MICROWAVE POWER TRANSMISSION FROM SPACE AND RELATED NONLINEAR PLASMA EFFECTS

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Abstract

We first present a brief historical review of the development of technology and scientific research related to the transmission of electrical energy via radio waves. The idea of radio power transmission was first conceived by Tesla about a century ago. However, the first practical use of radio waves was for transmitting intelligence and information, and not for transmitting electrical power per se. At the close of World War II, engineers and scientists re-examined the original Tesla idea of transmitting electric power to a distant place via radio, as high-power microwave technology became available. These efforts in 1960's resulted in the idea of the Solar Power Satellite (SPS) which was proposed by P. Glaser in 1968. The NASA/DOE concept of the SPS was extensively developed in the late 1970's. After reviewing the history of microwave power transmission and related theoretical/experimental studies from the beginning of this century up to 1980, we will discuss recent research on microwave power transmission after 1980. Our focus will be on related experiments conducted in the 1980's and 1990's, including those on ground-to-ground microwave energy transmission, ground-to-aircraft power transmission, and rocket-to-rocket power transmission. The rocket experiment we discuss was conducted to examine a possible nonlinear resonant interaction of intense microwaves with the ionospheric plasma. The result of the rocket experiment is further studied in detail by particle model computer simulations, and the results are explained in terms of nonlinear plasma effects. Such problems of interaction between the microwave power beam and the ionosphere must be resolved before space-to-ground and space-to-space power transmission can be realistically developed.

1. Introduction

On the occasion of the 75th Anniversary of URSI, it is appropriate to re-examine the historical traces of radio utilization for transmitting electric power without wires to a distant destination. Today, radio waves are mainly used for transmitting intelligence and information. However, the threat of the lack of energy resources, especially for electrical energy, is increasing as a result of

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the population explosion and rapid industrialization over the globe. Therefore, considering that the energy problem on our mother planet Earth, and the crisis of the Earth's environment have become urgent issues for mankind, we need to re-examine the use of radio waves for transmission of clean electrical energy from one place to another, especially from space to the ground, without wires.

There exists a good review paper by W. C. Brown [1] on the history up to 1980 of power transmission by radio waves. We briefly describe, in Section 2, the historical footprints of radio power transmission from a century ago to 1980. In the late 1970's, the NASA/DOE sponsored extensive studies on the Solar Power Satellite (SPS). The NASA/DOE SPS studies program contained an evaluation of the impact of a microwave power beam on the plasma environment of the ionosphere. Section 3 reviews the theoretical studies on Ohmic heating of the ionosphere, the thermal self focusing instabilities caused by the SPS microwave power beam and the related ionospheric heating experiments by ground-based heating facilities. Following these studies, the present author conducted a further study of microwave action on the ionospheric plasma, focusing on the nonlinear resonant scattering of the microwave power beam by magnetized ionospheric plasma. Section 4 presents a theoretical study of the nonlinear resonant interaction of a high-power microwave beam with ionospheric plasma, and a rocket experiment called MINIX (Microwave-Ionosphere Nonlinear Interaction eXperiment) which was conducted to test the theoretical estimate of nonlinear resonant interactions. Extensive computer simulations of nonlinear resonant interactions were carried out by the present author and his colleagues to interpret the MINIX result in terms of nonlinear wave-wave-particle interactions. Section 5 describes the computer simulation and its theoretical interpretation.

In Section 6 we outline two recent microwave-driven airplane experiments: SHARP in Canada and MILAX in Japan. The recent experiment on microwave power beam steering using an active phased array system developed in Japan is described as well. In Section 7 a brief account of a recent rocket experiment and recent ground-to-ground power transmission is given. In Section 8 we conclude with a summary and discussion for future plans of research and development on microwave power transmission (MPT).

2. History of microwave power transmission before 1980

In, 1864, James Clerk Maxwell [2] predicted the existence of radio waves by means of mathematical model. Twenty four years later, in 1888, bolstered by Maxwell's theory, Heinrich Hertz [3] first succeeded in showing experimental evidence of radio waves by his spark-gap radio transmitter. This experiment stimulated Marchese Guglielmo Marconi [4], who first achieved signal transmission by means of radio waves over 10 m in 1895, and over the Atlantic Ocean in 1901. It was Reginald Fessenden [5] who first succeeded in transmitting continuous wave (CW) for voice telecommunications [6]. Thus, the road to modern radio telecommunication was opened up around the turn of the century. Modern radio utilization has been directed into the area of radio telecommunications for transmission of "intelligence and information" over rather weak radio