AN ACTIVE ALIGNMENT SCHEME FOR THE MPTS ARRAY

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In order to maximize the efficiency of the microwave power transmission system (MPTS), the surface of the array antenna must be extremely flat, which is difficult to achieve using passive techniques over the 1 km dimensions of the array. In order to achieve and maintain this required flatness, a rotating laser beam used for leveling applications on earth has been utilized as a reference system. A photoconductive sensor with a reflective collecting surface is used to determine the displacement and polarity of any misalignment and automatically engage a stepping motor to drive a variable-length mechanism to make the necessary corrections. Once aligned, little power is dissipated since a nulling bridge circuit that centers on the beam is used, an important alignment feature since even laser beams broaden considerably at 1 km distances. A three-point subarray alignment arrangement is described which independently adjusts, in the three orthogonal directions, the height and tilt of subarrays within the MPTS array and readily adapts to any physical distortions of the secondary structure (such as that resulting from severe temperature extremes caused by an eclipse of the sun). Finally, it is shown that only one rotating laser system is required since optical blockage is minimal on the array surface and that it is possible to incorporate a number of redundant laser systems for reliability without affecting the overall performance.

1.0 ROTATING LASER BEAM REFERENCE SYSTEM

A commercially available rotating laser system, the Laser Level, appears to satisfy many of the requirements for achieving flatness over a very large area. A key element for achieving flatness is the use of a pentaprism for attaining exact perpendicularity about the rotating axis. A unique feature of the pentaprism is the automatic compensation of any tilting resulting from errors such as misaligned bearing surfaces.

The Helium-Neon laser source must use a collimator to minimize the inherent beam broadening, a limiting factor for defining alignments at long distances. It is estimated that the beam diameter expands from 1 mm at the laser to 3 inches at 500 m, and the sensor system must be able to accommodate this wide range of beam diameters.

2.0 OPTICAL SENSORS

A photoconductive sensor configuration has been devised to attain alignment with the center of a laser beam, for any laser beam diameter. The basis for this design is the use of a nulling-bridge detector circuit that utilizes symmetry about the separation (about 0.1 mm) of two colinear photoconductive strips which total five inches in length. The conductivity of the photoconductor increases with laser beam illumination so that equal illumination results in identical resistance and therefore a null in the resistive bridge. This null condition, when properly biased, dissipates very little power.

If the two colinear strips are asymmetrically illuminated as a result of the beam center being offset, however, the nulling condition is lost and a voltage imbalance occurs. The magnitude and polarity of this voltage inbalance can be used to drive an electric motor to realign the sensors as part of a negative feedback loop until null is again realized.

The 0.1 mm separation permits operation close to the rotating laser system, whereas the 5 inch overall length easily accommodates the 3 inch diameter laser beam at extremities of the array. Tapering of the tips of the photoconductive strips near the gap will compensate for relative signal strength changes by providing a variable resistance along the strip. Further improvements in the laser light collection efficiency can be obtained by using optical matching by protective thin film coatings and by shaping the glass supporting structure into a paraboloidal or semi-circular shape and metallizing it to form a reflective surface.

Redundancy can be readily implemented by having multiple adjacent photoconductive strips, each driving separate variable length motors. Using a pin-and-socket arrangement, these multiple photoconductive sensors can be as easily replaced as vacuum tubes.

The locations of the three photoconductive sensors required to align each subarray are just above the attachment points, which are referred to as the three point support.

3.0 THREE POINT SUBARRAY MOUNT

In order to reduce the number of adjustments required to align the subarrays, a three point mount with a single support has been studied. The entire subarray is attached to any secondary structure configuration by only a single sturdy support. This single support can readily adapt to any tilting arising from physical distortions of the secondary structure by simply adjusting the height of the subarray.

The initial alignment procedure, during fabrication, can use the rotating laser beam reference plane to adjust the position of the single support mount. Installation consists of sliding this mount into a keyed slot built into the secondary structure and centering the beam on the photoconductive sensor located at the center of the subarray where the single support is attached. The two orthogonal tilting directions are controlled by two variable length struts which form a triangular truss with the support and subarray. Each tilting direction is independent of the other so that iterative adjustment procedures are avoided. During fabrication, an astronaut would visibly align the photoconductive sensors above the struts within the laser beam reference plane, and subsequent adjustments would be implemented by the active alignment instrumentation.

4.0 OPTICAL SENSOR POSITIONING

The use of a rotating laser beam reference system requires that a clear field of view to all sensors is desirable such that only one laser system is necessary to align all the subarrays. Since there are supporting structures located beneath the subarrays, obviously the flat radiating surface of the array is a better choice.

If the rotating laser system is in the center of the array and the optical sensors are 0.125 inches wide, then the closest sensors 7.1 m away would subtend an angle of 0.05°. Sensors located at farther distances would subtend even smaller angles. For example, the second set 11.2 m away subtends 0.03°. Using the square symmetry of the array, it is possible to illuminate all of the sensors by offsetting the laser at least 0.125 inches from the exact center. Larger width photoconductive sensors can be used and would correspondingly subtend larger angles, but the offset concept is still valid. Adjustable position sockets for the photoconductive sensors can provide some flexibility in the event of inadvertent blockage.

If redundant rotating laser systems are used, a common baseplate is recommended to ensure that both reference planes are coincident. Multiple laser systems (with pentaprisms assumed to be 2 cm wide) placed 1 m apart in line with the service corridors discussed in section 6.0 will not obscure the required field of view of each other.

Electromagnetic interference arising from the microwave power radiated from the array is reduced by the normal orientation of the photoconductive sensor to the array and its 5 inch length, which, on the basis of a dipole on a ground plane, has minimal coupling effects. Also, the metallizing of the sensor, with the possible addition of wire grids on the exposed optical face, should not permit interference. The effective cavity formed by the metallized sensor is also non-resonant to the radiated microwave frequency. Therefore the placement of the sensors on the array face is not unreasonable.

5.0 VARIABLE LENGTH MECHANISMS

In developing the concepts for an active alignment system, two of the dominating criteria were to use simple designs and attempt to incorporate redundancy provisions suitable for operation in space, especially in view of the reluctance of using electric motors for long duration missions.

The variable length mechanism, which is basically a worm gear drive driven by a stepping motor, is the only electromechanical device used for this active alignment scheme. The redundant variable length mechanisms are short segments serially located along the strut, each independently driven by a separate photoconductive sensor nulling bridge circuit. If for some reason one motor or the bearings of one variable length mechanism fails, then the other redundant systems intrinsically maintain the variable length capability. And if multiple failures occur, replacement of the entire strut consists of removing and installing only two pins in a U-clamp arrangement.

The center support attachment is unique in that it uses a universal ball joint about which the subarray can readily pivot in any direction. The side orthogonal support struts, designated arbitrarily as azimuth (Az) and elevation (El), pivot about the axis formed by the central universal ball joint and the opposite side strut attachment point. Since three points in space define a plane and if these three photoconductive sensors align themselves to the laser beam reference plane, then the subarray is considered aligned. And on a macroscopic scale, if all subarrays are aligned, the array itself is aligned.

Since worm gear drives move by the rotation and translation along a pitched thread, the actual physical movement can be made quite small by means of gearing ratios and stepping motors. Further, by geometrical considerations of the triangular struts, the actual amount of tilting for a given amount of variable length change is quite small. Therefore an extremely high degree of resolution is achievable in adjusting the orientation of the subarray and therefore the array itself. Once this premise is accepted, then it is easy to imagine that the design engineers can extend the concept so that the desired practical resolution is feasible, by the proper choice of pitched threads and the specifications for the stepping motor.

6.0 MAINTENANCE SERVICE CORRIDORS

One aspect of the three-point support is the existence of a square matrix of service corridors or passageways directly under the subarrays for rapid accessibility for necessary repairs. A service vehicle traversing these corridors will be at most only half a subarray dimension away from any position in the array. In addition, since there are only three supports per subarray, the supporting under-structure is not cluttered.

The matrix of corridors also presents the possibility of incorporating a shadow-masking alignment monitoring scheme using 170 laser beams on two adjacent sides passing through strategically placed apertures under the subarrays and incident on detecting sensors on the opposite side. Misalignment is indicated by the loss of signals in both intersecting laser beams, thereby immediately locating the source of the problem.

7.0 MONOPULSE POINTING SYSTEM

A related topic of discussion to the alignment scheme is the accurate pointing of the MPTS array towards the effective location of a pilot beam, which may vary due to refractive variations of the ionosphere. One method which might be considered is a monopulse tracking system that senses the phase differentials of an encoded pilot beam and points the array in the proper direction. Although this scheme will not permit rapid compensation, if the ionospheric fluctuations are slow, the pointing accuracy will be adequate such that instantaneous fine pointing adjustment by an auxiliary retrodirective pilot beam phase reference system is possible.

Four receiving antennas, mounted within a microwave baffle to reduce coupling effects to the radiated microwave power, located at the extremities of the array, will allow active tracking of the pilot beam source located at the rectenna.

IONOSPHERIC POWER BEAM STUDIES

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<u>23 mW/cm^2</u>

A POWER DENSITY LEVEL OF 23 mW/cm^2 HAS ACHIEVED THE STATUS OF A FIRM DESIGN SPECIFICATION BASED ON THEORETICAL CALCULATIONS OF A THRESHOLD FOR MICROWAVE-IONOSPHERE NONLINEAR INTERACTION (THERMAL RUNAWAY).

THERMAL RUNAWAY IS NO LONGER A VALID THEORETICAL CONCEPT ALTHOUGH FOR COMPARABLE POWER DENSITIES ENHANCED ELECTRON HEATING IS OBSERVED TO CHANGE THE ELECTRON TEMPERATURE BY A FACTOR OF TWO OR THREE, BUT NOT BY AN ORDER OF MAGNITUDE.

THERE IS, SO FAR, NO EXPERIMENTAL EVIDENCE TO SUPPORT 23 mW/cm^2 AS AN UPPER LIMIT.

THE QUESTION TO BE POSED AND ANSWERED IS AT WHAT POWER DENSITIES IS THE IONOSPHERE MODIFIED IN A WAY THAT PRODUCES UNACCEPTABLE COMMUNICATION EFFECTS AND/OR ENVIRONMENTAL IMPACTS?

ARECIBO TEST RESULTS

CASE 1 HEATING WAVE PENETRATED THE IONOSPHERE

FREQUENCY	OHMIC HEATING AS A FRACTION OF 5 GW SPS HEATING	DIAMETER OF HEATED VOLUME RELATIVE TO SPS HEATED VOLUME	CROSS SECTION FOR FIELD-ALIGNED SCATTER IS LESS THAN
6-10 MHz	1%	3.00	$4 \times 10^{-3} M^2$
430 MHz	40%	0.10	$4 \times 10^{-3} M^2$
2380 MHz	5%	0.01	$10^{-3} M^2$

ARECIBO TEST RESULTS

CASE 2 HEATING WAVE REFLECTED BY THE IONOSPHERE (NOT THE SPS CONDITION)

PLASMA INSTABILITIES ARE EXCITED BY THE HF HEATER WAVE LEADING TO FIELD-ALIGNED STRIATIONS THAT SCATTER RADIO WAVES.

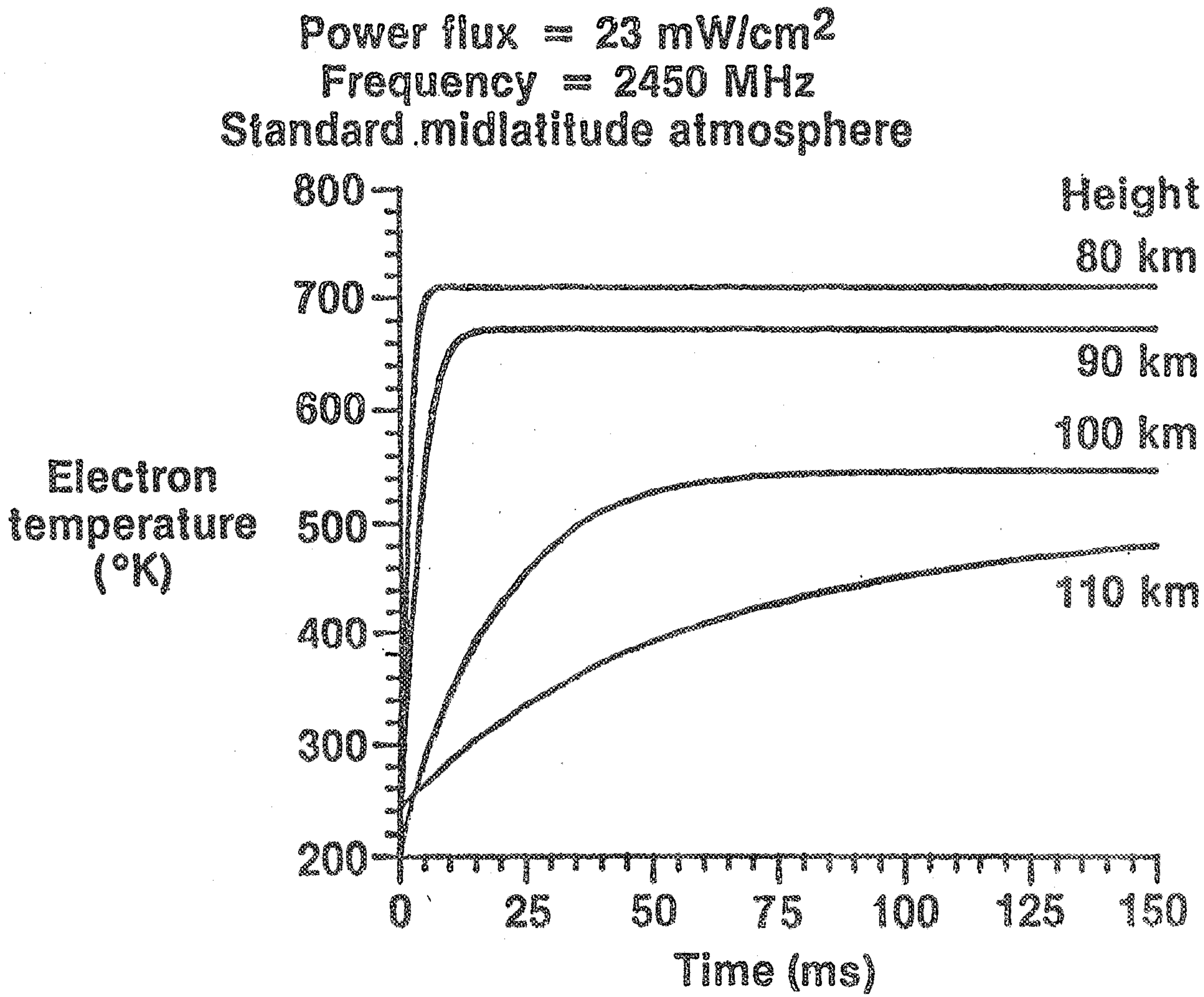
FIELD-ALIGNED RADIO-SCATTERING CROSS-SECTIONS UP TO $10^3 M^2$.

SINCE THE EXCITATION OF THESE INSTABILITIES REQUIRES A MATCHING OF THE HEATER FREQUENCY TO THE IONOSPHERIC PLASMA FREQUENCY, A CONDITION THAT IS NOT MET BY THE SPS, THEY WILL NOT BE EXCITED. NO OTHER INSTABILITIES ARE PRESENTLY KNOWN THAT THE SPS FREQUENCY WILL EXCITE.

THE SIMULTANEOUS ILLUMINATION OF THE IONOSPHERE BY THE SPS FREQUENCY AND A SECOND FREQUENCY SEPARATED BY ABOUT 15 MHZ OR LESS COULD PRODUCE THE INSTABILITIES DESCRIBED ABOVE.

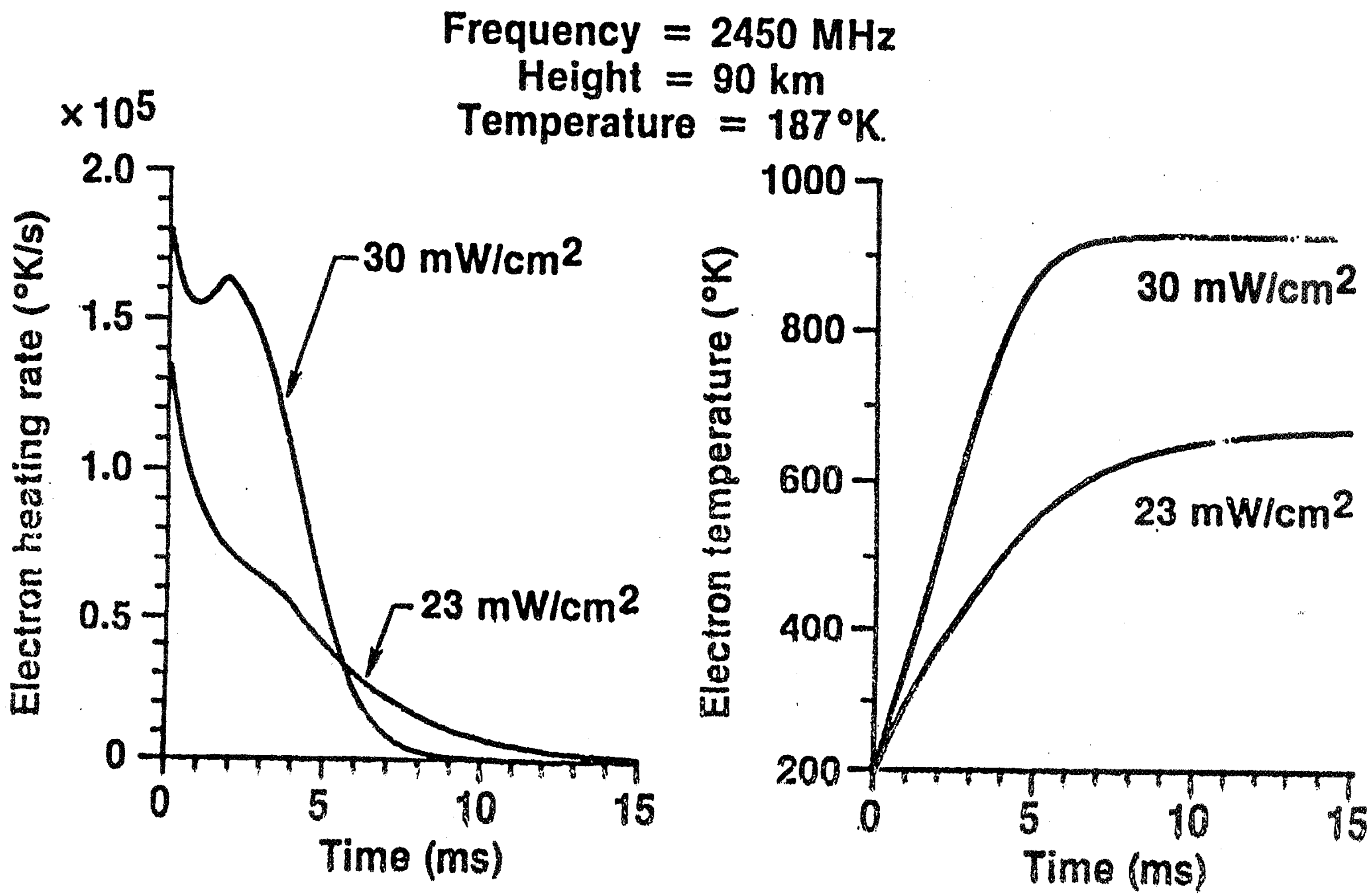
ENHANCED ELECTRON HEATING BY THE SPS BEAM

(1) WILL INCREASE ELECTRON TEMPERATURES BY UP TO A FACTOR OF THREE OR MORE, MOSTLY IN THE LOWER IONOSPHERE.



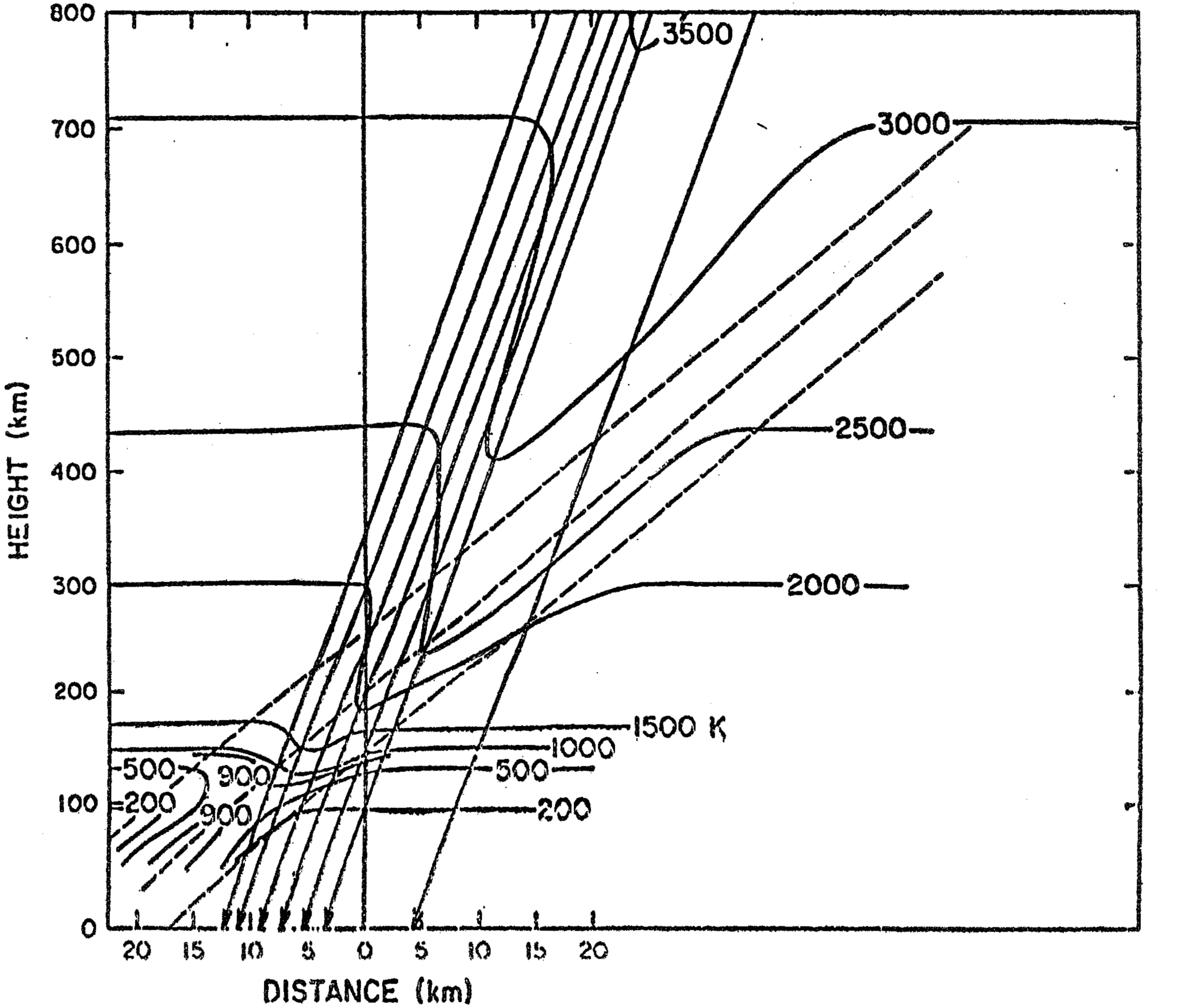
ENHANCED ELECTRON HEATING BY THE SPS BEAM

(2) IS PREDICTED TO BE DEPENDENT ON THE INCIDENT POWER DENSITY.



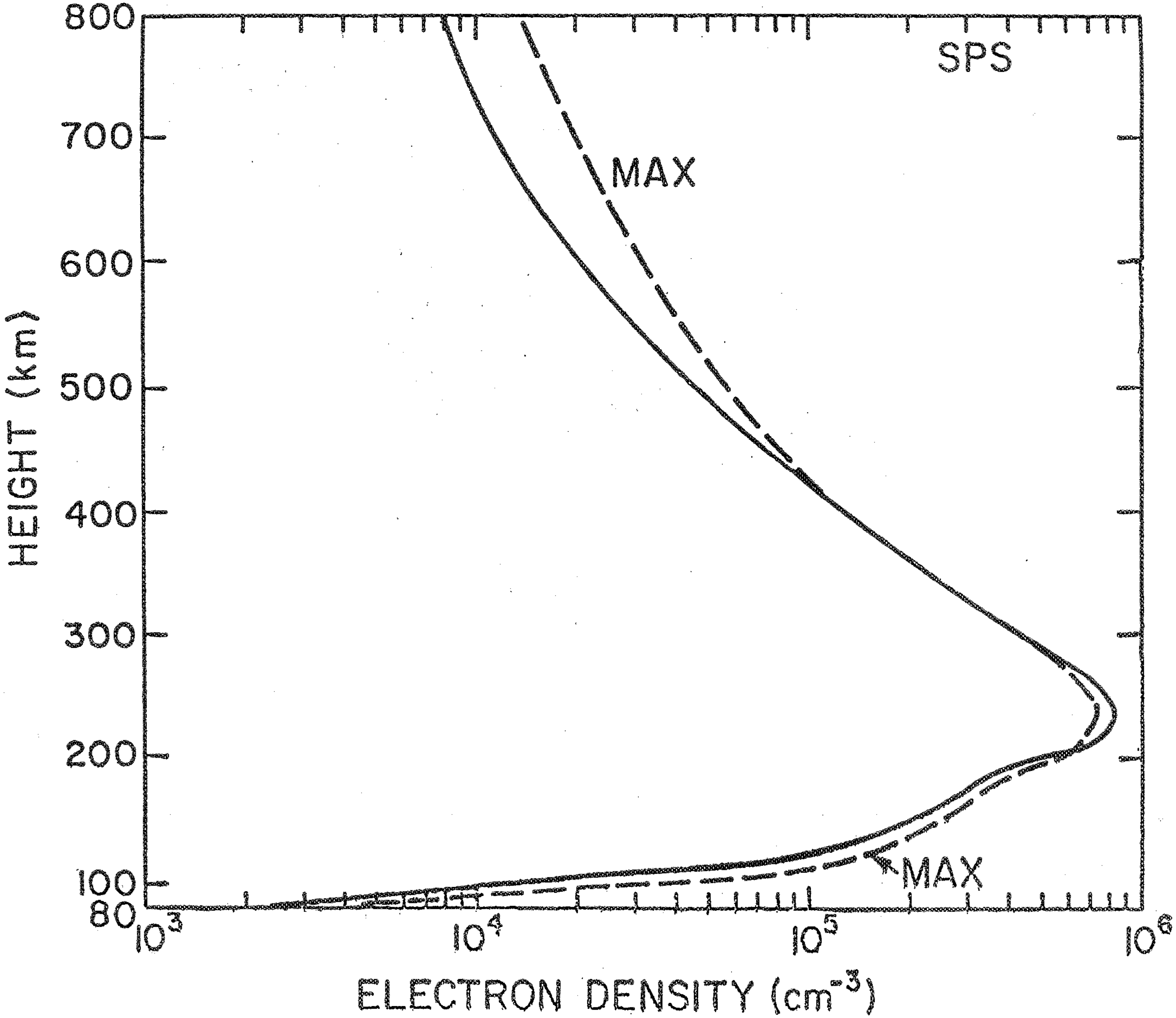
ENHANCED ELECTRON HEATING BY THE SPS BEAM

(3) WILL INCREASE ELECTRON TEMPERATURES IN AND NEAR THE BEAM BY SMALL FACTORS.

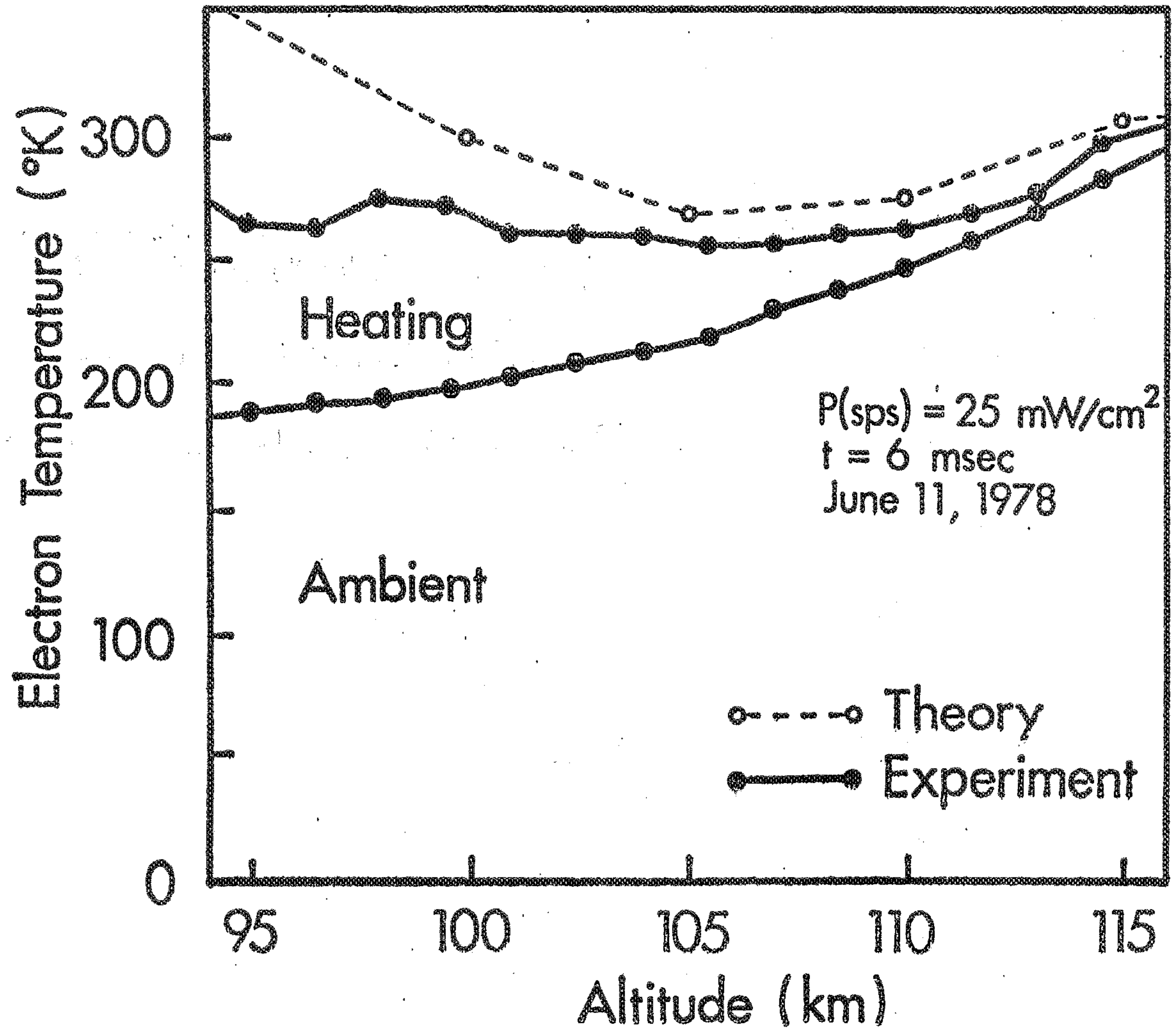


ENHANCED ELECTRON HEATING BY THE SPS BEAM

(4) WILL CHANGE THE ELECTRON DENSITY IN THE BEAM BY SMALL AMOUNTS.



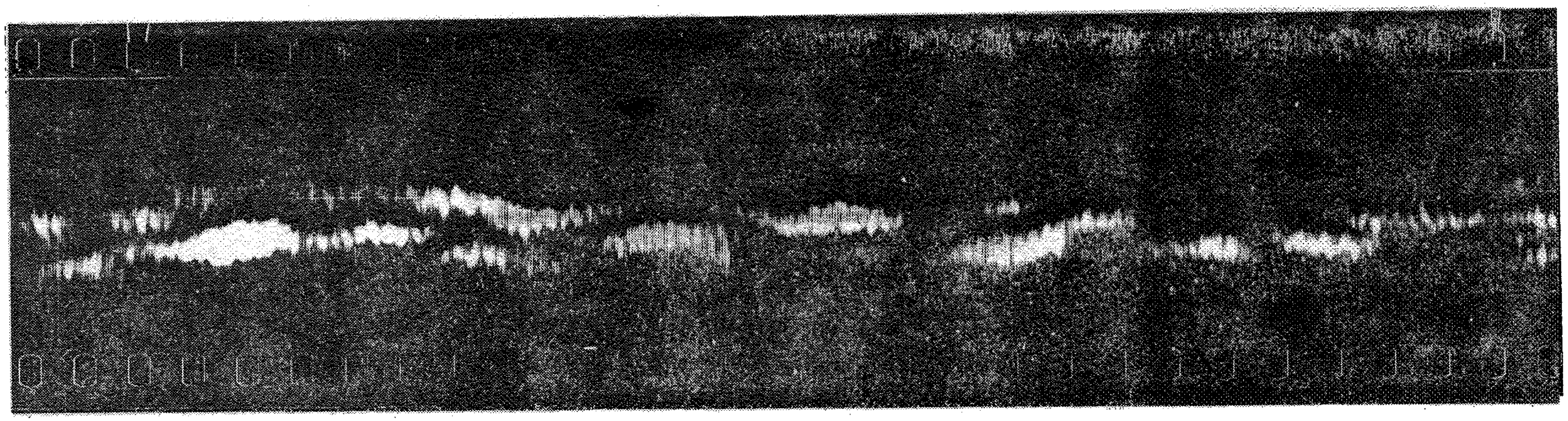
OBSERVATIONS OF ENHANCED ELECTRON HEATING AT ARECIBO ARE CLOSE TO, BUT BELOW, THE PREDICTED INCREMENTS.



COMPARISON OF 5800 MHz AND 2450 MHz

MEDIUM		2450 MHz	5800 MHz
IONOSPHERE		1 KW	0.25 KW
NEUTRAL ATMOSPHERE AT 60° ELEVATION ANGLE		90 MW	100 MW
RAIN (25MM/HR OVER 20 KM PATH IN BEAM)		45 MW	1.450 GW
HAIL (1.93 CM DIAMETER HAILSTONES, 10 KM PATH THROUGH THE BEAM)	DRY	0.2 GW	1.7 GW
	WET	2.7 GW	4.99 GW

RADAR ECHOES FROM FIELD-ALIGNED STRIATIONS



RADAR ECHOES FROM FIELD-ALIGNED STRIATIONS