Selecting Wire Radius for Grid/Mesh Models

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Abstract

Conducting bodies such as antennas and scatterers can be modelled by thin wire segments. However, a generally accepted and consistent criteria for selecting optimum radius for the wire segments in the model has yet to be specified. This paper presents some results from modelling microstrip patch antennas with thin wires and the effects of wire radius on the resonance characteristics of the antenna.

1 Introduction

Solutions to complex electromagnetic problems can be more easily obtained through the use of computer software based on numerical methods. Some programs require processing power available to a simple microprocessor while other more sophisticated programs require high performance host computers with vector processors such as the CRAY X-MP. Such power may be employed to accurately predict the EM properties of conducting bodies or to verify results obtained in the laboratory. Fortunately, most EM field problems can be expressed in Greens functions or as magnetic and electric field integral equations. These equations can then be applied to models of a conducting body and a numerical solution evaluated commonly by the method of moments. With certain limitations, especially for a closed body, results so obtained have previously been shown by other authors to reasonably approach measurements.

Computer packages for modelling conducting bodies with thin wires are now commonly available but there is as yet no consistent criteria for selecting an optimum wire radius for all such models. The intention of this paper is to show the effects of varying the radius of wire in microstrip patch antenna (MPA) models without necessarily comparing the accuracy of computed results to measurements. Richmond's program,[2] based on the reaction concept,[3] is simple, readily available code which has been successfully applied by several authors to dipole antenna and scatterer problems. Although more exact programs for modelling conducting bodies may be as readily available, the aforementioned qualities fulfil the basic requirements for this investigation.

2 Microstrip Patch Antenna Model

A single element microstrip patch antenna (fig.1) has a shaped conducting patch printed on a grounded dielectric substrate. The patch is commonly fed either by a coaxial cable whose inner conductor protrudes through the groundplane and substrate or by a microstripline feed at the edge. Because of the discontinuities at the edges of the patch, radiation is mostly in the broadside direction (perpendicular to the surface of the patch) into the ambient medium, commonly free space.

The constraint of homogeneity is adhered to so that we can use Richmond's code with minimal change. Thus, any patch antenna we model is assumed to radiate into the same medium as its substrate. Furthermore, we assume that the MPA has a large groundplane and thus apply image theory. The resultant true and image patches can then be approximated by an array of equi-radii circular cylindrical thin wire segments forming a grid pattern.

For a specified wire grid structure, a set of overlapping subsectional piecewise sinusoidal (PWS) basis functions is defined on the surface of the wires segments as are normalised PWS dipole test functions along their axis. Given an excitation voltage V_1, complex current samples can be obtained by solving the reaction integral equation[1] which reduces to the matrix equation

$$\begin{pmatrix} Z_{11} & Z_{12} & \cdots & Z_{1N} \\ Z_{21} & Z_{22} & \cdots & Z_{2N} \\ & \vdots & & \\ Z_{N1} & Z_{N2} & \cdots & Z_{NN} \end{pmatrix} \begin{pmatrix} I_1 \\ I_2 \\ \vdots \\ I_N \end{pmatrix} = \begin{pmatrix} V_1 \\ 0 \\ \vdots \\ 0 \end{pmatrix}$$

where, in the circular cylindrical coordinate system $(\hat{n}, \hat{\phi}, \hat{l})$ with $\hat{l}$ along the wire axis,

$$Z_{tn} = \int_n F_n(l) \left\{ \frac{1}{2\pi} \int_0^{2\pi} (-\hat{l}.\vec{E}_t + Z_s \hat{\phi}.\vec{H}_t) d\phi \right\} dl$$

is the mutual impedance between test dipole t and expansion mode n. Also, $F_n(l)$ is a normalised PWS expansion function extending over the two adjacent wire segments of mode n, and Z_s is the surface impedance for exterior excitation.

Thus the equivalent current distribution on the wire structure can be deduced and its electromagnetic properties evaluated. This expansion current is considered to represent an approximation to the sum total of the inner (or groundplane facing) and outer surfaces of the true patch.

The *coax* model in figure 2 allows precise positioning of the feed point. This is achieved by adjusting the "nearest" (excluding the perimeter) set of collinear wire segments such that they intersect to form a node at the feed position. Only the segments which are directly connected to this node may have lengths which differ from the other segments along the same axis. The grid structure is appropriate because it implies that no presumptions have been made about the direction of current flow on the patch. Its regularity also allows the co-ordinates and unique number of each node to be easily and consistently computed for different size patches and location of feed points. These form part of the input data to Richmond's program.

3 Results

The characteristics of the coaxially fed rectangular patch antennas modelled here have, with one exception, been investigated by other authors. In all cases the patch elements are divided into 8x8 wire grids. Thus elements along orthogonal axes can only have the same lengths when the patch is square in shape. The fixed grid size acts as a constant parameter in the investigation and is also a compromise between better accuracy with a denser mesh and longer computation time. In line with Richmond's constraints, this division of each patch ensures that the wire radius is electrically small, the shortest segment is more than a wire diameter, and the longest is fractions of a wavelength.

Enhancements to the original source code allow iteration of frequency in order to show the variation of impedance with frequency and also to search for resonance for a range of wire radii. A commonly used first approximation to the resonance frequency, based on its dimensions and substrate permittivity, significantly speeds up the search.

Figure 4 shows, on both a Smith Chart and a linear plot,[4] the variation of resistance and reactance with frequency for a model of an edge-fed patch antenna at a fixed wire radius. The classic characteristic of resonance is clearly evident in the latter. Measured values[5] are marked on the Smith chart for comparison.

Figure 5 shows the computed resonance frequency and resonance resistance for the model of an almost identical square patch antenna[6] at various wire radii. The loss tangent in the model is $D = 0.0004$ (typical for a PTFE substrate) but it is not a critical value. The two extra sets of plotted curves are for the same patch element fed by two similar models of a microstripline (fig.3). We note here that the resistance curves for all three models have a similar slope although the frequency curve for the *coax* model is appreciably below that of the stripline models.

Figure 6 shows a different representation of the previous plot. The base or normalisation values for the percentages are taken at the wire radius at which the surface area of the metal on the actual patch antenna is equal to that of the wires in its model. If computations are not possible at this radius the largest permissible radius is used. This applies to our experimental patch antenna reported in Fig.7. Normalisation of results obtained for another MPA model (from Reference [5]) is shown in Fig.8.

4 Discussion

As an initial consideration, it is reasonable to suggest that the surface area of wire segments in the model should be related in some way to the area of the true patch. Such a hypothesis is supported by previous investigators of this particular problem who, almost without exception, have consistently recommended criteria based on these surface areas. The selection below suggests that the surface area of the wires in the model should be :-

- $\geq$ surface area of modelled surface { Moore & Pizer }[7]
- $\approx 2 \times$ surface area of continuous surface { Lee, *et al* }[8]
- (parallel to one polarization) = S.A. of modelled surface { Burke & Poggio }[9]

- = 2 × S.A. of *one* side of closed surface

  or

  = 2 × S.A. of *both* sides of open surface { Elliot & McBride }[10]

The respective authors and others have demonstrated that the recommended ratio may vary by up to a factor of 5 depending on the structure being modelled. In addition, Richmond recommends that a coaxially fed conducting body should be modelled by wires of equal radius to the coaxial probe.

In figure 4 the characteristics of resonance is conspicuous on the linear plot. On the Smith chart the impedance characteristics for the measured antenna and for its model are very similar in trend. There is a slight difference in frequency range and input impedance but this is mostly explained by the non free space higher permittivity substrate medium into which the model radiates. As a consequence, the model generally understates frequency and overestimates resistance. The slight displacement in frequency between peak resistance and the zero crossing of the reactance curve is caused by the rounding errors inherent in numerical computations and exacerbated particularly by the iterative process of matrix solving. This effect is more visibly on plots for smaller antennas.

In Fig.5 the depression of the frequency curve for the *coax* model is related to the direct interaction between vertical probe and radiating edge currents. For the stripline feed models this vertical component is only present at the stripline edge where there is much less current and is sufficiently remote from the patch edge. The stripline and the patch are of course coplanar and their interaction is mostly complementary and horizontal. The seemingly erratic albeit inconsequential behaviour of the reactance curve is due to two factors. In the first instance, resonance is considered to be at peak resistance and we earlier noted a displacement with reactance. Secondly, computations are performed at a minimum of 1MHz intervals and hence peak resistance is accurate within such a limit. The reactance curves are included in the plot simply for completeness.

From Figures 5 and 6 it is evident that the relative effects of varying wire radius are the same for different models of the same patch antenna. In each case, both input impedance and resonance frequency vary to some extent with the radius of wire of the model. We observe from the plots that the relative variation in resonance frequency against wire radius is negligible, whilst two apparently shape dependent trends are identified for the variations in resonance resistance :-

(i) upto 140% decrease in resistance against 200% increase in wire radius when patch resonance length is equal or greater than width (figs.6,7).

(ii) a very small variation of resistance against relative increase in wire radius for patches with length less than width (fig.8).

The factor common to both trends is the apparent convergence of the curves characterised by a decrease in gradient at larger wire radii. Computations were performed up to the maximum possible wire radius for each model but one may speculate that convergence may well continue beyond limits allowed by the program. The validity of results so obtained will require theoretical justification. The observations thus far suggest that a better approximation to measurements of resonance characteristics can be obtained with larger wire radius. We have not been able to establish any consistent correlation between surface area and the extent of convergence.

In conclusion the relative effects of varying wire radius is practically independent of the model chosen. The variation of frequency is negligible and need not be considered any further except for how it relates to measured values. Computations with the largest permitted wire radius for each model yield results which are within 10% of measurements of MPAs with low permittivity substrates. Most of this difference is attributable to homogeneity in the model. Inevitably, this wire radius may agree with one obtained from applying criteria recommended by previous researchers who may not have investigated microstrip patch antennas. We are unable to state incontrovertibly that there is an optimum ratio of surface area of a measured antenna to its model. Neither are can we affirm that the probe radius is necessarily ideal for the wires in the model. There is, however, sufficient evidence for one to infer that a radius twice that for surface area parity gives results well into the region of highest convergence. This may be considered as our recommendation for MPA models within the limitations imposed by the underlying assumptions in the thin wire approximation method.

We have carried out this investigation within the framework laid down by Richmond but it may be necessary to exceed this in order to find better convergence which may further justify our recommendation. We are aware of some problems with the original code but we anticipate that any adverse effects are nullified by our consistency in forming the wire grid models. In general MPAs radiate into a medium of different characteristics to its substrate but reasonable accuracy is still achievable even without compensating for homogeneity in the model. The assumption of an infinite substrate is also significant but this may be eliminated if the substrate can be modelled by volume equivalent elements. Further computations will need to be performed to establish a more precise or definitive relationship between wire radius and resonance behaviour.

5 Acknowledgements

Computations on the wire grid antennas were performed on an Amdahl 470/V8 mainframe computer based at the University of London Computer Centre. Postprocessing of the results was done on a VAX 8700 Cluster using UNIRAS package for the plots and this document is produced using LaTeX.

References

[1] J.H. Richmond, "Radiation and scattering by thin-wire structures in the complex frequency domain," NASA Contractor Report CR-2396, May 1974.

[2] ----------, "Computer program for thin-wire structures in a homogeneous conducting medium," NASA Contractor Report CR-2399, June 1974.

[3] V.H. Rumsey, "Reaction concept in Electromagnetic theory," Physical Review, Vol. 94, pp. 1483-1491, June 15, 1954.

[4] A. Oyekanmi and J. Watkins, "Modelling microstrip patch antennas with thin wires", IEE Colloquium, Digest No. 1989/121, pp 4/1-4/4, Oct. 89.

[5] M.D. Deshpande and M.C. Bailey, "Input impedance of microstrip antennas," IEEE Trans. Antennas and Propagation, Vol. AP-30, No.4, pp. 645-650 July 1982.

[6] P.K. Agrawal and M.C. Bailey, "An analytic technique for microstrip antennas," IEEE Trans. Antennas and Propagation, Vol. AP-25, No. 6, pp. 756-758, Nov. 1977.

[7] J. Moore and R. Pizer, "Method of Moments in Electromagnetics," Research Studies Press, 1984.

[8] K.H.S. Lee, L. Marin, and J.P. Castillo, "Limitations of wire-grid modeling of a closed surface," IEEE Trans. Electromag. Compatibility, Vol. EMC-18, No.3, pp. 123-129, Aug. 1976.

[9] G.J. Burke and A.J. Poggio, "Numerical electromagnetic code (NEC) - Method of moments," Naval Ocean Syst. Center, San Diego, CA, NOSC Tech. Document 116, Jan. 1981.

[10] P.G. Elliot and S.T. McBride, "Wire grid moment method (NEC) models of a patch antenna," Applied Computational Electromagnetics Soc. Journal, Special Issue 1989.

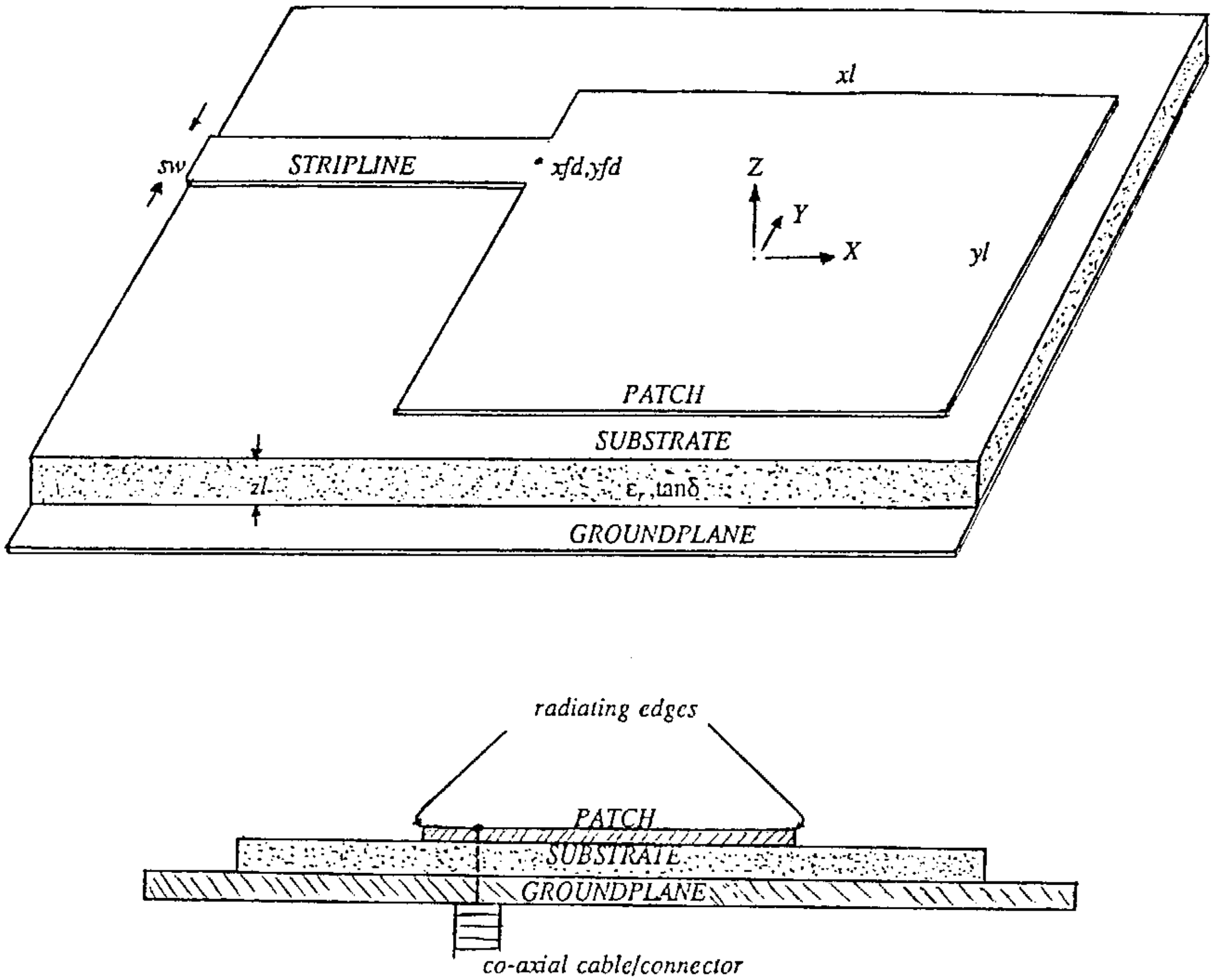


Figure 1: Stripline- and Coax-fed Rectangular Microstrip Patch Antenna

Figure 2: Model of Coaxially-fed Antenna

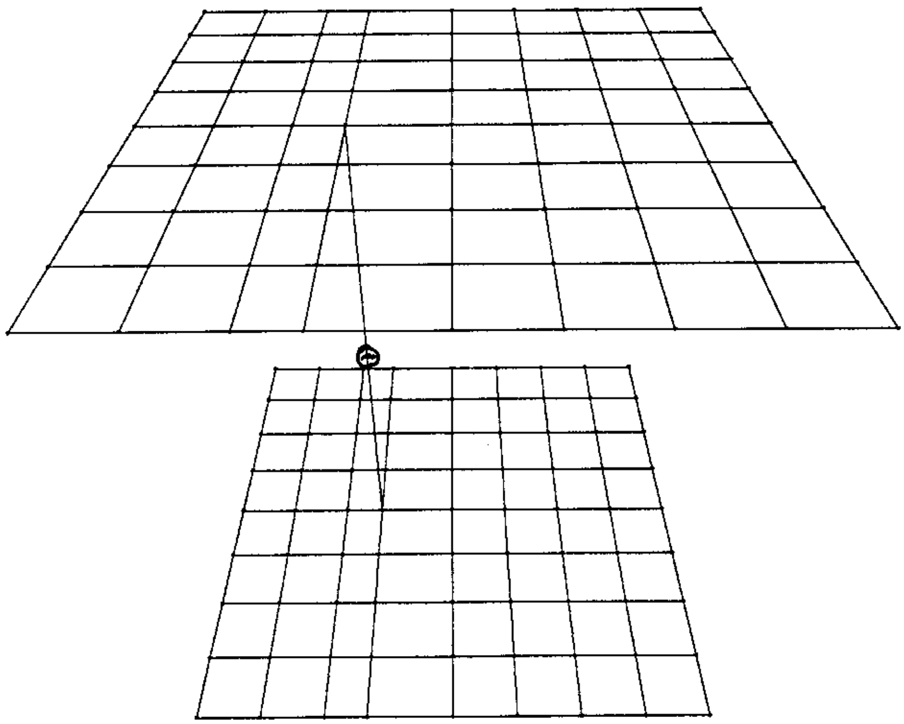
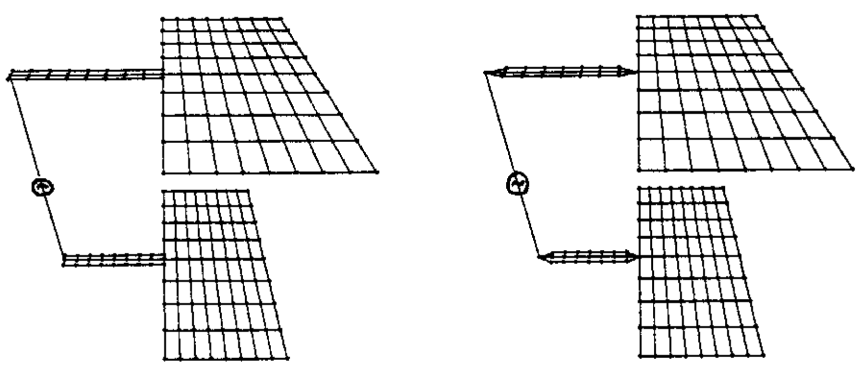


Figure 3: *Hex & Rect* Models of a stripline-fed antenna



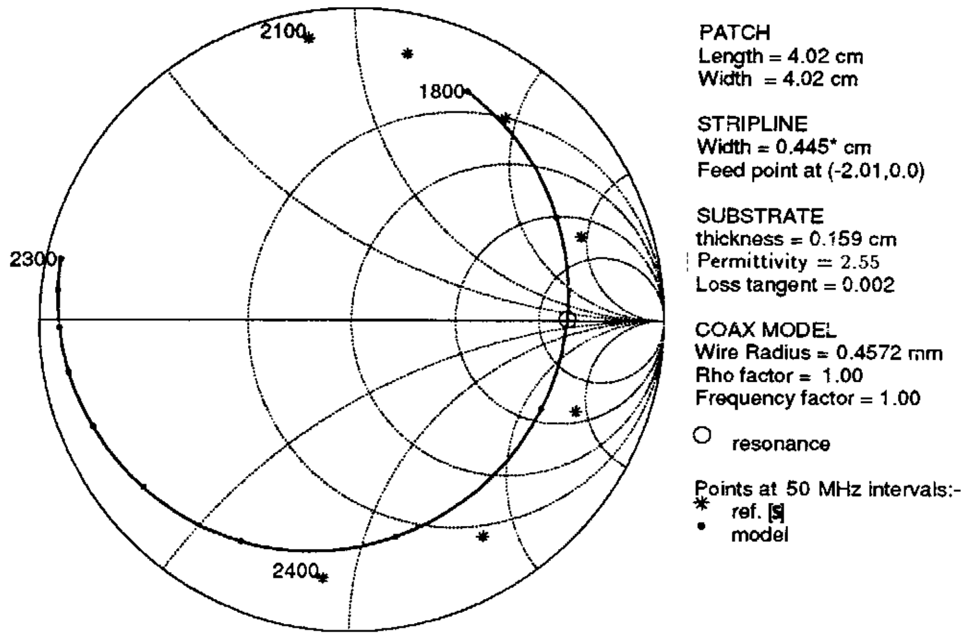


Figure 4: MPA with Edge-Center Feed at Resonance

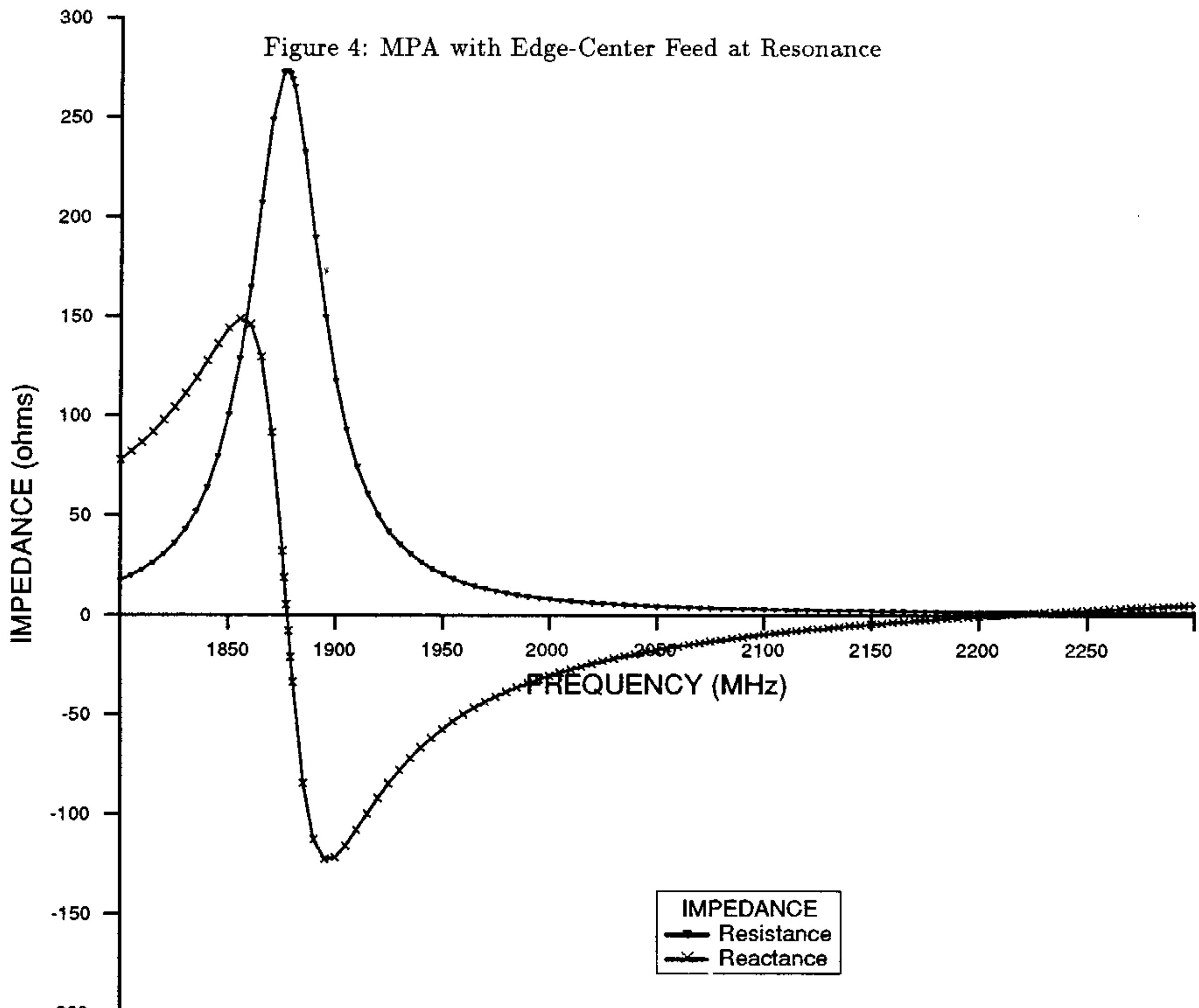


Figure 5: Resonance Characteristics of an MPA

with Edge-Center Feed

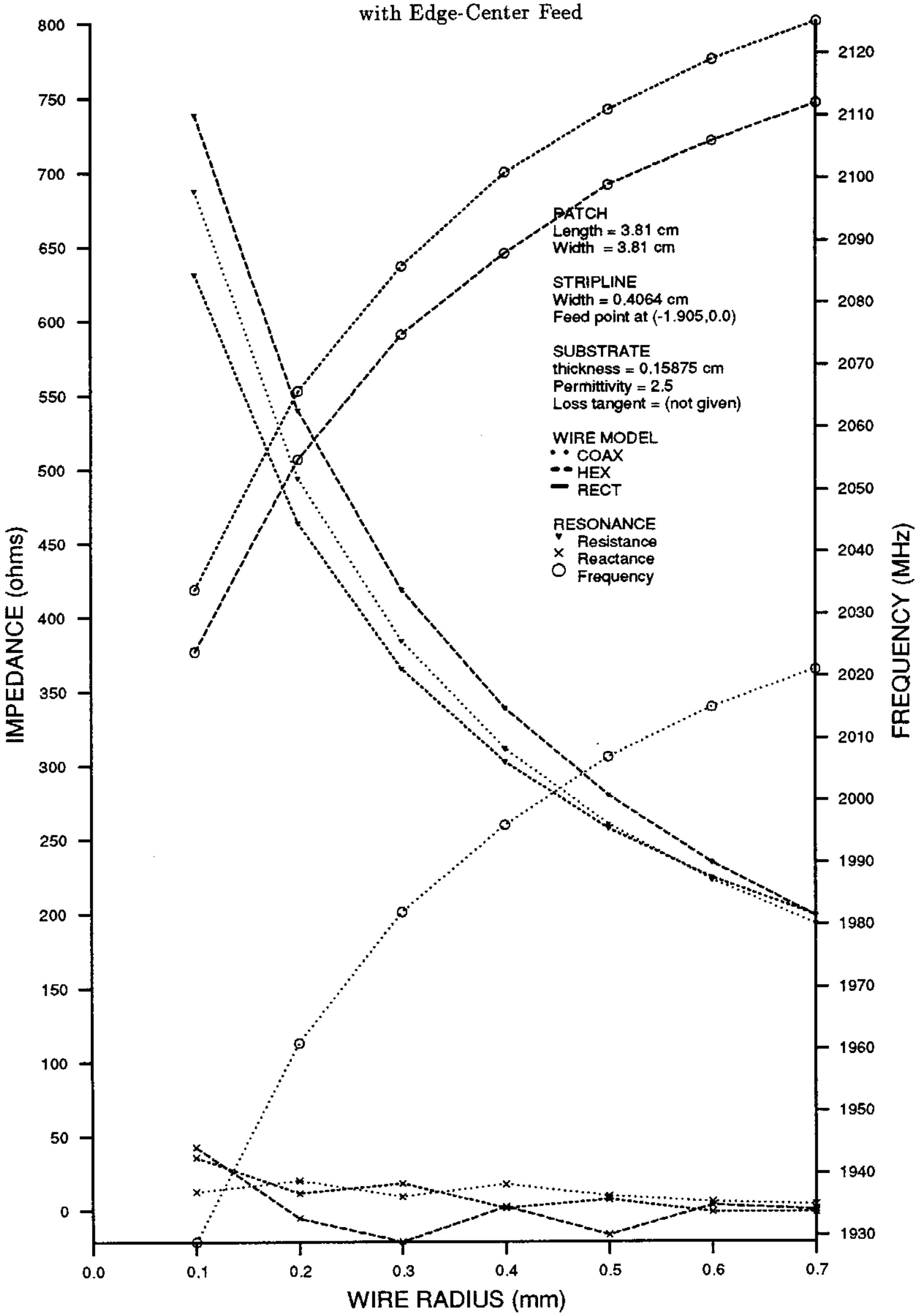


Figure 6: Normalised Resonance Characteristics of MPA with Edge-Center Feed

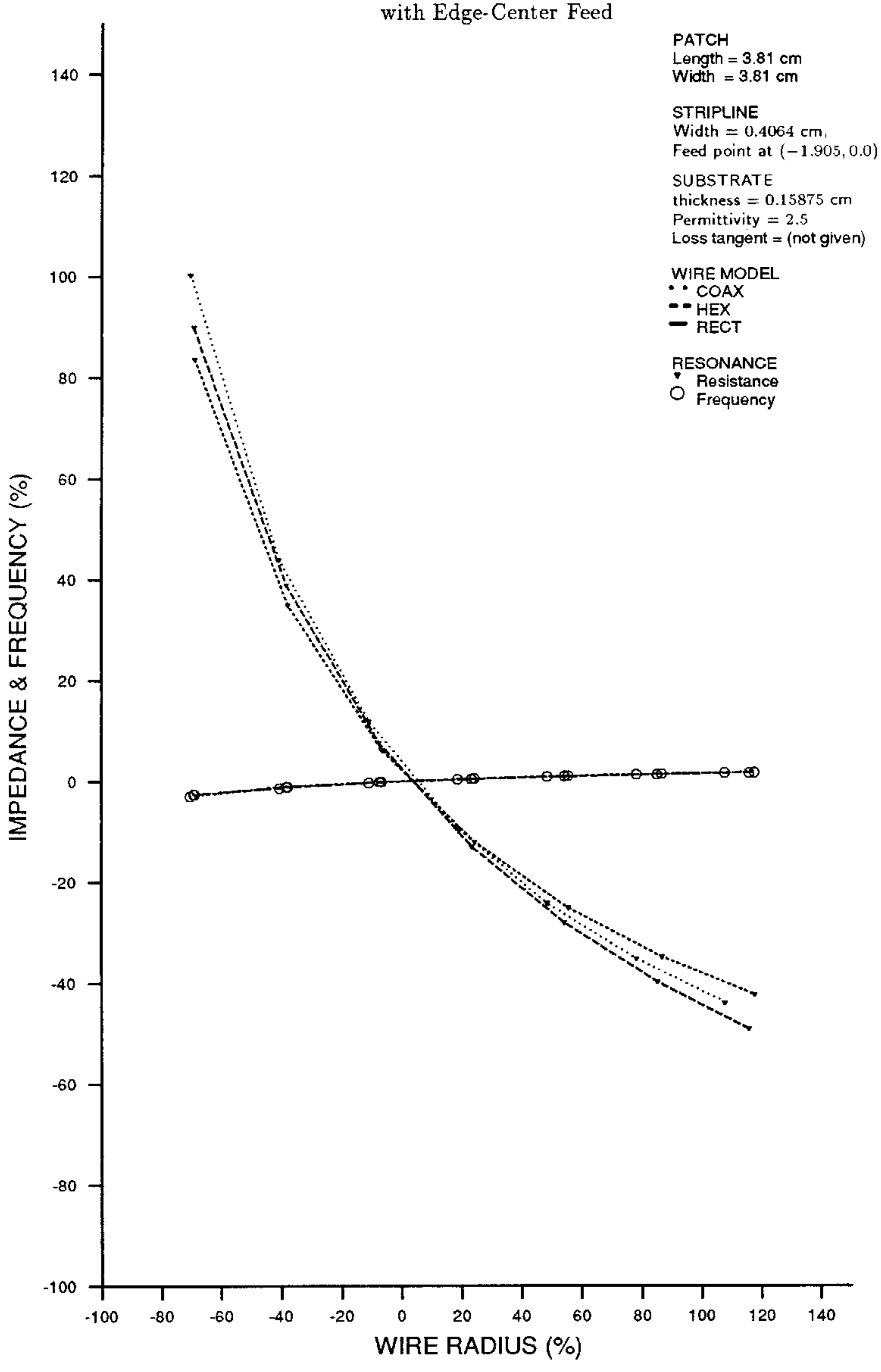


Figure 7: Normalised Resonance Characteristics of an MPA

with Inset-Center Feed

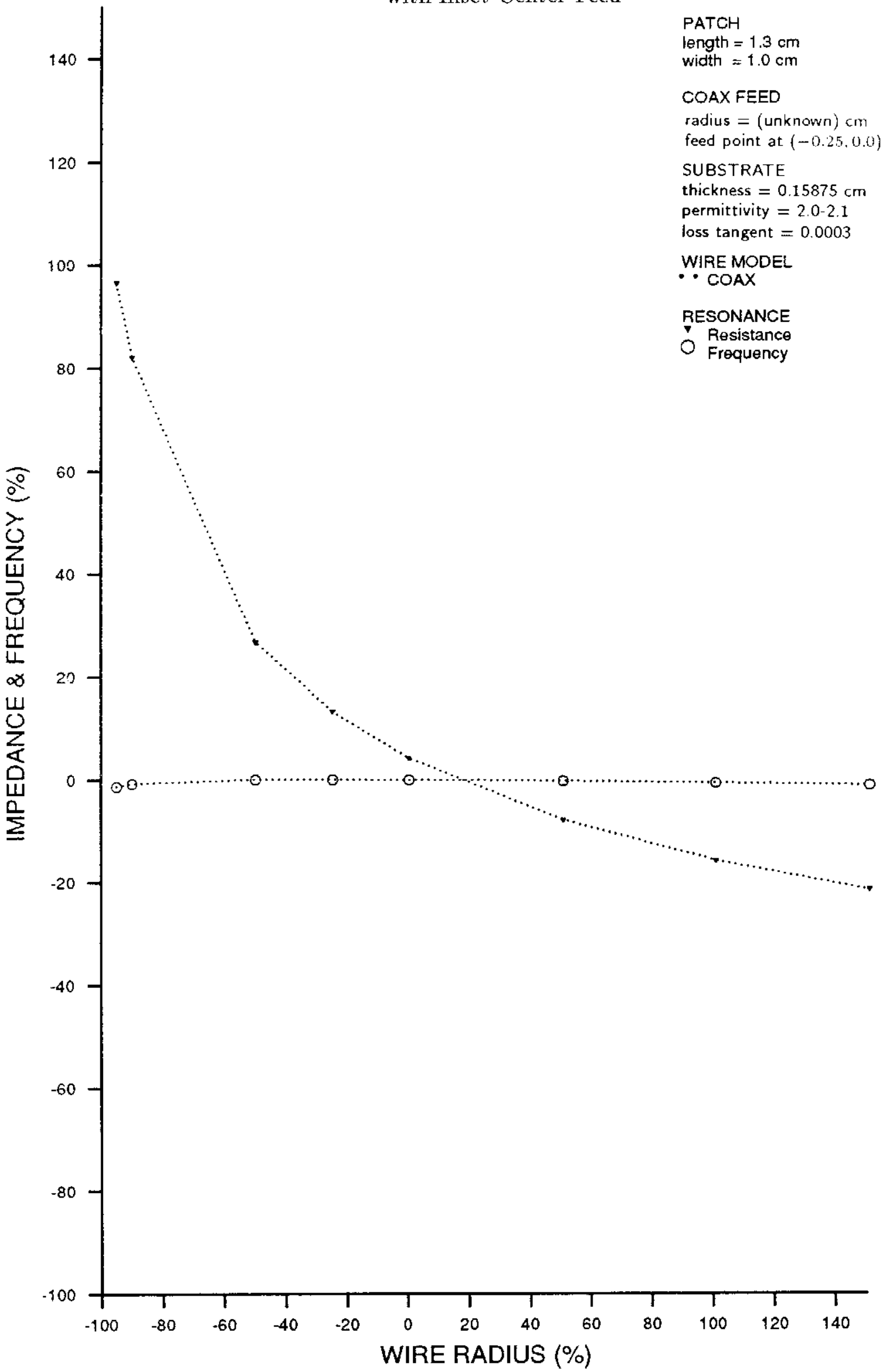


Figure 8: Normalised Resonance Characteristics of an MPA

with Inset-Off-Center feed