T) to detect the signal produced by a powerful signal generator (GR 1211C) through a Delta Bridge (Delta OB-1). Frequency was controlled by a digital meter.
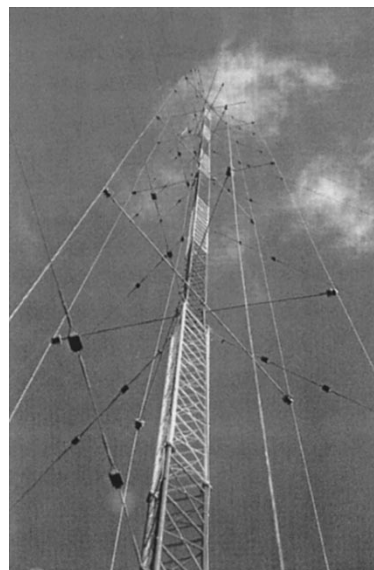

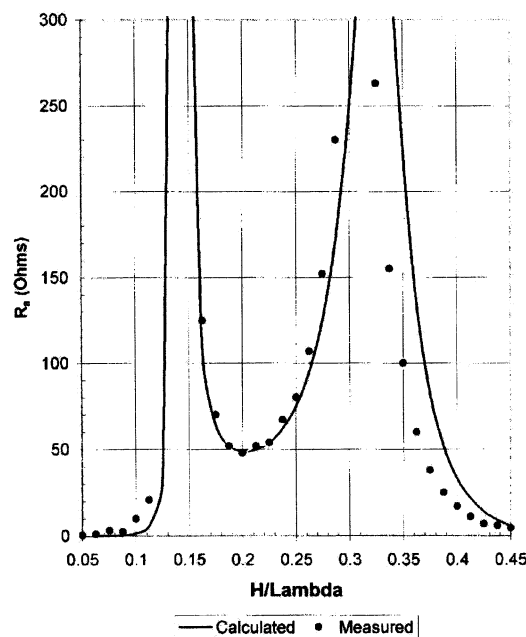Fig. 2. Folded monopole tower and cage view.

Fig. 3. Folded monopole input resistance.

Figs. 3 and 4 show measured and calculated input impedance values confirming similar behavior for the theoretical and real models. Impedance measurements were performed at the antenna base between the cage and the mast ground. The theoretical model is approximately 7% higher in frequency than the real one. This seems to be a constant in every calculation. Physical dimensions of full scale models must be shortened between 5 to 10% in order to get similar input impedance values.

Something to be taken into account is a lower coincidence between theoretical and actual input impedance values as frequency or monopole height is increased, beyond the antenna third resonance. As shown in Fig. 4 this result is evident no matter which D/H parameter value is involved.
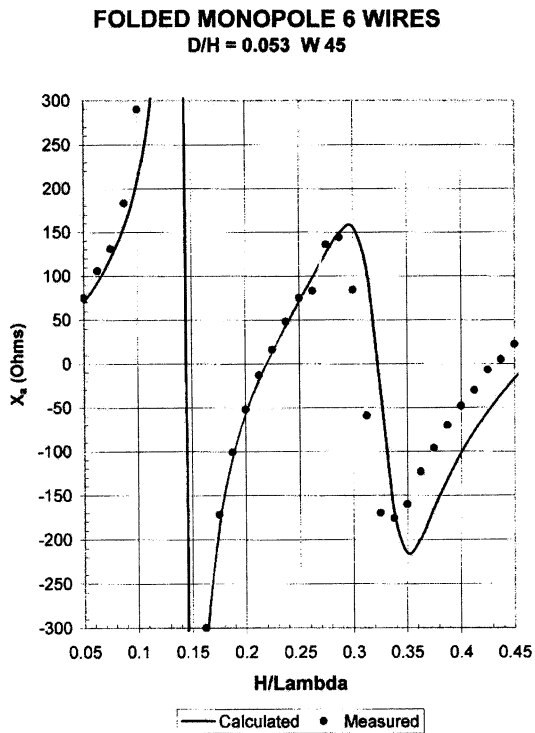
FOLDED MONOPOLE 6 WIRES
D/H = 0.053 W 45

Fig. 4.   Folded monopole input reactance.

TABLE I
FULL SCALED MODEL FOLDED MONOPOLE MEASURED INPUT IMPEDANCE

f (MHz)	H/λ	Z_a/Z_0	VSWR
0.85	0.204	1.00 - j 0.27	1.31
0.86	0.206	1.01 - j 0.17	1.19
0.87	0.209	1.02 - j 0.09	1.09
0.88	0.211	1.04 +j 0.07	1.08
0.89	0.214	1.07 +j 0.21	1.24
0.90	0.216	1.08 +j 0.32	1.38

$Z_0 = 50$ ohms   D/H = 0.0556

increasing bandwidth and radiation efficiency. This is an important advantage of this antenna even if antenna gain is not a maximum and the service areas are not an optimum.

Table I shows measured input impedance values as a function of antenna height giving a good idea of this antenna bandwidth.

It can be seen from input impedance measurements, a remarkable bandwidth for this folded monopole, close to 50 KHz for a VSWR less than 1.3.

Between 0.25 and 0.35 H/λ a third antenna resonance is achieved with again high input impedance, but with lower impedance values compared to the first one. Finally a forth resonance with low input impedance values is achieved close to 0.45 H/λ. Beyond that, more resonances can be achieved but outside the practical range.

III. WAVE PROPAGATION

In order to determine the antenna radiation efficiency, near and far field calculations and measurements have been carried out [7]. Fig. 8 shows a comparison between calculated and measured near electric E and H fields. From these values power density, conductive soil current and space impedance can be calculated. Power soil dissipation permits the antenna efficiency calculation to be 96.5%.

Most of the measured points lay over a standard 120 wire buried ground plane whose radius is around a quarter wavelength. This artificial ground plane is very important in that it decreases the physical soil surface impedance [$Z_s = (14.7 + j13.5)\Omega$ at 1.52 MHz], to very low values, especially close to the antenna feed point. It is well known that the artificial ground plane surface impedance is a function of distance from the feed point [8]. Its effect is to facilitate the ground returning conducting currents flowing through the antenna circuit. The complete transmitting antenna consist not only of the metallic structure but it also includes an hemispherical area of the free space around it, where the radiated far field or radiated energy is created. Within this hemispherical area, whose diameter is approximately one wavelength, the reactive near field is the essential part of the oscillating system whose variations produces the radiating electromagnetic wave. Radio frequency current on the antenna structure is the trigger that produces this oscillation in the hemispherical area. It is very important to understand that this hemispherical area is the antenna circuit and it must be of minimum loss, like in a LC resonant circuit.

The metallic cage wires and tower are made up of high conductivity material and thus have a very low power dissipation effect to the metallic conductive current. Free space around them,
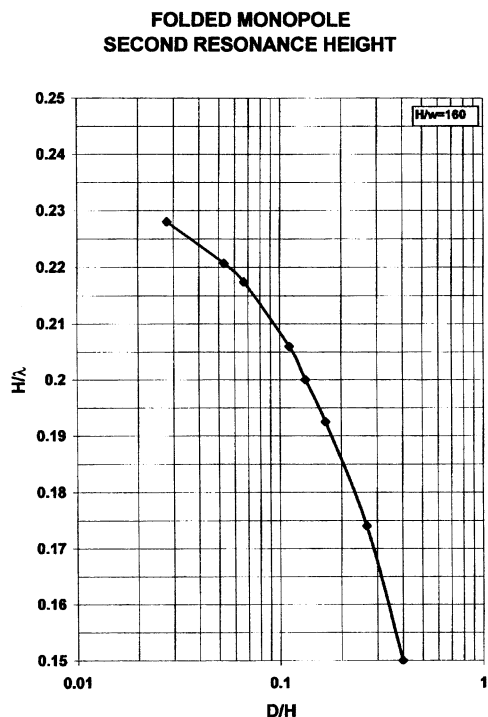
From measured and calculated values the following regions, can be seen: Below 0.15 H/λ the real part of the input impedance has a very sudden increase as a function of frequency or antenna height and its reactive component is inductive. This could be useful because high input resistance leads to high radiation efficiency but unfortunately the impedance variation as a function of frequency is so fast that very sharp antenna tuning is achieved. This means a very narrow bandwidth inappropriated for a high fidelity operation. This feature could be useful for continuous wave operation (CW) or telegraphic transmission where the transmission carrier is interrupted according to the Morse code.

Between 0.1 and 0.15 H/λ a first antenna high impedance resonance occurs having a behavior similar to an loop antenna.

Between 0.17 and 0.25 H/λ a very useful region is achieved, where the antenna self input impedance has a real part very close to 50 ohms.

This region corresponds to the first resonance in a standard isolated series fed classical monopole where the typical capacitive reactance of short monopoles is approaching a zero value. As in the folded monopole case, this value occurs for a standard series fed monopole antenna heights slightly lower than a quarter wavelength.

In the folded monopole case, a second resonance is achieved and input impedance variation is slow, permitting a wide bandwidth operation, very convenient for high fidelity and digital transmissions. [See Figs. 3 and 4.]

Physical dimension choice in this region permits a direct connection between a standard 50 ohms coaxial transmission line and the antenna cage, avoiding tuning systems and of course

**FOLDED MONOPOLE
SECOND RESONANCE HEIGHT**

Fig. 5.   Calculated second resonance height as a function of D/H.

**FOLDED MONOPOLE
SECOND RESONANCE DIRECTIVITY**

Fig. 7.   Calculated second resonance directivity as a function of D/H.

**FOLDED MONOPOLE
SECOND RESONANCE RESISTANCE**

Fig. 6.   Calculated second resonance input resistance as a function of D/H.
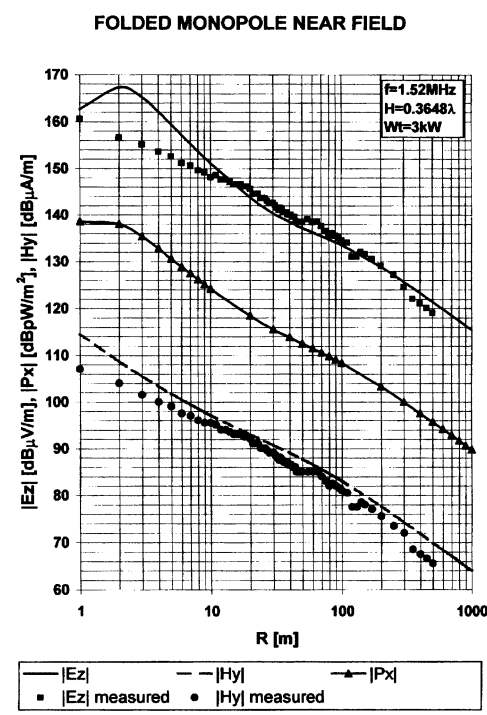
FOLDED MONOPOLE NEAR FIELD

Fig. 8.   Near electric, magnetic fields and power density.

is air, an almost perfect dielectric of very low loss to the displacement current. For this reason the ground path must be metallized because the ground is the only part of the path with high loss in the antenna circuit.

This policy will assure the antenna high radiation efficiency.

Figs. 9 and 10 show the free space impedance calculated close to the antenna. Its value is the near E and H field relationship as a function of Range (R). From these calculations, the real (resistive) free space impedance starts at a half wave distance from

the antenna feed point. Impedance behavior permits to observe clearly the half wave hemispherical area radius. It is known that within this area, the reactive oscillating field exists. Artificial buried ground plane has around a quarter wavelength radius, nevertheless its efficiency decreases as distance from the feed point increases. This is due to the divergent buried wires. Close to the artificial ground plane wire tips, the impedance is approaching the real soil impedance. Beyond half a wavelength from the feed point no antenna current is flowing back to it, and
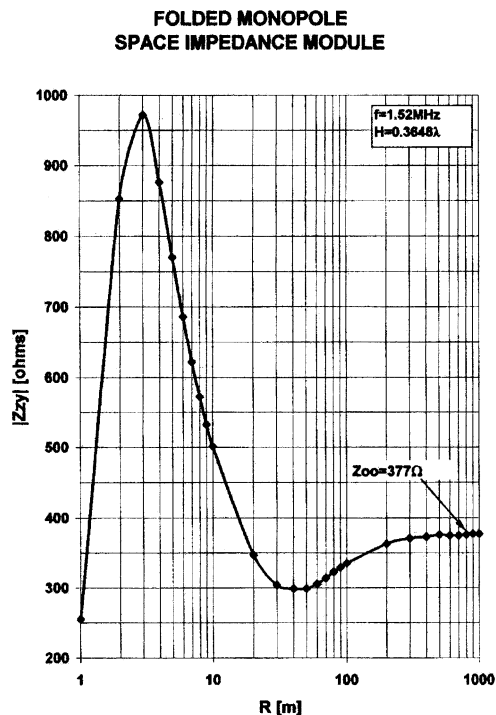
**FOLDED MONOPOLE
SPACE IMPEDANCE MODULE**

Fig. 9.   Calculated space impedance module as a function of distance (z=0),

**FOLDED MONOPOLE
SPACE IMPEDANCE PHASE**
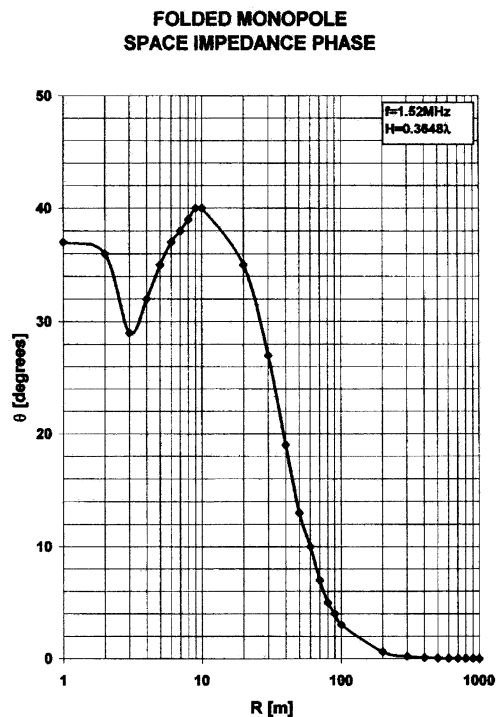

Fig. 10.   Calculated space impedance phase as a function of distance (z=0).

the power dissipated in the soil is taken into account in the wave propagation, as the surface wave Sommerfeld–Norton attenuation factor ($\mathbf{A}$).

Fig. 11 shows the E far field intensity calculated as a function of distance.

Buenos Aires Province is wet land with a high conductivity soil, close to 30 mS/m, specially south of this transmitting location.
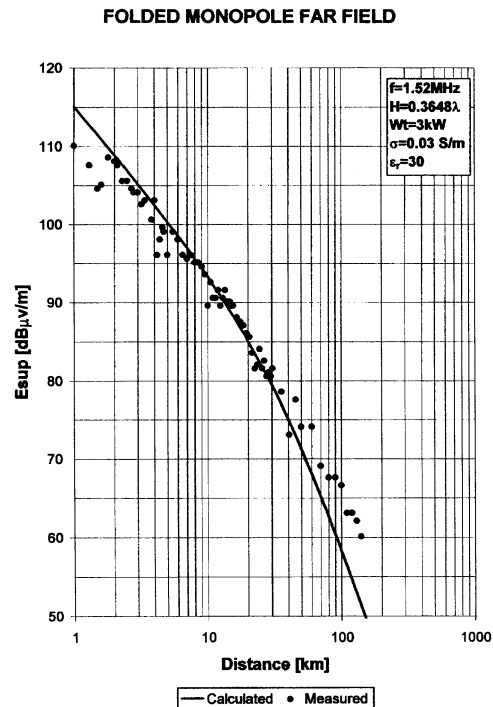
FOLDED MONOPOLE FAR FIELD

Fig. 11.   Folded monopole far field.

Night ionospheric wave has been calculated. Ionospheric and surface wave field intensity values on the surface of the earth arrive at similar intensity, when measured at approximately 100 Km distance. For this reason a night service area can be estimated around 90 kilometers. Signal distortions due to its self interference can be expected beyond this distance.

IV. CAGE EFFECT

Confidence in calculations, obtained by measurements on a full scale model, permits several cage diameter input impedance determinations. In this case the triangular guyed supporting tower has 0.45 meter width and 6 wire cage. Wire radius is 4 millimeter and cage diameter at 2, 4, 8 and 12 meters correspond to D/H factor of 0.027, 0.053, 0.107 and 0.16.

Figs. 12 and 13 show the folded monopole input impedance as a function of antenna height and for several cage diameter–height factors (D/H). A decrease in the first resonance frequency for higher D/H factors is observed, permitting a lower operating frequency for the same height. Additionally a decrease of the operating frequency in the second resonance frequency for a higher D/H factor, can be seen. In these cases wider bandwidth is achieved, even if the input impedance is lower than 50 ohms.

Practically the same third resonance frequency (close to 0.32 H/λ), for any D/H factors is an interesting feature of this antenna. Antenna directivity has been calculated for the same D/H factors and practically no difference in directivity is observed for antenna height lower than $H/\lambda = 0.4$. A sharp decrease in directivity appears for higher antennas and closer to 0.4 H/λ as D/H is increased as Fig. 14 indicates.

Looking at one of the more useful impedance regions, antenna second resonance is strongly a function of D/H factor. This antenna height and input impedance could be very convenient for standard installations.
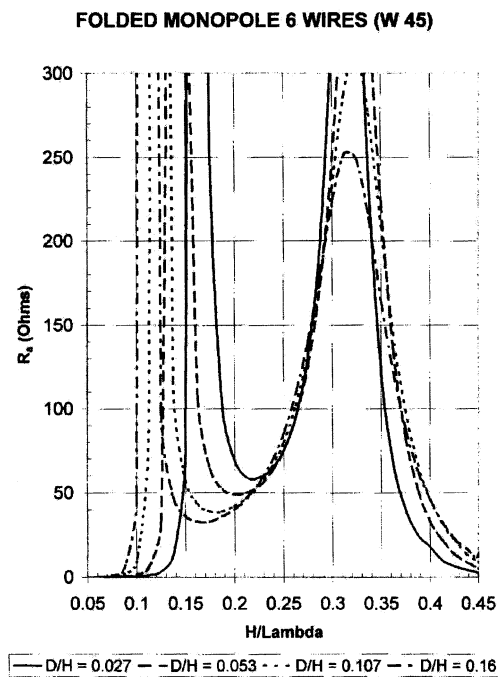
FOLDED MONOPOLE 6 WIRES (W 45)

Fig. 12.   Input resistance as a function of the antenna height and D/H factor.
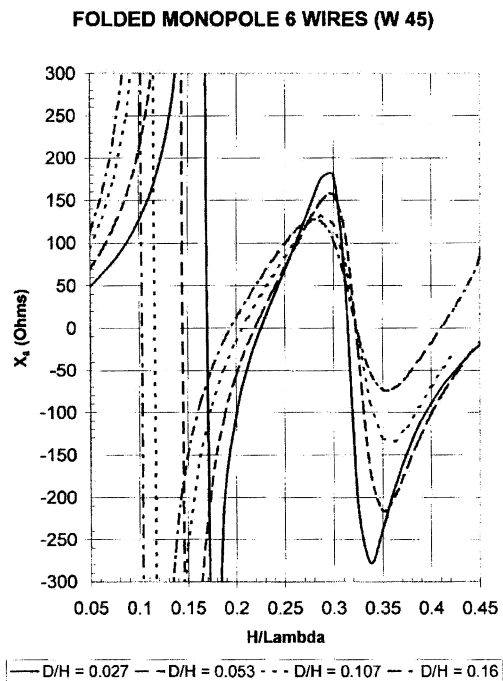
FOLDED MONOPOLE 6 WIRES (W 45)

Fig. 13.   Input reactance as a function of the antenna height and D/H factor.

In Figs. 5–7, the antenna resonance height, antenna input resistance and directivity as a function of D/H factor, can be seen.

Calculations have been made using AWAS [9], for different tower width and results are very close to those shown here.

AWAS (Analysis of Wire Antennas and Scatterers) is a computer program capable of analyzing wire antennas operating in the transmitting and receiving mode, as well as scatterers. In this case the transmitting mode was used only. This computer technique is based on the two potential equations (Scalar and Vector potentials) for the distribution of the antenna current on its wires. The integro-differential equation is solved numerically

FOLDED MONOPOLE 6 WIRES (W 45)

Fig. 14.   Calculated directivity as a function of the antenna height and D/H.

using the method of moments (MOM) [10], [11] with a polynomial (power series) approximation for the current distribution on wires. Wire structure is placed in free space (air, perfect dielectric) and above a perfe*ctly conducting ground plane. Antenna is driven at one port in the transmitting mode, between the lower cage side and the ground plane by means of an ideal voltage generator. Supporting tower is connected directly to the ground plane. The program first evaluates the current distributions on the antenna wires. Supporting tower is simulated like three thick wires (tower legs) connected together at the ground plane and at its top. The same procedure for the cage metallic spreaders. Based in the current distribution the input impedance is evaluated. In this program wire segmentation is performed automatically according to the wire length in wavelengths. Power series polynomial degree can be chosen in order to increase accuracy in each wire current distribution. Ones current distribution is determined, near electric and magnetic fields produced by currents and charges of the wire structure can be calculated and the transmitting antenna radiation pattern and gain are analyzed. Antenna wires are considered as perfectly conducting and for this reason the tangential component of the total electric field on the wire surface must be zero. Computer simulation is following the same way as in the antenna theory texts using the numerical analysis, impossible to be done few year ago by analytical methods. This technique is well explained in classical antenna books [12], [13].

V. TOWER WIDTH EFFECT

Calculations simulating several tower width have been made [9].

In this case 0.45 meter (1.5 feet) (w45), 0.6 meter (2 feet) (w60) and 0.9 meter (3 feet) (w90) width have been used for calculations in order to observe its effect on the antenna input impedance and directivity. These are standard towers used in the
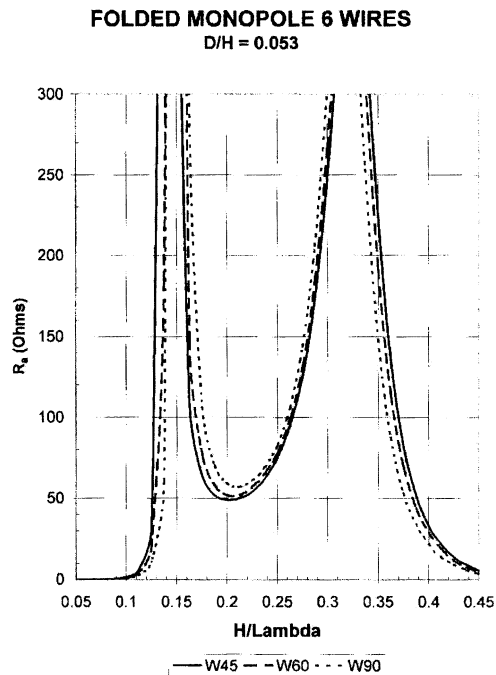
FOLDED MONOPOLE 6 WIRES
D/H = 0.053

Fig. 15.   Calculated input resistance as a function of tower width (w).
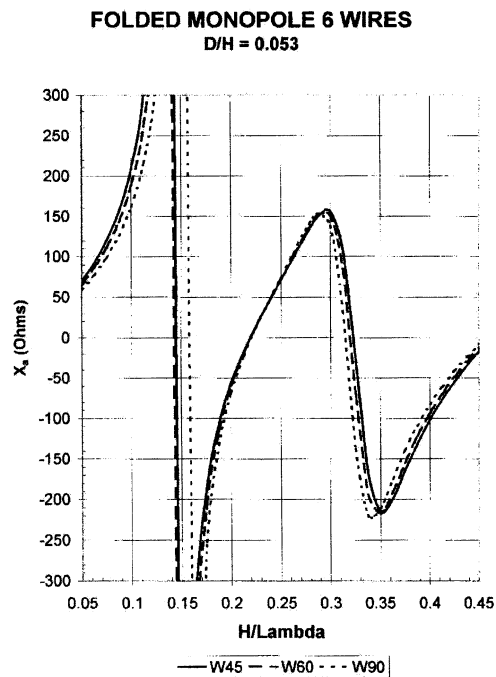
FOLDED MONOPOLE 6 WIRES
D/H = 0.053

Fig. 16.   Calculated input reactance as a function of tower width (w).

MF AM band and produced by several manufacturers around the globe.

Figs. 15 and 16 show the case for $D/H = 0.053$ where a small effect on the input impedance is observed when changing the tower width, but it seems a thinner tower is a better choice. Other D/H factors have been employed in calculations with practically the same results.

VI. CONCLUSIONS

Folded monopole antenna full scale model has been analyzed by means of input impedance and field strength measurements. These parameters have been calculated using a computer program software in order to get a comparison with measured values. As a result antenna input impedance has a similar behavior in the simulated as well in the actual model but a shift to higher frequency is observed in the simulated model. This shift is approximately a 7% in the first and second antenna resonances and it starts to diverge as frequency is increased. Project engineers must be aware of this effect when a new antenna is designed. Simulation can save time and money to optimize the radiating system but measurements are always necessary to evaluate and to certify the operation of a new actual installation.

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