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MODELING OF COMPACT LOOP ANTENNAS

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ABSTRACT

A general compact loop antenna model which treats all elements of the antenna as lossy transmission lines has been developed. In addition to capacitively-tuned resonant double loop (RDL) antennas the model treats stub-tuned resonant double loop antennas. Calculations using the model have been compared with measurements on full-scale mockups of resonant double loop antennas for ATF and TFTR in order to refine the transmission line parameters. Results from the model are presented for RDL antenna designs for ATF, TFTR, Tore Supra, and for the Compact Ignition Tokamak (CIT).

INTRODUCTION

Compact loop antennas in a variety of configurations are being planned for ICRF heating on present and future fusion experiments, including the Compact Ignition Tokamak. Compact loop antennas, in particular the resonant double loop, are capable of operation over a wide frequency range at high rf power levels, can be moved relative to the plasma, and require no external impedance matching. In order to predict the performance of the antennas under a variety of operating conditions, over as large as a 3:1 frequency range, accurate models are required. The model described in this paper is able to predict the performance of antennas over the full frequency and load range of interest. The model is thus usable for determining the optimum position of the input coaxial feed and for determining the actual capacitance (or stub length) range needed for a specific application.

DESCRIPTION OF THE CIRCUIT

A schematic diagram of the circuit used in the model is shown in Fig. 1. The configuration shown is that of a resonant double loop with capacitor tuning,[1] the configuration for the ATF, TFTR, and Tore Supra designs. Rf power is fed to the antenna through an arrangement consisting of a gas break of arbitrary impedance, a fixed stub for cooling fluid input, and an impedance matched vacuum feed-through. Any of these components can be omitted from the calculation, if desired. The antenna current strap is tapped at some intermediate point along its length by means of a low-inductance connection, where α represents the fraction of total current strap length from one end of the strap. A dielectric disk at the end of the vacuum feed coax is included which serves the dual purpose of providing partial mechanical support for the current strap and of canceling most of the effect of the feed inductance. The current strap is connected to the tuning capacitors, designated C1 and C2 in Fig. 1, by short transmission line segments. Each variable capacitor also has an inductance, designated LC1 and LC2 in the figure, associated with it which is not negligible for the designs considered. The option of replacing the tuning capacitors with shorted stubs has been provided. Stub tuning looks attractive for CIT and for high frequency operation on Tore Supra. Except for the lead inductance and for the tuning capacitors, each element is treated as a lossy transmission line in the model.

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Circuit Model

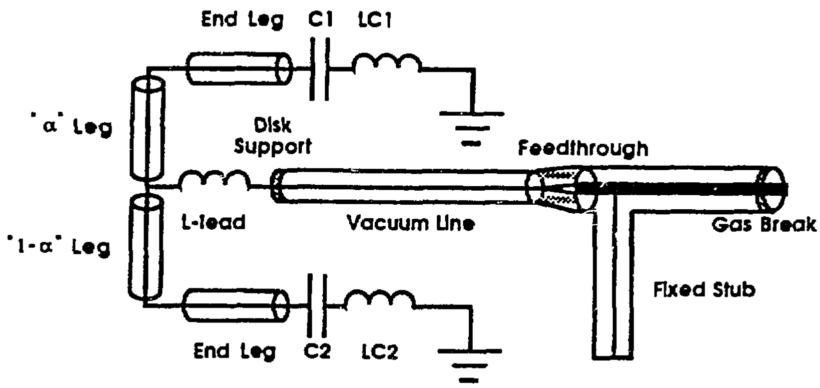

Fig. 1. Schematic diagram of the circuit used in the model.

The two capacitors tune the antenna to the desired frequency and adjust the input impedance to match the transmitter impedance. No additional matching components are required. The effect of the fixed stub can be eliminated over a 3:1 bandwidth by slight retuning of the capacitors.

The model requires the characteristic impedance and phase velocity for each transmission line segment. For the current strap this data can be obtained from 2-D calculations[2] which include the effect of the Faraday shield or from experimental measurements on a mockup.

The model can be used to calculate the voltage and current distribution along the current strap and tuning elements and the tuning positions required as a function of antenna load resistance. This information is required during the design of an antenna in order to determine the optimum tap position along the current strap for the frequency and load range of operation anticipated, and to determine the power handling capability of the antenna resulting from voltage and current limitations on the various components.

RESULTS

Resonant double loop antennas for fast wave heating have been designed for TFTR[3] at PPPL, for Tore Supra[3] at CEN-Cadarache, for ATF at ORNL, and conceptual designs have been studied for CIT. The antennas for TFTR and for Tore Supra have several similarities. Both have two current straps side by side with a common Faraday shield, both are designed to couple 2 MW per loop into the plasma, and both work in about the same frequency range (35 to 80 MHz for Tore Supra). The antenna for the ATF stellarator has a single loop and operates over a lower frequency range (10 to 30 MHz) than TFTR and Tore Supra. The CIT antenna has two current straps stacked end to end in a single port. The design frequency will depend on the final CIT parameters, but should be in the range of 70 to 120 MHz.

Current and voltage profiles for the Tore Supra antenna at 35 MHz and at 80 MHz are shown in Figs. 2 and 3, respectively. The plot extends from one capacitor terminal to the other. The dotted vertical line represents the position of the feed line, and the two solid vertical lines are drawn at the ends of the current strap. Both the cases plotted are near the minimum loading required to couple 2 MW into the plasma for the frequency under consideration, using capacitor limits of 1 k A rms current and 50 kV peak voltage. Note that the tap position, α, of 0.65 is nearly optimal for loads in this frequency range, resulting in fairly symmetric profiles. The voltage and current in the vacuum feed line and fixed stub are shown in Fig. 4 for the 80 MHz case. The fixed stub was chosen to be a quarter wavelength at 57 MHz, but the antenna can be matched to the transmitter impedance of 30 Ω over the entire frequency band.

For operation at 120 MHz on Tore Supra the capacitors can be replaced with shorted stubs. The voltage and current profiles on the antenna for this case are shown in Fig. 5, where the plot extends to the shorted end of the stubs. Even at 120 MHz the tap position of 0.65 results in a nearly symmetric waveform on the current strap. For this high frequency operation on Tore Supra the fixed stub must be reduced in length by half. Note that the antenna is nearly one half wavelength long.

For the CIT geometry shown in Fig. 6 capacitor tuning is still feasible up to frequencies greater than 100 MHz, but above 100 MHz stub tuning looks more attractive. An example of a capacitor tuned antenna at 100 MHz is shown in Fig. 7. For a loading of 10 Ω/m and a maximum capacitor voltage of 50 kV, 1.3 MW per loop can be achieved. Nevertheless, with higher loading or voltage limits, it would appear that 1.6 MW per loop is a realistic goal for CIT antennas operating near 100 MHz.

REFERENCES

1. T. L. Owens, F. W. Baity, D. J. Hoffman, Radiofrequency Plasma Heating (AIP Conference Proceedings No. 129, N.Y., 1985), p. 95.
2. G. L. Chen, P. M. Ryan, D. J. Hoffman, F. W. Baity, D. W. Swain, J. H. Whealton, "Resonant Loop Antenna Design with a 2-D Electromagnetic Steady State Analysis," this conference.
3. D. J. Hoffman, F. W. Baity, W. E. Bryan, G. L. Chen, K. H. Luk, T. L. Owens, J. M. Ray, P. M. Ryan, D. W. Swain, J. C. Walls,"The Design of High Power ICRF Antennas for TFTR and Tore Supra," this conference.

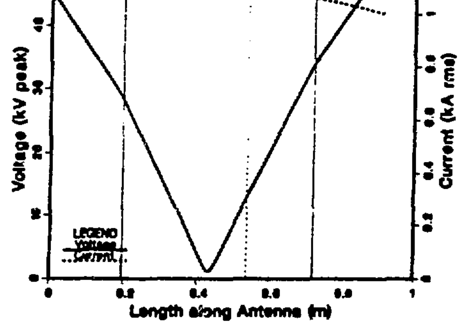

Fig. 2. Current and voltage profiles for the Tore Supra antenna at 35 MHz.

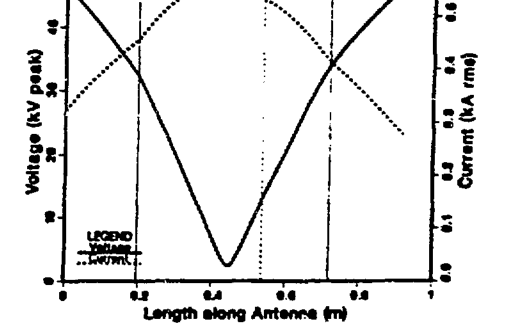

Fig. 3. Current and voltage profiles for the Tore Supra antenna at 80 MHz.

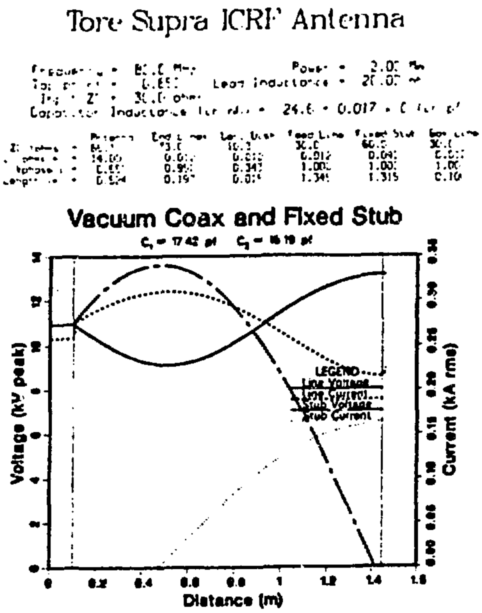

Fig. 4. Current and voltage profiles in the vacuum coax and fixed stub for the Tore Supra antenna at 80 MHz.

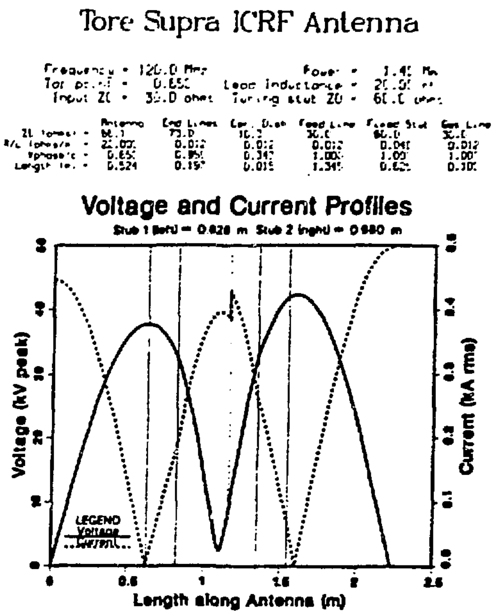

Fig. 5. Current and voltage profiles for the Tore Supra antenna at 120 MHz with stub tuning.

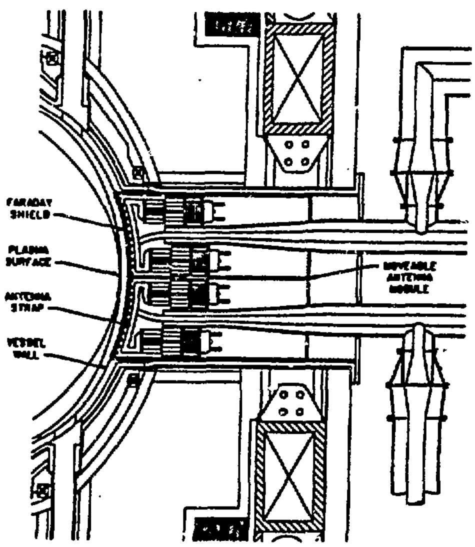

Fig. 6. Conceptual CIT ICRF antenna with capacitor tuning.

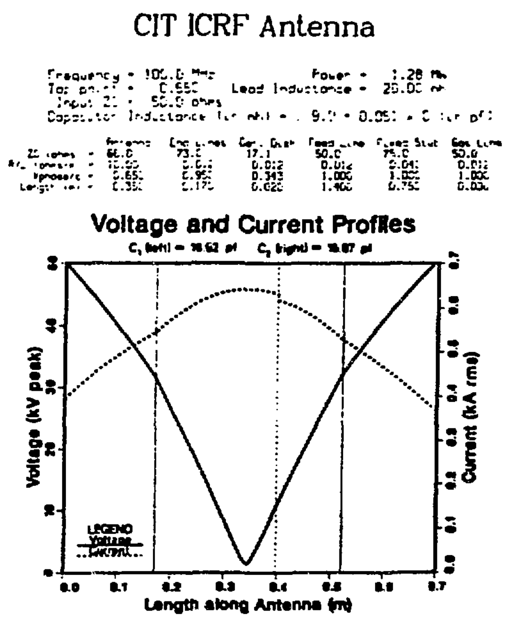

Fig.7. Current and voltage profiles for the CIT antenna at 100 MHz.