On the Functioning of Folded Dipole Antennas on Conducting Masts

Derek A. McNamara, *Senior Member, IEEE,* and Louis Botha

***Abstract*—The radiation properties of individual folded dipole antennas mounted at various radial distances from the center of conducting masts of different diameters are described in a compact fashion.**

I. Introduction

CONSIDER the arrangement of the mast-mounted folded dipole shown in Fig. 1. Such single folded antennas mounted on conducting masts of small electrical diameter are widely used in VHF and UHF comunications. One often requires radiation pattern information regarding, among other things, the optimum spacing between the folded dipole and mast (distance d in Fig. 1) for a given mast diameter (D). Since comprehensive quantitative data for the geometry of Fig. 1 do not appear to be available elsewhere, the results of a theoretical parametric study of the above configuration are presented in this paper in the form of a set of performance curves. It is shown how the results of a large number of combinations of D/λ and d/λ can be succinctly summarized in the form of a set of simple rules which enable one to predict approximately antenna performance for cases which were not specifically computed as part of the parameteric study. While the emphasis is on pattern data, curves of input impedance for the same range of spacings and mast diameter as that for which the pattern information is presented, are also given. The idea is not that such curves should not be considered extremely accurate ones, according to which an antenna design is completed[1], but that they will give an indication of the order of change in the input impedance when the folded dipole is placed on a mast. This, in turn, will determine the requirements of the matching network which can then be fine-tuned when the antenna is mounted in its final position. The same cannot be said of the pattern information; while the matching behavior is easily adjusted *in situ,* it is usually far too expensive to attempt to adjust the physical dimensions (e.g., d/λ) in order to maximize forward gain, or to determine the number and directions of the unwanted pattern maxima there might be once the antenna is mounted in place.

Manuscript received July 23, 1991; revised March 15, 1993.
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IEEE Log Number 9210674.

[1]The actual input impedance values are very sensitive to the specific feed region details.

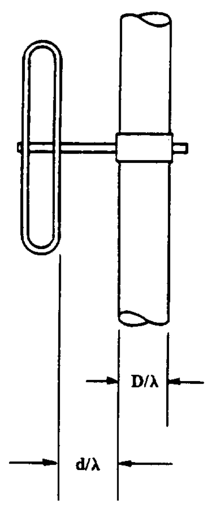


Fig. 1. Geometry of the folded dipole mounted at a distance d from a conducting mast of diameter D.

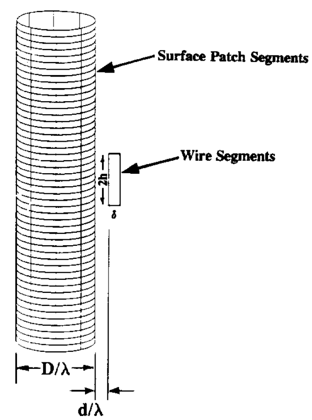


Fig. 2. $NEC2$ patch and wire-segment model of configuration in Fig. 1.

II. Numerical Modeling

In the present paper, the method of moments antenna analysis code $NEC2$ [1] has been used for the numerical modeling of the geometry in Fig. 1. Surface patches are used to model the mast, and wire segments the folded dipole antenna, as shown in Fig. 2. Use of $NEC2$ with both thin-wires and patches allows analysis with masts that are electrically small but not really sufficiently so as to be assumed thin-wires; thus

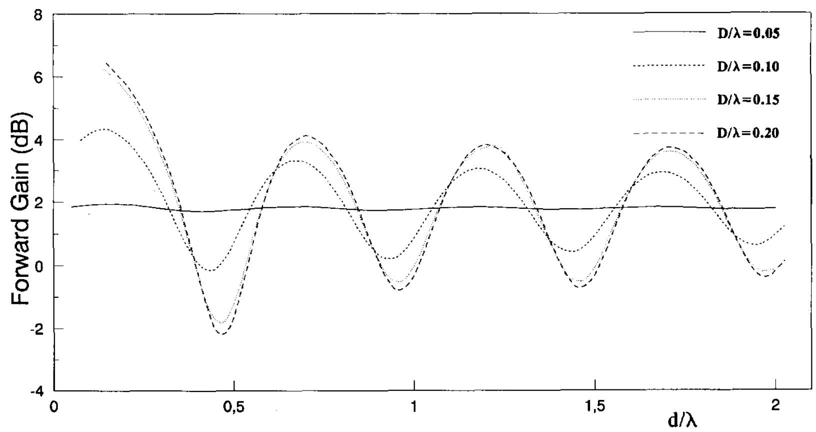


Fig. 3. Forward gain versus separation d/ λ, with mast diameter D/λ as a parameter.

the approach is more general than the method in [2], which required that the cross-section of the mast be sufficiently small to be regarded as a thin-wire.

It is immediately apparent that the two parameters for the study are the mast diameter (D/λ) and spacing (d/λ) of the folded dipole in front of it, since these will clearly affect the performance of the antenna. The computations were done at a frequency of 300 MHz, at which λ is unity. This facilitates normalization of the results in terms of wavelength. Concerning the folded dipole thin-wire model shown in Fig. 2, the wire radius is 0.001λ, the length $2h = 0.23\lambda$, and width $\delta = 0.03\lambda$. Each vertical section is modeled by eight wire segments and the bridging portion by one segment. The forward directivity of the folded dipole, with no mast present, is 1.81 dB. The computed input impedance is $Z_{\text{in}} = 323.8 + j3.97$, and thus the folded dipole is very nearly resonant. The cylinder geometry model in Fig. 2 consists of 50 patches along the length of the 5λ long cylinder and eight patches around the circumference. In addition eight patches were used on each endcap. In other words, a total of 416 patches are used for the numerical modeling of the mast. That this is sufficient for the computation of far-zone characteristics and *changes* in input impedance was established through a convergence test consisting of the computation of the input impedance as the number of patches used was increased. As a representative result, we obtained $Z_{\text{in}} = 273.8 + j243.5\Omega$ for 208 patches, $Z_{\text{in}} = 265.4 + j245.1\Omega$ for 416 patches, and $Z_{\text{in}} = 261.8 + j249.9\Omega$ for 832 patches, with d/λ = 0.5 and D/λ = 0.2. We have selected D/λ values in the range $0.05 \leq$ D/$\lambda \leq 0.2$ as representative mast diameters for the purposes of examining the effect of D/λ.

III. Outcome of the Parametric Study

Before conclusions of a general form can be drawn, it is necessary to perform a very large number of computations involving many variables (a decidedly multi-variable problem). In the remainder of the paper, we attempt to summarize the results of such a study in a concise and useful form.

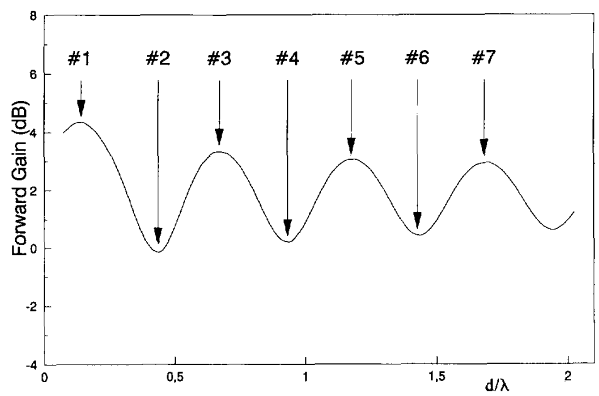


Fig. 4. Forward gain versus separation d/ λ, for fixed mast diameter D/λ = 0.1, with specific points highlighted for use in the discussion of Section III of the text.

Fig. 3 shows the forward gain as a function of the spacing d/λ for different fixed D/λ values. For a given mast diameter, there are clearly optimum separations d/λ as far as the forward gain is concerned. The levels of the pattern maxima decrease for increasing separation. The forward gain curves eventually converge to the gain of a folded dipole in free space (i.e., without a conducting mast present).

Next, for the purposes of illustration, consider specifically the case D/ $\lambda = 0.1$. The forward gain versus d/λ has been repeated in Fig. 4, but with certain points highlighted; the latter are referred to in the discussion which follows immediately. For d/λ = 0.175 (Point No. 1, which corresponds to the first forward gain peak), the radiation pattern is as shown in Fig. 5, with a single pattern maximum in the desired direction. When the separation is d//λ = 0.425 (Point No. 2 in Fig. 4, which corresponds to a forward gain dip) the pattern is the one shown as a solid line[2] in Fig. 6. The reason for the dip in the forward gain for this separation is clear; there are now two "additional pattern maxima" in directions other than the

[2]These and all subsequent patterns presented have been normalized relative to that in Fig. 5.

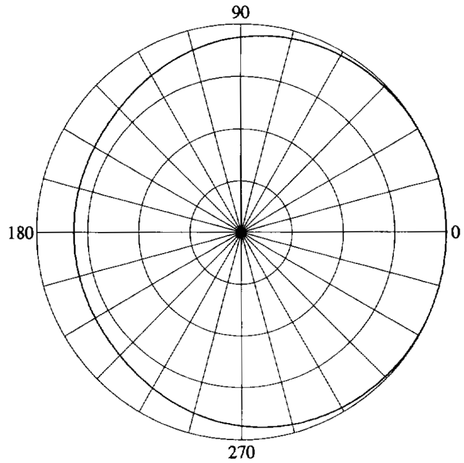


Fig. 5. Radiation pattern (10 dB/division) for the case d/λ = 0.175, with D/λ = 0.1.

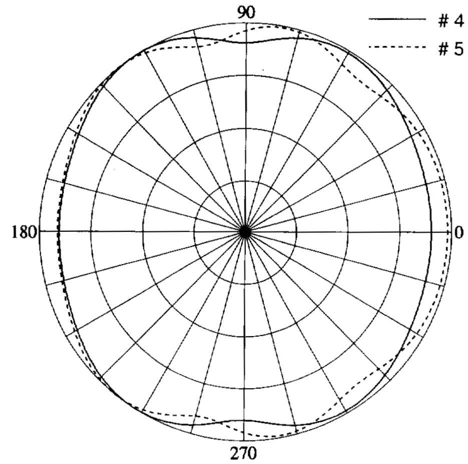


Fig. 7. Radiation pattern (10 dB/division) for the case d/λ = 1.175, with D/λ = 0.1.

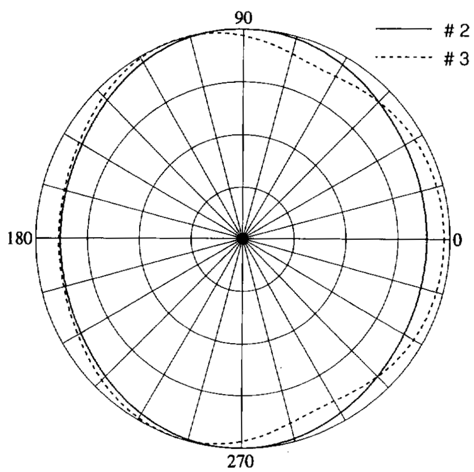


Fig. 6. Radiation pattern (10 dB/division) for the case d/λ = 0.425, with D/λ = 0.1.

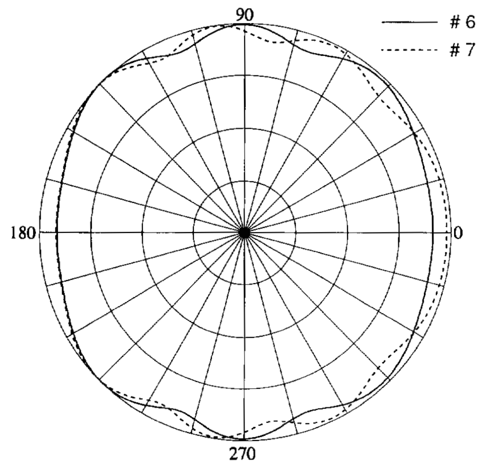


Fig. 8. Radiation pattern (10 dB/division) for the case d/λ = 1.425, with D/λ = 0.1.

desired forward direction. Increasing the separation still further to d/λ = 0.625 brings us once more to a forward gain peak, with a pattern as shown by the dashed line in Fig. 6. The increase in forward gain is clear, but it is less than the case in Fig. 5 because of the fact that the two "additional maxima" have not been removed, but are simply close to the level of the forward lobe.

Continuing, we consider the cases d/λ = 0.925 (second forward gain dip) and d/λ = 1.175 (third forward gain peak), with corresponding patterns being those in Fig. 7. At the second dip (Point No. 4 in Fig. 4), two further "additional maxima" are added to the pattern (and hence the decrese in forward gain), while at the third peak (Point No. 5 in Fig. 4), the four "additional maxima" are still there, but the level of radiation in the forward direction has increased to the point that the gain in this direction is close to that in the directions of the additional maxima.

Finally, in order to complete the picture, we consider the cases d/λ = 1.425 (third forward gain dip) and d/λ = 1.675 (fourth forward gain peak), with corresponding patterns being those in Fig. 8. At the third dip (Point No. 6 in Fig. 4), we once

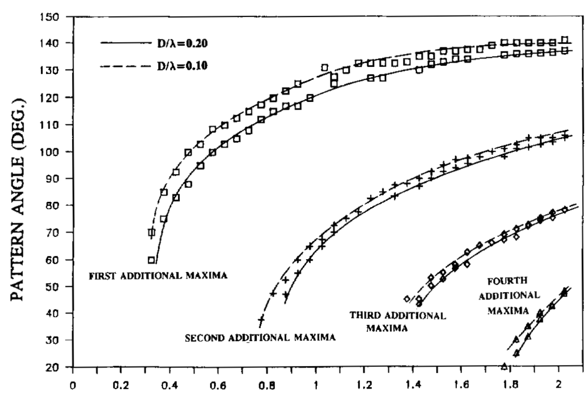


Fig. 9. Approximate angular locations of the additional pattern maxima versus d/λ, with mast diameter D/ λ as a parameter.

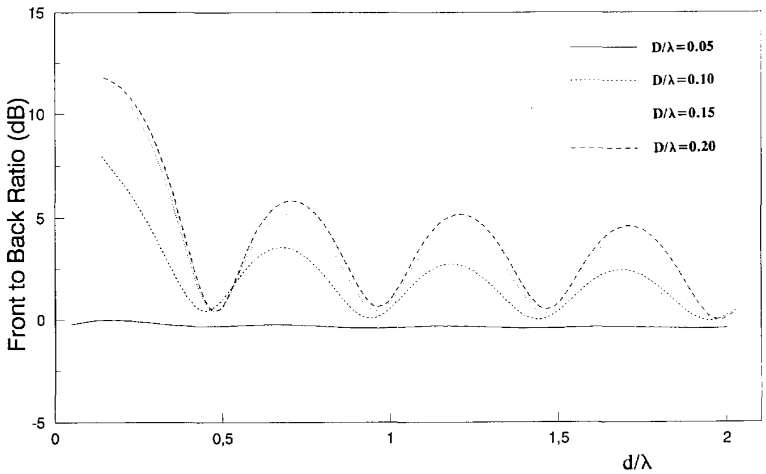


Fig. 10. Front-to-back ratio versus d/λ, with mast diameter D/λ as a parameter.

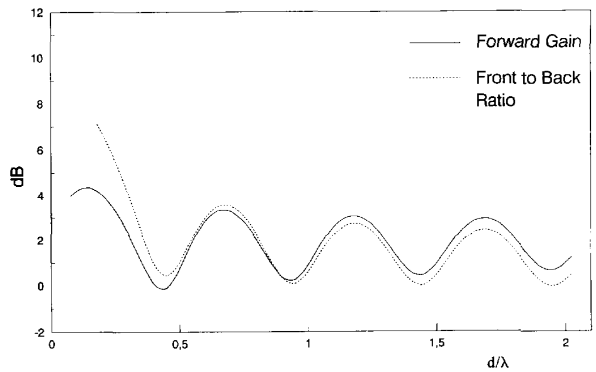


Fig. 11. Graph demonstrating the coincidence of forward-gain and front-to-back ratio peaks when plotted versus d/λ, for $D/\lambda = 0.1$.

again have the formation of another two further "additional maxima" in the pattern (and hence the decrease in forward gain), while at the fourth peak (Point No. 7 in Fig. 4), these six "additional maxima" are still there, but the level of radiation in the forward direction has once more increased to the point that the gain in this direction is close to that in the directions of the additional maxima (albeit lower than that for Fig. 5, as is clear from the curve in Fig. 4). The general behavior is thus clear:

1. At the nth dip in a forward gain versus d/λ curve, there are $2n$ additional pattern maxima, with a lobe in the forward direction whose gain level is up to 4 dB less than that in the direction of the additional maxima.
2. At the nth peak in a forward gain versus d/λ curve, there are $2(n-1)$ additional pattern maxima, with a lobe in the forward direction whose gain level is just slightly less than that in the direction of the additional maxima.

The angular locations of the above-mentioned additional pattern maxima versus d/λ are shown[3] in Fig. 9 for different mast diameters D/λ. Therefore, the curves in Fig. 3, those in Fig. 9, and the observed "rules" listed in 1) and 2) above provide complete information on the pattern behaviour of the mast-mounted dipole antenna in a suitably compact form for the range of mast diameters considered. As additional information, the computed front-to-back ratio versus d/λ is shown in Fig. 10 for the range of D/λ values. It has also been established that the peaks and dips in forward gain and front-to-back ratio occur at the same value of d/λ, as illustrated in Fig. 11. Although the latter fact may have been suspected, it is not obviously so in the light of the additional maxima formation.

Figs. 12 and 13 present input resistance and reactance data, respectively. Observe that as d/λ is increased, the values assumed by these quantities vary about those computed for the folded dipole without a mast. As mentioned in Section I, these can be used as indicators of the range of the change in the input impedance of the folded dipole when it is mounted on the mast, and can thus guide the matching network requirements. The general behavior of the impedance agrees with that obtained in [2], though, as was mentioned earlier, their results do not apply to masts with D/λ as large as that considered here.

[3]These curves should be considered approximate, since to construct them, the angular locations of the maxima were read off the radiation patterns that had been plotted, the individual points were then plotted anew, and the curves shown in Fig. 9 were fitted through these points.

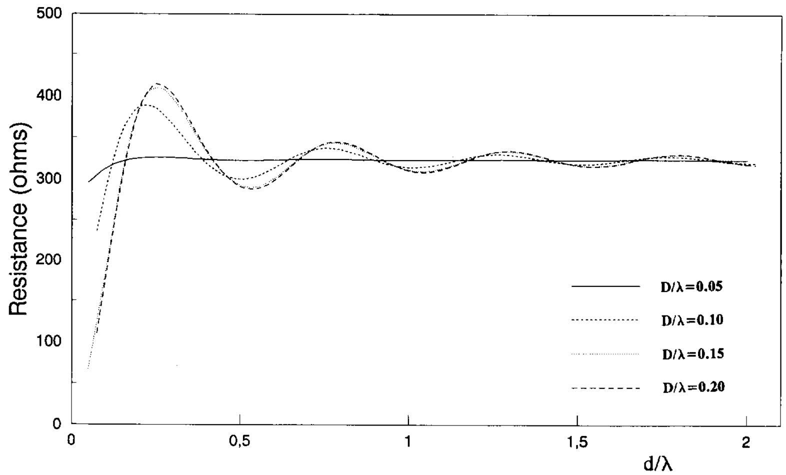


Fig. 12. Input resistance versus d/λ. with D/λ as a parameter.

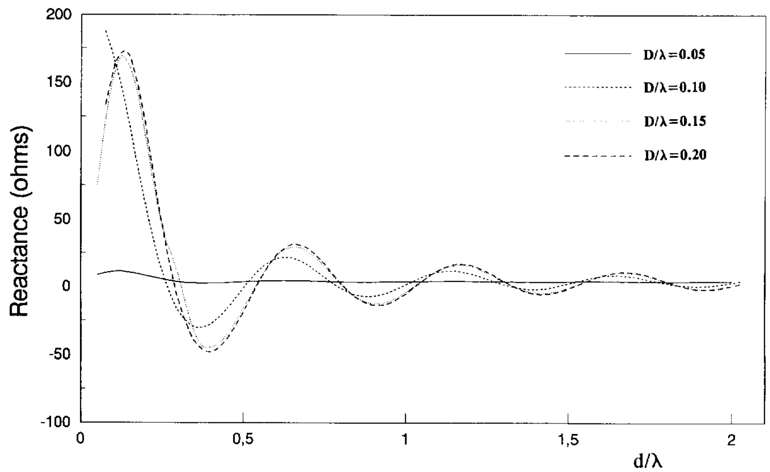


Fig. 13. Input reactance versus d/λ, with D/λ as a parameter.

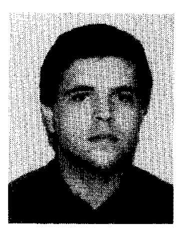
IV. Conclusions

The directivity, pattern and impedance-perturbation properties of individual folded dipole antennas mounted at various distances (d/λ) from the center of conducting masts of different diameters (D/λ) has been considered. It has been shown what computations need to be made (namely, those of the type given in Fig. 3 and Fig. 9) in order to determine the overall pattern behaviour. The latter have been demonstrated through examination of the results of a relatively comprehensive parametric study presented in a compact form.

References

[1] G. J. Burke and A. J. Poggio, "Numerical electromagnetics code (NEC)—method of moments," Lawrence Livermore Laboratory, USA, Rept. NOSC TD 116, Jan. 1981. (Available NTIS)

[2] H. A. Kalhor and A. R. Mallahzadeh, "Analysis of a folded dipole antenna mounted on a cylindrical metallic mast," *IEEE Trans. Antennas Propagat.*, vol. AP-34, pp. 99–103, Jan. 1986.



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