Development of High Power Radio Frequency Components for Fusion Plasma Heating

Final Report
CRADA No. TC-0462-93

LLNL-99001310

Date: September 11, 1997

Revision: 3

A. Parties

The project is a relationship between the Lawrence Livermore National Laboratory (LLNL) and General Atomics (GA).

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B. Project Scope

The purpose of this CRADA was to develop advanced microwave heating systems for both ion cyclotron heating and electron cyclotron heating for magnetic fusion reactors. This involved low-frequency (UHF), high-power (millimeter-wave) microwave components, such as antennas, windows, and matching elements. This CRADA also involved developing conceptual designs for new microwave sources.

C. Technical

The technical aspects of the GA/LLNL CRADA consisted of the following:

- i) Development of a Megawatt CW millimeter-wave vacuum barrier window using the distributed cooling concept. The window was to be applicable to high power microwave plasma heating sources such as Gyrotrons and Free Electron Masers.
- ii) Development of a high power ferroelectric tuner for matching low frequency microwaves into a varying plasma load. This tuner was based on the potential availability of unique low loss barium titanate material from Russia.
- iii) Development of a new "comblane" ion cyclotron antenna for low frequency heating systems which eliminated the requirement of multiple feeds to each strap and gave superior matching characteristics to the antenna.
- iv) Development of designs for a Multi-Megawatt, CW, tunable millimeter microwave plasma heating source based on the Free Electron Maser concept, as was being developed at the FOM Institute, Netherlands, with Russian collaboration.
- v) Development of designs for a millimeter wave overmoded circuit ring resonator structure capable of testing Megawatt windows using only a modest power microwave source(100kW).

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GA built and tested the distributed cooled window. LLNL computer codes were used to analyze the electrical, thermal and mechanical characteristics of the window verifying that it was capable of handling 1MW microwave power (CW) at 110 GHz. Accurate calculation of the reflection and transmission properties of the window using finite element codes allowed for the determination of the correct sapphire window thickness. LLNL also contributed to the manufacturing process of the window through use of the hot press facility and ultrasonic test facility to hot press two niobium plates together and verify a good bond with few voids.

LLNL developed a design for a ferro-electric tuner utilizing the low loss barium titanate material which was coming from Russia. A complete facility was constructed for measuring loss tangent of material as a function of frequency (50-100MHz range), bias voltage and temperature. A number of Russian samples were tested to verify their superior loss characteristics and suggestions for further improvement were made.

LLNL constructed a combline antenna based on a GA design and performed 3D EM calculations to determine the "S" parameters of the system and the effects of the Faraday shields and antenna feed position. The antenna was tested in the LLNL anechoic chamber and microwave lab indicating excellent agreement between experimental data and computer prediction.

A design for a 5MW CW tunable Free Electron Maser extrapolated from the Dutch 1MW device was developed and the performance predicted using LLNL computer codes. Cost estimates were also made indicating that such a device could be a serious contender for the next generation of millimeter microwave sources for plasma heating.

Finally, a conceptual design was developed for a millimeter wave overmode ring resonator utilizing the step-waveguide concept originally developed in Russia.

D. Partner Contribution

General Atomics built and tested the distributed cooled window and provided LLNL with transmission and reflection test data in order to then benchmark the EM computer codes. The combline antenna built and analyzed by LLNL was based on a GA design. GA provided LLNL with a number of niobium plates for hot pressing and provided the necessary guidance to allow successful bonding. GA representatives were on site at LLNL on numerous occasions to consult and give guidance on the ferroelectric tuner, combline antenna and distributed window analysis.

E. Documents/Reference List

1. Presentations and Publications:

The following lists presentations and publications of the work performed during the GA/LLNL CRADA from September 1993 to September 1996.

- 1) "Predicted Operating Conditions for Maintaining Mode Purity in the 1 MW 200GHz FOM Free Electron Maser," M. Caplan, LLNL; T. Antonsen, U. Maryland; A. Tulupov, FOM Instituut voor Plasma Physica, Rijnhuizen, The Netherlands; 16th International Free Electron Laser Conference, Stanford CA, Aug 1994; and Nuclear Instruments and Methods in Physics Research A 358 1995.
- 2) "Electromagnetic and Thermal Analysis to Distributed Cooled High Power Millimeter Wave Windows," S. Nelson, T. Reitter, M. Caplan, LLNL; and C. Moeller, General Atomics; AIP Conference Proceedings 355, 11th Topical Conference on Radio Frequency Power in Plasmas, Palm Springs CA, May 1995.

- 3) "Comblaine Antenna Modelling for Plasma Heating," S.Nelson, G. Kamin, R. van Maren, LLNL; C. Moeller, D. Phelps, General Atomics; AIP Conference Proceedings 355, 11th Topical Conference on Radio Frequency Power in Plasmas, Palm Springs CA, May 1995.
- 4) "Analysis of Distributed Cooled High Power Millimeter Wave Windows," S. Nelson, M.Caplan and T.Reitter; 20th International Conference on Infrared and Millimeter Waves, Orlando, FL, December 1995.
- 5) "Extrapolation of the Dutch 1MW Tunable Free Electron Maser to a 5 MW ECRH Source," M.Caplan, S. Nelson and G. Kamin, LLNL; T. Antonen and B. Levush, U. Maryland; and A. Tulupov, FOM; 9th Joint Workshop on Electron Cyclotron Emission and Electron Cyclotron Resonance Heating, Borrego Springs CA, January 1995.
- 6) "Extrapolation of the FOM 1MW Free Electron Maser to a Multi- Megawatt Millimeter Wave Microwave Source," M. Caplan, LLNL; M.Valentini, W.Urbanus and A.Verhoeven, FOM; A. Tulupov, Soliton-NTT Moscow; 18th International Free Electron Laser Conference, Rome, Italy, August 1996; and Nuclear Instruments and Methods in Physics Research A, 393 1997.
- 7) "Quasi Optical Confocal Schemes for High Power Microwave Components," G Denisov, C. Shmelyov, IAP Russia; W. Urbanus and A.Verhoeven, FOM; and M.Caplan, LLNL; 21st International Conference on Infrared and Millimeter Waves, Berlin, Germany, July 1996.

Quarterly Reports 03/01/94- 06/30/94
 07/01/94- 09/30/94
 10/01/94- 12/31/94
 01/01/95- 03/30/95
 04/01/95- 06/30/95
 07/01/95- 06/30/96

2. Intellectual Propoerty:

- 1) The following Subject Inventions were made under this project:

LLNL Subject Inventions: None Reported

General Atomics Subject Inventions: None Reported

- 2) LLNL Background Intellectual Property

"Vacuum-Barrier Window for Wide-Bandwidth High-Power Microwave Transmission,"
U.S. Patent #5,548,257; M. Caplan and C. Shang (IL-9203).

AMOS Code
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- 3) Licensing Background Intellectual Property:

General Atomics has not approached LLNL for a commercial license to any LLNL
Background Intellectual Property.

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F. Acknowledgment

Participant's signature of the final report indicates the following:

- 1) The Participant has reviewed the final report and concurs with the statements made therein.
- 2) The Participant agrees that any modifications or changes from the initial proposal were discussed and agreed to during the term of the project.
- 3) The Participant certifies that:
 - a) all reports either completed or in process are listed;
 - b) all subject inventions attributable to the project have been disclosed or are included on a list attached to this report; and
 - c) appropriate measures have been taken to protect intellectual property attributable to this project.
- 4) The Participant certifies that if tangible personal property was exchanged during the agreement, all has either been returned to the initial custodian or transferred permanently.
- 5) The Participant certifies that proprietary information has been returned or destroyed by LLNL.

Richard W. Callis 9/28/98
Richard W. Callis
General Atomics
Date

Malcolm Caplan Sept 29, 1998
Malcolm Caplan
Lawrence Livermore National Laboratory
Date

9/28/98