RADIATION FROM A MULTIFILAR HELIX FED BY A CIRCULAR WAVEGUIDE

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1. Introduction

In the usual application of the helical antenna as a circular polarisation end-fire radiator, the helix is fed by a coaxial cable against a finite ground plane: provided that the ground plane dimensions are adequate, this particular form of excitation prevents the launching of the complex mode known in the literature as the scanning mode, which is responsible for a back-fire radiation [1].

The multifilar helix can also operate in the axial mode with the advantage over the monofilar helix of an improved pattern circular symmetry; in this case the previous form of excitation is no longer adequate. Vaughan and Andersen [2] use the aperture of a circular waveguide carrying a circularly polarised TE_{11} wave to feed the multifilar helix, with the added advantage that the direct feed radiation has good polarisation purity in both on-axis and off-axis directions.

The waveguide parameters and the helix parameters determine the relative importance of the axial mode, the scanning mode and direct feed radiation in the total pattern. With this feed, the scanning mode of the multifilar helix can be strongly excited and may even dominate the radiated field instead of the axial mode. As an example, experimental patterns corresponding to a particular arrangement of the basic structure, are presented in *fig. 1*.

The theoretical study of the complex wave radiation of a finite length multifilar helix fed by a dielectric loaded circular waveguide of arbitrary dimensions is rather difficult. We restrict the analysis to the case where no dielectric loading is present. and both the helix and the waveguide have the same diameter. To allow the waveguide operation in the TE_{11} mode alone, this further restricts $k_o a$ to the range [1.841, 2.405], which is clearly outside the range for the usual axial mode operation.

An approximate analysis, which is outlined in the next section, is used to obtain the radiated fields. A detailed discussion of the procedure and the approximations involved is made elsewhere [3]. Comparison with experimental data shows that this procedure is good enough to estimate and interpret the radiation pattern of a finite length multifilar helix fed by a circular waveguide aperture of the same diameter.

2. Theoretical analysis

The sheath helix model is used to describe the multifilar helix; it is an idealised anisotropic cylindrical surface which conducts only in the helical direction. The waveguide aperture is replaced by a plane circular sheet of equivalent currents with the same radial and circunferential variation as the circularly polarised TE_{11} mode.

In a first step the sheath helix is assumed to be infinite, and centrally fed by the circular sheet of equivalent currents. The corresponding inhomogeneous vector wave equation is solved and the solution is obtained using the Fourier Transform (FT) technique. A standard change of variables is performed, which maps the two-sheeted complex plane of the inverse FT integration variable k, into a complex angular plane ϕ which removes the known square root branch cut. Further the original integration path is deformed to the steepest descent path of the dominating exponential factor of the integrand. The solution is thus expressed as a sum of a continuous spectrum term, corresponding to an integral along the steepest descent path, and the residue terms corresponding to the poles captured by the contour deformation. In the source region, both the integral term (space-wave) and the discrete modes may have a significant contribution to the near-field. Despite the fact that the steepest descent considerations are based on the assymptotic behaviour of the integrand, this contour is still a good choice for the numerical evaluation of the space wave integral, near the structure [3].

Using the Franz formulation of the Kirchhoff-Huygens theory, this near-field is integrated over a finite length surface of the infinite sheath helix, and over the open end of the truncated structure. In the open-end integration only, the space-wave contribution is neglected.

3. Numerical and experimental results

In *fig.*2, the poles which may have a significant contribution to the near field are represented as a function of the sheath helix pitch angle ψ, for $k_o a = 2.17$. For each observation angle θ, the poles to be considered lie between the $SD(\theta)$ path and the original S path. For $z > 0$ $(0 < \theta < \pi/2)$ an improper complex pole (scanning mode) and a real pole (axial mode) can be captured. For almost all ψ, the attenuation constant of the complex pole is small; this corresponds to a wave that contributes for several wavelengths along the sheath helix surface, thus originating in the far-region a narrow side-fire beam at an angle θ_0 close to the pole capture angle θ_c . The migration of the axial mode pole in the ϕ plane is strongly dependent on ψ. For large ψ, the axial mode is loosely bound to the structure, so it will easily relegate its energy to the free space at the open end of a truncated sheath helix; conversely for small ψ, strong reflection is expected at the open-end.

In the negative region of the infinite structure $(\pi/2 < \theta < \pi)$ also a real and a complex mode exist: in the limit when $\psi \rightarrow 0^0$ or $\psi \rightarrow 90^0$,these modes become the "mirror-symmetric" pairs of the axial and scanning modes. In a truncated sheath helix, the energy reflection at the open end will also excite these "mirror" modes in the $z > 0$ region, together with a continuous spectrum wave. This second order problem is left out of consideration in the present work.

The total radiation pattern will display the individual characteristics stated before, weighted by each mode excitation amplitude. In fig. 3 the normalized current amplitude of the axial and the scanning modes, (calculated at the respective pole capture distance $z_c = a\cot(\theta_c)$) is represented against ψ. Except for small ψ, the axial mode has lower excitation amplitude then the scanning mode, showing a deep minimum near $\psi = 18^\circ$. This corresponds to the point in *fig.*2 where the scanning mode root locus approaches the real axis and becomes a guided wave, with exactly the same radial and longitudinal wavenumbers of the TE_{11} waveguide mode [3]. In this case , all the energy incident from the waveguide is transferred to the scanning mode alone.

*Fig.*4 shows plotted against z a typical plot of the amplitude of the electric-field tangent to the sheath helix surface, for $\psi = 45^\circ$. In the neighborhood of the source only the space wave contributes to the total field; it "fills in" the discontinuity of the discrete mode fields at their capture distances, so that the total field has a smooth behaviour along z. In the region where both poles contribute, the amplitude of the space wave is small compared to the discrete modes amplitudes, and it decays very slowly with z. In *fig. 5a* the calculated radiation pattern for the example in *fig. 4* is presented. As expected there is a radiation peak near $\theta = 49.5^\circ$ due to the scanning mode; there is also an end-fire radiation which is partly due to the loosely bound axial mode, and partly to the space wave. Comparing the total pattern in *fig. 5a* with the pattern of the discrete modes contribution alone, the influence of the space wave is seen in all directions, but an important contribution is for low θ_0.

The multifilar helices used in the measurements are constructed winding close $0.14mm$ wires arround low permitivity cylindrical foam cores. An axial mode monofilar helix is used as a simple way to excite the circular polarized TE_{11} mode in the waveguide (refer to *fig. 1*); good axial ratio is obtained but the bandwidth is drastically reduced to a few percent of the isolated helix bandwidth. The radiation patterns are measured $2.5m$ away from the waveguide end. In *fig. 5b* the experimental pattern corresponding to the exemple in *fig.4* and *fig. 5a* is compared to the calculated pattern; each pattern is normalized to the respective maximum. The agreement is satisfactory, although some discrepancies are observed. In the theoretical model the source is taken to be the unperturbed TE_{11} mode of the circular waveguide, the reflected and the evanescent modes inside the waveguide being neglected;this affects the excitation amplitude of the helix modes and of the continuous spectrum, and probably explains the $3.5dB$ difference between measured and calculated patterns, at the end-fire direction. It is expected that the discrepancy for large θ_0 comes from two reasons: a) the tangential magnetic field over the waveguide wall ($r = a_+$) is taken to be zero in the Kirchhoff-Huygens integration of the near-field; b) the energy reflection at the open-end is not taken into account in the theoretical model.

These comments also apply to the example of *fig. 6* where the axial mode is tightly bound to the structure, and some discrepancy is seen between calculated and measured patterns, for large θ_0. There is no significant end-fire radiation; it was verified numerically that in this case the space-wave cancels the small endfire contribution of the axial and the scanning modes. As expected from *fig.2* the radiation peak due to the scanning mode occurs at a higher θ_0 value.

It must be noted that apart from the antenna positioner blockage near back-fire, the influence of other factors like the waveguide wall thickness, the TE_{11} polarisation purity, the helix construction tolerance, the dielectric support and the wire thickness can not be easily identified in the experimental patterns.

No qualitative alterations to what was discussed are observed for other k_0a values in the range [1.841,2.405].

4. Conclusions

The radiation of a finite length multifilar helix fed by the circularly polarised TE_{11} mode of a circular waveguide of the same diameter is explained in terms of the discrete modes and the space wave existing in the source region of an infinite sheath helix excited by a circular sheet of equivalent currents. Typical measured radiation patterns are presented, which show satisfactory agreement with the computed patterns. Further examples for other values of k_0a and length L will be presented at the conference.

5. References

[1] - Nakano H., Yamauchi - "Backfire Radiation from a Monofilar Helix with a Small Ground Plane", IEEE Trans. AP vol. 36, N.10, OCT 1988

[2] - Vaughan R., Andersen J. - "Polarisation Properties of the Axial Mode Helix Antenna", IEEE Trans. AP Vol 33. N.1, JAN 1985

[3] - Fernandes C., Barbosa A. - "Complex Wave Radiation From a Dielectric Loaded Sheath Helix Excited by the Circular Waveguide TE_{11} Mode" , to appear

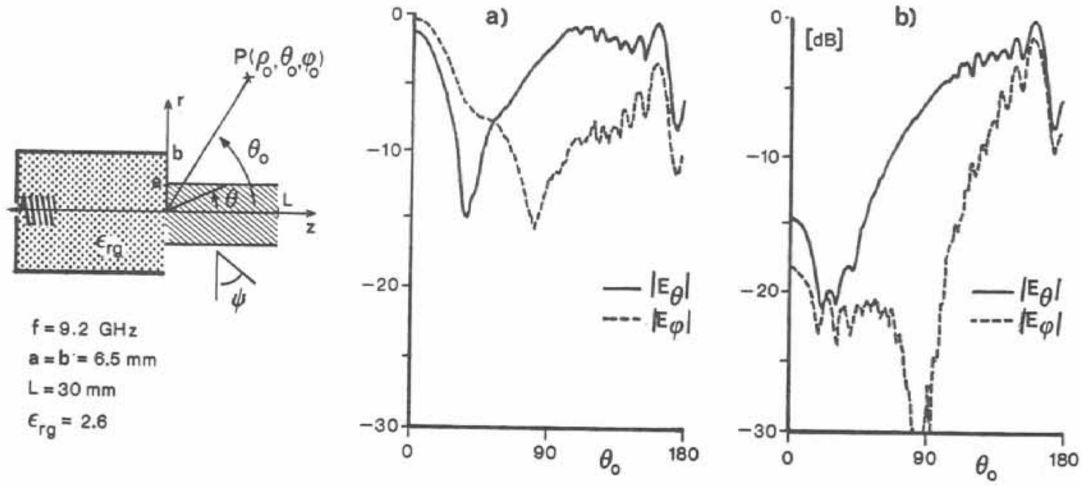

Fig.1 - Measured radiation patterns of n-filar helices fed by a dielectric loaded circular waveguide: a) $\psi = 10^0, n = 8$; b) $\psi = 3.1^0$, $n = 4$

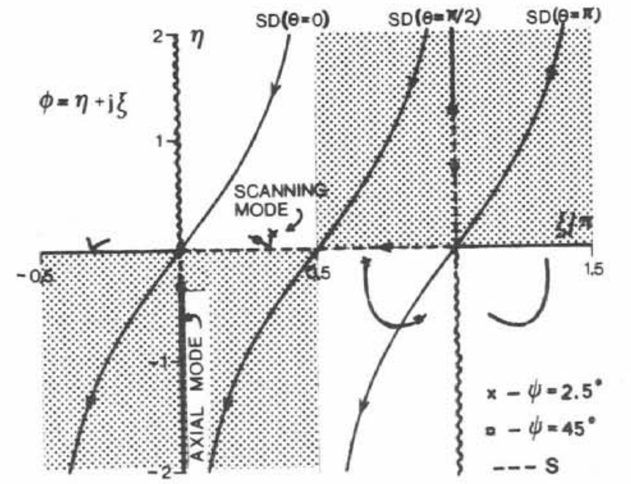

Fig. 2 - Roots of the modal equation in the ϕ plane, as a function of ψ; $k_0a = 2.17$

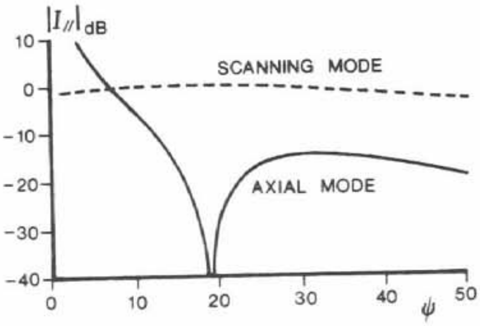

Fig. 3 - Calculated normalized current amplitude in the axial and scanning modes; $k_0a = 2.17$

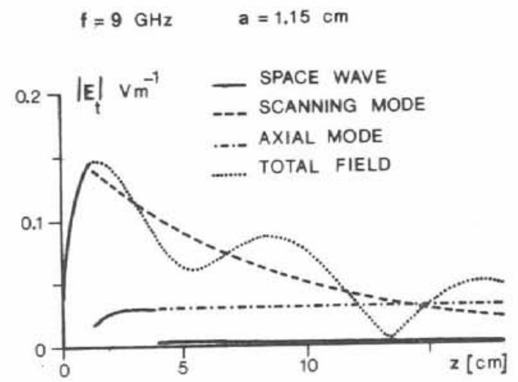

Fig. 4 - Calculated electric-field tangent to the sheath helix surface, $\psi = 45^0$

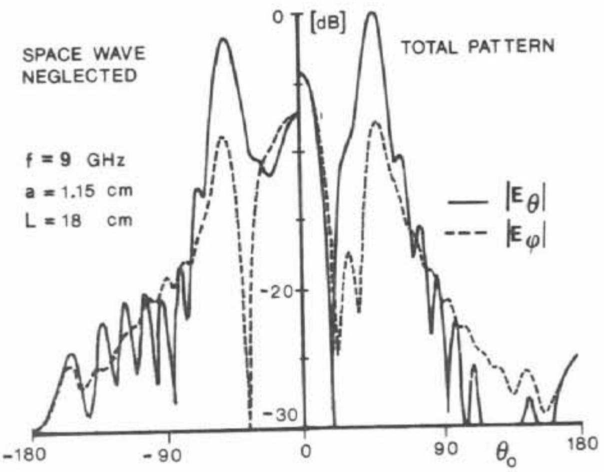

Fig. 5a - Computed radiation patterns. $\psi = 45^0$

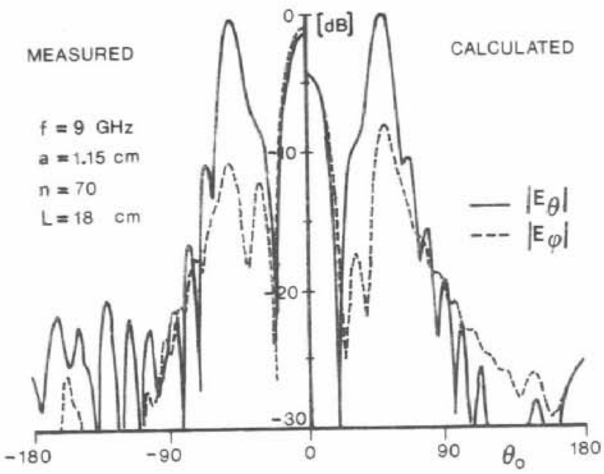

Fig. 5b - Measured and computed radiation patterns, $\psi = 45^0$

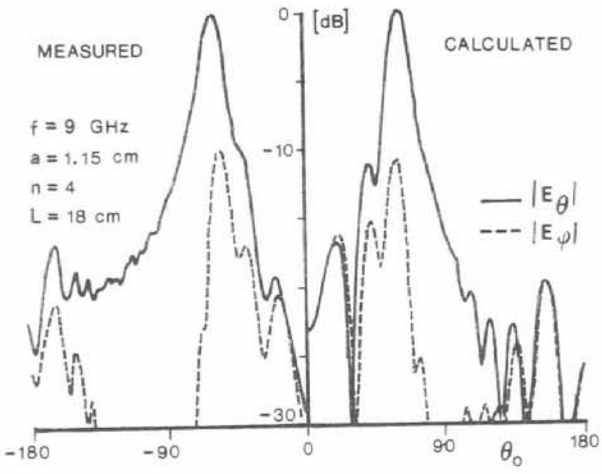

Fig. 6 - Measured and computed radiation patterns, $\psi = 2.5^0$